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Tomato and Pepper Production in the Tropics

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Asian Vegetable Research and Development Center

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Contents

Foreword ix

Acknowledgments xi

Genetic Resources and Conservation

1. Genetic Resources of *Capsicum* for Tropical Regions 2
   B. Pickersgill
2. Genetic Resources of Tomato and Pepper at AVRDC 10
   David C.S. Tay
3. Genetic Resources of Tomato in India, Their Buildup, Evaluation, Maintenance and Utilization 22
   T.A. Thomas and Umesh Chandra
4. Problems of Seed Production and Storage of Pepper 28
   P. Belletti and L. Quagliotti

Varietal Improvement

5. Tissue Culture of Tomato and Pepper: New Tools for Plant Breeding 44
   Robert A. Morrison and Willie H.-T. Loh
6. Pepper Breeding and Genetics at New Mexico State University 51
   P.W. Bosland
7. The Use of *Capsicum chinense* as Sweet Pepper Cultivars and Sources for Gene Transfer 55
   S.S. Cheng
8. Evaluation of Tomato Materials for Use in the Processing Tomato Breeding Program in Martinique 63
   B. Denoyes and G. Anais
9. Genetic Improvement of Tomato Adaptability to the Tropics: Progess and Future Prospects 70
   R.T. Opeña, S.K. Green, N.S. Talekar and J.T. Chen
10. Pepper Improvement for the Tropics: Problems and the AVRDC Approach 86
    J.Y. Yoon, S.K. Green, A.T.Tschanz, S.C.S. Tsou and L.C. Chang
11. Breeding for Combined Resistance to Bacterial Wilt and Rootknot Nematodes in Tomatoes 99
    S.K. Tikoo, N. Anand, R. Kishun and P.P. Reddy
12. Breeding of Processing Tomatoes with Genetic Resistance to Rootknot Nematodes (*Meloidogyne incognita*) 107
    G.S. Gallardo
13. Breeding for Resistance to *Scrobipalpula absoluta* (Meyrick) among *Lycopersicon* Accessions in Brazil 113
    F.H. França, W.R. Maluf, P.E. Ferreira-Rossi, J.E.C. de Miranda, M.C.F. Coelho, M. Castelo Branco and A.M. Resende
14. Use of Tomato Fruit Ripening Mutants to Enhance Fruit Storage Life 123
    E.C. Tigchelaar and J. Silvas Rios

Stress Physiology

15. Relationship between Hormonal Levels in Pistils and Tomato Fruit-Set in Hot and Cool Seasons 138
    C.G. Kuo, H.M. Chen, B.J. Shen and H.C. Chen

16. Abscission of Reproductive Structures in Pepper: Causes, Mechanisms and Control 150
H.C. Wien, K.E. Tripp, R. Hernandez-Armenta and A.D. Turner
17. Salt Tolerance in Tomato: Sodium Accumulation, Uptake and Recirculation in *Lycopersicon esculentum* and *L. pennellii* 166
Edith L. Taleisnik
18. Biological Activities of BAS 112 W and BAS 113 W on Fruit-setting and Fruit Development in Tomatoes 174
A. Watanabe, J. Beck, H. Rosebrock, J. Huang, U. Busse, M. Luib and P. Schott

Diseases and Pests

19. Resistance to Anthracnose (*Colletotrichum* spp.) in Pepper 184
B.S. Kim, H.K. Park and W.S. Lee
20. Anthracnose of Pepper Caused by *Colletotrichum* spp 189
J.F. Hadden and L.L. Black
21. Genetic Resistance to Bacterial Spot in Tomato 200
J.W. Scott, J.B. Jones and G.C. Somodi
22. Relationship of Lesion Development on Resistant and Susceptible Tomatoes to Internal Populations of *Xanthomonas campestris* pv. *vesicatoria* 208
G.C. Somodi, J.B. Jones and J.W. Scott
23. Quantitative Resistance to Bacterial Leafspot of Pepper Compared in Mono and Polycyclic Disease Progress Tests 213
A.M. Hibberd
24. Additive Gene Action Controlling Resistance to Bacterial Leafspot in a Pepper Plant Introduction Line 220
A.M. Hibberd
25. Search for Bacterial Wilt-Resistant Tomato Varieties in Réunion 229
J.C. Girard, J.L. Marchand and R. Michellon
26. Environmental Influences on the Severity of Tomato Bacterial Wilt in the French West Indies: Interactions with Varietal Resistance 235
C.M. Messiaen
27. Importance of Plant Resistance in the Control of Whiteflies and Whitefly-borne Viruses in Tomato and the Development of Screening Methods 239
M.J. Berlinger and R. Dahan
28. Virus Diseases of Tomato and Pepper in Queensland and Some Aspects of Their Control 249
J.E. Thomas, D.M. Persley, D.J. McGrath and A.M. Hibberd
29. A Quick Diagnostic Test for Tomato Yellow Leaf Curl Virus 260
H. Czosnek, N. Navot, S. Ovadiah, A. Reinhartz, M. Herzberg and A. Zilberstein

Integrated Pest Management

30. Biological, Chemical and Physiological Approaches to Control Gray Mold Disease on Tomato and Pepper 268
Y. Elad
31. Practical Application of Pest Management on Tomatoes in Florida 275
D.J. Schuster and K. Pohronezny
32. Tomato Pest Management in the Midwestern United States 283
A.C. York

33. Evaluation and Validation of a Tomato and Bean Polycultural Cropping System as a Component of IPM for Tomatoes in Nicaragua 289
Peter M. Rosset
34. Propamocarb-HCl, a Fungicide Suitable for Integrated Pest Management 303
T.H. Wilde

Cultural Management

35. Water Management of Tomatoes in the Tropics 308
Cláude J. Phene
36. Water-fertility Management for Subsurface Drip Irrigated Tomatoes 323
C.J. Phene, K.R. Davis, R.L. McCormick, R.B. Hutmacher and J.D. Pierro
37. Effect of Irrigation Rates on Rainshelter-protected Tomato Yields with and without Methyl Bromide Fumigation of the Soil 339
B.A. Kratky, I.P. Wu, W. Nishijima and H.M. Koi
38. The Influence of Shade Nets on the Growth and Yield of Sweet Pepper ... 345
F. El-Aidy, M. El-Afry and F. Ibrahiem
39. Some Aspects of Cultural Management in Tomatoes at AVRDC 349
A. Sajjapongse, Y. Ota, Y.C. Roan and C.L. Wu
40. Hydroponic Production Studies on Lowland Tomato in Malaysia: The Effect of Pruning System and CHPA Application on Yield 358
E.S. Lim and S.T. Chen
41. Irrigation and Nitrogen Management for Bell Pepper (*Capsicum annuum* L.) in Tropical India 365
D.M. Hegde
42. Managing Nitrogen Fertilization of Tomatoes Using Nitrate Quick Tests 375
R.R. Coltman

Country Reports

43. Tomato and Pepper Production and Research Status in Australia 386
D.J. McGrath
44. Tomato and Pepper Production in Brazil 396
H. Nagai
45. Tomato Production in Cambodia and Screening for Tomato Leaf Curl Disease Tolerance 406
A.B. Rowell, T.E. Lay and B. Chhum
46. Production of Tomato and Pepper in China 416
C.Y. Yang, T.W. Zhu and S.D. Lee
47. Production and Utilization of Pepper and Tomato in Taiwan, China 422
C.Y. Lin and S.H. Lai
48. The Contribution of AVRDC Tomatoes in Taiwan, China 432
S.H. Lai, J.J.S. Tsay, S.C.S. Tsou, H. Imai and S.L. Hwang
49. Hot Pepper and Tomato Production and Research in Ethiopia 442
Y. Haile and Y. Zewdie
50. Present Status of Tomato and Pepper Production in India 452
J.H. Singh and D.S. Cheema
51. Tomato and Pepper Production in Indonesia: Problems, Research and Progress 472
Anggoro Hadi Permadi

52. Pepper and Tomato Cultivation, Production and Research in Japan.....480
T. Narikawa, Y. Sakata and K. Hida
53. Tomato and Pepper Production and Research in Korea.....490
K.Y. Kang
54. Tomato and Pepper Production and Its Problems in Liberia.....504
M. A-As-Saqui
55. Tomato and Chili Pepper Growing in Malaysia.....508
N.M. Shukor, B.H. Chew, S. Norainii and M.N.M. Roff
56. Tomatoes and Peppers in Mexico: Commercial Production and Research Challenges.....521
J.A. Laborde and E. Rendon-Poblete
57. Present Status and Prospects for Increased Production of Tomato and Pepper in Northern Nigeria.....536
I.D. Erinle
58. Tomato and Pepper Production in the Philippines.....549
Jose M. Soriano, Ruben L. Villareal and Virginia P. Roxas
59. Major Disease Problems of Tomato Production and Their Control in the Sudan.....561
A.M. Yassin
60. Tomato and Pepper Production and Improvement in Thailand.....566
Manee Nikornpun and Pipob Lumyong

Participants.....577

Subject Index.....585

Foreword

Tomatoes and peppers are among the most widely grown and consumed vegetables worldwide. Not only are they nutritious and highly acceptable, they also provide good income to farmers who produce them. While research on the improvement of both crops have progressed so much in the temperate zone, research on their tropical counterparts have lagged in many aspects.

The symposium on "Tomato and Pepper Production in the Tropics" is an attempt to bring together scientists working on both vegetables, particularly those from developing countries to exchange current information on a broad spectrum of themes ranging from genetic resources conservation, varietal improvement, pests and disease management, and cultural management. It is hoped that the proceedings in this volume will prove to be a valuable reference to students of tropical tomatoes and peppers. The country reports from Asia, Africa and America should provide additional information on the status of these crops under different agro-climatic and socio-economic conditions.

Emil Q. Javier
Director General

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Genetic Resources and Conservation

1

Genetic Resources of *Capsicum* for Tropical Regions

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Abstract

Chili peppers were domesticated at least five times by prehistoric peoples in different parts of South and Middle America. The major species on a world scale is undoubtedly *Capsicum annuum*, but other domesticates remain of local importance. Genetic resources for the improvement of any given domesticated pepper include, firstly, conspecific accessions (both wild and domesticated); secondly, domesticated peppers belonging to other species and their conspecific wild relatives; and thirdly, wild species which have never been domesticated. All species can probably be intercrossed through conventional sexual methods, though manipulations such as bridging crosses, change in ploidy level and embryo rescue may be needed. Chromosomal structural changes are common between and, to a lesser extent, within species. Interspecific and some intraspecific hybrids are usually at least partially sterile and interspecific transfer of genes on those chromosomes involved in structural changes may be hampered. Collection of genetic resources of *Capsicum* is proceeding actively, but evaluation and classification of these resources are lagging behind our understanding of how to utilize them. As major collections are grown and evaluated for morphological and other characters, our present limited knowledge of the geographical distribution of diversity, in general, and of useful characters, in particular, should improve. Isoenzyme studies of these collections should show the extent to which domesticates are genetically depauperate compared to their wild relatives and should provide information on breeding systems, organization of genetic variation, and markers useful in breeding programs. Analyses of these data will improve our understanding of how the presently available genetic resources of *Capsicum* came into being and how they may best be maintained.

Introduction

Capsicum and *Lycopersicon* provide an interesting comparison in the understanding and exploitation of genetic resources. Both genera originated in the American tropics, the majority of species are South American, and the taxonomic boundaries of both genera are poorly defined. In *Capsicum*, the domesticated peppers and their close wild relatives form a coherent group of species recognizable by their pungent berries which have shiny surfaces and bright clear colors when ripe. Species which do not conform to this description have been transferred between *Capsicum* and other genera such as *Aureliana* and *Witheringia*. These species are not well known, most are not represented in living collections, and none has yet been crossed successfully with the chili peppers. In pepper, unlike tomato, genetic resources for the improvement of the crop at present include only species in the genus *Capsicum*.

In *Lycopersicon*, only a single species was domesticated, whereas in *Capsicum* there have been at least five independent domestications, involving three clearly distinct wild species. There is much parallel variation within each of the domesticated species in fruit color, size, shape and pungency. Nonpungent mutants have been established in most if not all of the domesticates.

so that each domesticate is in effect a dual-purpose crop including both spice and vegetable types.

The existence of several distinct domesticated species makes discussion of the genetic resources of *Capsicum* for tropical regions more complicated than comparable discussions for tomato. For any given domesticated pepper, the genetic resources available are, firstly, other domesticated accessions of the same species; secondly, wild forms belonging to the same species; and thirdly, wild or domesticated peppers belonging to other species. The International Board for Plant Genetic Resources (IBPGR) has been sponsoring collection of domesticated and wild species of *Capsicum* in Latin America and elsewhere, but many accessions are still held in national collections and have not yet been transferred to the two global base collections, at the Centro Agronómico de Investigación y Enseñanza (CATIE), Costa Rica, and the Asian Vegetable Research and Development Center (AVRDC).

Evaluation of material in both national and global collections of *Capsicum* is still incomplete. In *Lycopersicon*, on the other hand, wild species have been exploited as sources of useful characters for many years (Rick, 1982). However, many of the barriers to interspecific gene transfer in *Capsicum* have already been identified, so much of the groundwork required for utilizing effectively genetic resources from different species is already in place.

The Domesticated Species of *Capsicum*

The domesticated species of *Capsicum* comprise two species (*C. baccatum* L. and *C. pubescens* R. and P.) which are clearly distinct by any taxonomic criterion, plus a species complex which is currently treated as containing three independently domesticated species (*C. annuum* L., *C. frutescens* L. and *C. chinense* Jacq.).

Capsicum annuum

This species was domesticated in Mexico (Pickersgill, 1971) and is the most important cultivated pepper in Mexico and adjacent countries. It is also the most important species on a world scale, since it includes all the commercially important sweet peppers and many spice types. Some purple-leaved cultivars are grown as ornamentals. The center of morphological diversity for *C. annuum* is probably Mexico. Some Mexican hot peppers are used dried, while others are used fresh and may be harvested green or fully ripe. Pericarp thickness, and hence ease of drying, vary in different types. Each named type has its own unique characteristics of pungency, flavor and color.

After Columbus introduced peppers to Europe in 1493, *C. annuum* spread rapidly from Europe to Asia and Africa. The range of germplasm initially introduced to the Old World was probably small, but during the subsequent 400 years of exposure to Old World pests and diseases some useful resistances have evolved (Hendy et al. 1985). Some parts of the Old World tropics may prove to be important secondary centers of diversity for this species.

C. annuum is distinguished from the other domesticated species by its solitary flowers and fruits, and its clear white corollas.

Capsicum frutescens

Peppers which are morphologically identical to wild *C. frutescens* are grown or exploited throughout much of Latin America. These peppers have also been introduced to the Old World and are grown where extreme pungency is required, for example for oleoresin extraction. In parts of the Old World, such as Papua New Guinea, they have escaped from cultivation and established themselves as weedy components of the flora.

Large-fruited types of *C. frutescens* include the Tabasco pepper. They are grown in the lowlands of Middle America and other circum-Caribbean countries, and have also been introduced

to the Old World. They often have rather soft flesh and may or may not have thin pericarps suitable for drying. Mild or even nonpungent types are common in Costa Rica and Panama.

Domesticated types of *C. frutescens* usually have solitary flowers and fruits, whereas wild forms have two or three flowers at each node. The flowers are greenish white, unlike the pure white flowers of *C. annuum*.

Capsicum chinense

This is the most variable of the domesticated species and the most widespread within Latin America. Large-fruited, thick-walled types which are used fresh are common in the West Indies and some other parts of the Caribbean, while in coastal and montane parts of the Andean region thin-walled types which are used dried also occur. In Amazonia, small-fruited types reputed to have good flavor in addition to pungency are widespread. Some Amazonian accessions of *C. chinense* are claimed to be amongst the most pungent peppers known.

C. chinense has reached West Africa, probably through Portuguese trading contacts soon after the European discovery of Brazil, but it does not seem to be widely known in the Asian tropics. It is morphologically similar to *C. annuum* and *C. frutescens*. The flowers are usually greenish white, usually two or more per node, and when the fruits are mature, there is usually a characteristic hairline constriction where the calyx joins the fruit stalk. Individual accessions may deviate in any one of these characters but, with a little practice, can be correctly identified on their overall characteristics.

Capsicum baccatum

This species is grown on a garden and field scale in South America, particularly in Peru, Bolivia and Brazil. Again, there is intraspecific variation in features such as pungency and pericarp thickness. The dried orange fruits of escabeche peppers are perhaps the most common condiment in Peru, while the mild-flavored, large, thick-walled fruits of chapéu de frade are sold fresh in markets in southern Brazil.

C. baccatum reached Europe by the 17th century but is not widely grown in Africa or Asia, possibly because *C. annuum* and *C. frutescens* were already well established. There seem to be no ecological constraints which would prevent wider cultivation of this species.

C. baccatum is easily distinguished from the other domesticates because its flowers have yellow spots on a white corolla.

Capsicum pubescens

This is a highland pepper found throughout the Andean region and now grown also in the highlands of Middle America. It seems to have a narrower ecological amplitude than the other domesticated peppers. It does not set fruit satisfactorily in many parts of the lowland tropics, nor in the field or greenhouse in many temperate countries. Its morphological variation is also more limited than that of the other domesticated peppers. It has pungent fruits with thick pericarps and a large moisture content.

C. pubescens cannot be confused with any of the other domesticated peppers. Its combination of purple, unspotted corollas and dark seeds is unique.

Economic Potential of the Different Domesticates

It seems to have been largely historical accident that has led to the Middle American peppers *C. annuum* and *C. frutescens* being grown throughout the world, while the South American domesticates *C. chinense* and *C. baccatum* have remained little known outside their native continent. There is some anecdotal evidence that the flavor of the pungent types may differ in the different species and that this may preclude acceptance of South American species in Mexico.

or Mexican chiles in South America. However, it is not clear whether any such differences in flavor would be present in oleoresins extracted from the different species.

Founder Effect in the Domestication and Dispersal of *Capsicum*

Each of the domesticated species of *Capsicum* seems to have been derived from a small sample of the total diversity present in its wild progenitor. The evidence is most conclusive for *C. annuum* and to some extent for *C. baccatum*. Wild accessions of *C. annuum* from Middle America belong to two different chromosome races. One race has a single pair of acrocentric chromosomes and occurs from Costa Rica to the southern United States. This race is found also in *C. chinense* and *C. frutescens* so is presumed to be the basic chromosome race in the *C. annuum* complex. The second chromosome race has two pairs of acrocentric chromosomes, is confined to central Mexico, and is apparently derived from the first race by fixation of a single unequal reciprocal chromosomal interchange. Hybrids between the two races are partially sterile (pollen stainability is reduced to about 50%). Virtually all domesticated *C. annuum* belongs to the second chromosome race. This suggests that *C. annuum* was domesticated in central Mexico, from local wild peppers belonging to the derived chromosome race. Wild peppers representing the basic chromosome race may not have contributed directly to the gene pool of domesticated *C. annuum*. It is therefore not surprising that some potentially useful disease resistances are now being found in accessions of wild *C. annuum* from Central America (Pochard, 1982; Hendy, et al. 1985). The multivariate analyses of Pickersgill, et al. (1979) suggest that domesticated *C. chinense* and domesticated *C. frutescens* were likewise derived from different elements of the same widespread wild complex.

In *C. baccatum*, all accessions so far tested belong to the same chromosome race. However, some accessions of wild *C. baccatum*, when crossed reciprocally with *C. chinense*, produce F_1 hybrids which are morphologically normal, while others produce morphologically abnormal hybrids when used as pollen parents. These accessions are known respectively as noncarriers and carriers of a virus-like syndrome of abnormalities. All accessions of domesticated *C. baccatum* which have been tested are carriers, and were presumably derived from carrier strains of wild *C. baccatum*. Unfortunately there is no geographic pattern in the distribution of carrier versus noncarrier strains of wild *C. baccatum*, so it has not been possible to locate the center of domestication of this species very precisely (Pickersgill, unpublished).

Each of the domesticated peppers seems therefore to have passed through an evolutionary bottleneck associated with domestication. They are probably genetically depauperate in their overall variation compared to their wild progenitors, but this is obscured by their increased variability in fruit characters, developed by human selection under domestication. The loss of variability associated with founder events in the domestication and subsequent intercontinental dispersal of the various species of *Capsicum* could be quantified by examining allelic diversity among isozyme-coding genes. So far, however, isozymes have been used in chromosome mapping and linkage studies in *Capsicum* (Tanksley, 1984), rather than in studies of genetic diversity.

Characterization and Evaluation of Genetic Resources in *Capsicum*

IBPGR (1983) published a recommended list of descriptors for *Capsicum* but it is not yet clear how widely these descriptors have been accepted and how far characterization of the various national and global collections has proceeded. Many raw data pertinent to characterization have been gathered in the course of studies such as those of Eshbaugh (1970, 1979), Pickersgill, et al. (1979) and Laborde and Pozo (1982) but these remain in the authors' archives and are not generally available.

Various species of *Capsicum* have been reported to be sources of pest and disease resistances, but evaluation of collections for these attributes lags behind characterization. In most cases, resistance is probably a property of a particular accession rather than of the species to which

it belongs. Resistance to various virus diseases has been reported in *C. baccatum* (Dumas de Vaulx and Pitrat, 1978), but observations on *C. baccatum* in South America and in the greenhouse in England (Pickersgill, unpublished) suggest that many accessions of this species are in fact extremely virus-susceptible. A promising allele for resistance to tobacco mosaic virus (TMV) has been reported from two accessions of *C. chacoense* Hunz. (Boukema, 1982; 1984a) but it is not clear how widespread this allele is in *C. chacoense*.

Interspecific Gene Transfer in *Capsicum*

Most interspecific hybrids in *Capsicum* are heterozygous for one or more chromosomal interchanges (Tanksley, 1984; Egawa and Tanaka, 1986; Pickersgill, unpublished). Interchanges have also occurred within *C. annuum*, *C. chinense* and probably *C. pubescens* (González de León, 1986; Pickersgill, unpublished). If the gene to be transferred is carried on one of the chromosomes involved in an interchange, then it will be difficult to recover fertile recombinants for that gene in later segregating generations, especially if the gene is located close to a breakpoint on an interchanged chromosome. On the other hand, if the desired gene is located on a chromosome which is not involved in an interchange, then no major difficulties may be experienced in its transfer from one species to another. Transfer of the L^4 allele for TMV resistance from *C. chacoense* to *C. annuum* seems to be proceeding smoothly even though the F_1 hybrid between *C. chacoense* and domesticated *C. annuum* is heterozygous for three chromosomal interchanges involving five pairs of chromosomes. Presumably the L gene is carried on one of the other seven chromosomes in the complement.

At Reading, we are using isozyme-coding genes to identify the chromosomes involved in interchanges in different interspecific hybrids. We hope to discover whether some chromosomes are involved in interchanges more frequently than others and if so, what the consequences for plant breeders may be.

Nucleocytoplasmic interactions frequently accompany interspecific hybridization in *Capsicum*. The virus-like syndrome which occurs in F_1 hybrids of *C. chinense* × domesticated *C. baccatum* is one example. Other less well understood interactions produce male sterility, either sporadically, as for example in the first backcross generation of crosses between wild and domesticated *C. annuum* (Pickersgill, unpublished), or consistently, as when *C. chacoense* is used as the female parent in crosses with members of the *C. annuum* complex (Boukema, 1984b). If such nucleocytoplasmic interactions affect only male, not female, fertility, they may serve as new sources of male sterility for the production of F_1 hybrid seeds.

Unilateral incongruity is frequently found in interspecific crosses in the Solanaceae. It has been much studied in *Lycopersicon* (Hogenboom, 1979). In *Capsicum*, unilateral incongruities separate the species into two groups. For example, pollen of *C. pubescens* can fertilize ovules of the *C. annuum* complex and of *C. baccatum*, but in the reciprocal crosses, pollen tubes of the white-flowered species stop growing in the upper part of the *C. pubescens* style (Koompai, 1976). Because of this unilateral incongruity, transfer of alleles from purple to white-flowered species should be easier if the hybrid derivatives are consistently used as male parents, whereas transfer of alleles from white to purple-flowered species should be easier if the hybrid derivatives are used as female parents. This prediction will be tested in our laboratory.

Some interspecific crosses fail to produce any viable seeds, for example crosses between *C. chacoense* and the purple-flowered species. Breakdown of these seeds follows a pattern which seems to be typical for the Solanaceae, since it has been reported in *Lycopersicon* (Barbano and Topoleski, 1984) and other genera. The embryo develops to the globular stage, then loses its integrity, while the embryo sac becomes prematurely filled with a mass of cells. At the same time, cells immediately outside the embryo sac enlarge greatly. The embryo sac becomes distorted and eventually collapses (Bermawie, unpublished). Some of these effects may be attributable to hormonal imbalances, and we intend to investigate effects of both *in vivo* and *in vitro* applications of plant hormones and changes in ploidy level in post-fertilization events in these crosses.

In *Lycopersicon* undesirable linkages, for example between nematode resistance and wild-type characteristics, have posed problems in recovery of commercially desirable types after interspecific gene transfer. These problems have been alleviated by the use of isozyme variation to facilitate both selection of desirable recombinants and rapid return to the phenotype of the recurrent parent (Tanksley and Rick, 1980).

In *Capsicum*, we do not yet know what difficulties may be experienced because of undesirable linkages, and isozyme work is still in its infancy compared to the accomplishments in tomato. However, the potential uses of isozymes to accelerate breeding programmes seem as great in *Capsicum* as in *Lycopersicon*.

Nomenclatural Considerations

There has been considerable confusion over the scientific names of the domesticated chili peppers and some of their wild relatives. Excessive taxonomic splitting in the 19th century led to the publication of many binomials, some of which are still used by some authors although they should more properly be treated as synonyms. For example, *C. nigrum* Willd. is still sometimes used for a purple-leaved ornamental pepper which is simply a mutant form of domesticated *C. annuum*, so should be included in that species.

Bailey (1923) treated all the domesticated peppers known to him as a single species, for which he used the name *C. frutescens*. This started a confusion which persists today. Some authors use *C. frutescens* to include peppers which other workers would separate as *C. annuum*, while others use the name *C. frutescens* in a narrow sense, as a species distinct from *C. annuum*. Many papers published in the early part of this century, as well as some later ones, thus use '*C. frutescens*' for what is now called *C. annuum*. Domesticated *C. frutescens* and domesticated *C. annuum*, as defined in this paper, were domesticated independently, incorporate different samples of the ancestral gene pool, belong to different chromosome races and offer different resources to the plant breeder. If research results are to be communicated unambiguously, it is vital that authors establish as clearly as possible the identity of their experimental material. While some workers will undoubtedly disagree with the taxonomic treatment adopted by IBPGR (1983), these names do now seem reasonably stable and likely to help mutual understanding of results obtained by different groups of workers.

Conclusions

Genetic resources for the improvement of peppers in tropical regions are far from exhausted by *Capsicum* breeders. Collections are reasonably adequate, though still distributed between many different research institutes. Characterization and evaluation are still very incomplete, though work is in progress to rectify this. Gene transfer between many species in the genus is possible without use of special techniques. Where barriers to interspecific hybridization have not yet been breached, they may sometimes be circumvented by use of bridging crosses. Although *Capsicum*, like other Solanaceae, is likely to be suitable for genetic manipulation through techniques of genetic engineering, there is still much diversity which can be exploited through conventional plant breeding.

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Symposium Discussion

C. Duranton: Concerning *Capsicum* species, the situation is, for me, a little bit intricate and I need more data for my breeding work. Could you indicate the best means of improving my

knowledge on this subject, an article or a book, which will allow me to recognize more easily the different species in the *Capsicum* group and the best way to get some standards of each main species to work on directly.

B. Pickersgill: Brief diagnostic descriptions and a key to help with identification of the five domesticated species of *Capsicum* are given in the IBPGR booklet on Genetic Resources of *Capsicum* (AGPG/IBPGR/82/12:August 1983). This can be obtained from the IBPGR Secretariat, FAO, Rome, Italy. I have suggested to IBPGR that kits of seeds containing one typical accession for each species be made available for distribution so that people can grow authentically identified material and observe for themselves the species-diagnostic characters. I hope that IBPGR will take up this suggestion.

C.H. Hung: In Taiwan we often find dark seeds (indicating poor quality seeds) instead of normal golden seeds in materials for F_1 sweet pepper seed production originating mostly from Europe or the USA. Is it possible that those materials may be the progenies of *C. pubescens* which you mentioned is the major source of black seed, or that they result from infection with pathogens?

B. Pickersgill: *C. pubescens* is not grown commercially in the USA or Europe. It does not hybridize easily with *C. annuum* and any seed set on *C. annuum* by *C. pubescens* pollen is straw colored like the maternal parent. Embryo culture is usually necessary to raise the F_1 hybrid, which is extremely sterile. I am therefore certain that *C. pubescens* is not the source of your dark seeds. If your seed parent has reduced female fertility (which may be a consequence of some forms of male sterility) or reacts adversely with pollen of the pollinator, fertilization, embryo and/or endosperm development may fail, producing empty seeds which may become necrotic. If your dark seeds contain embryo and endosperm of normal size, then I think you should seek a pathological explanation.

B.S. Kim: The genetic barrier between *Capsicum* species may be a problem in the utilization of germplasm. Can biotechnology such as protoplast fusion techniques solve the problem and replace pollination?

B. Pickersgill: Most species of *Capsicum* can be intercrossed via interspecific pollination, either directly or by use of bridging crosses. The hybrids have sufficient fertility to produce F_2 or backcross generations and pairing and crossing-over between chromosomes from different species usually occurs. The major problem in interspecific gene transfer via the sexual route is obtaining fertile recombinants for the desired character. This problem would occur also in somatic hybrids derived from protoplast fusion. The somatic hybrids would also be tetraploid, which would complicate any further backcross programme. I think plasmid-mediated transformation, which would generate diploid recombinants immediately, may be the most efficient method of interspecific gene transfer. However, as Dr. Loh told us, this technology will not be available in *Capsicum* until a technique is available for regenerating *Capsicum* plants from single cells or callus cultures.

B. Villalon: What are the main reasons for the occurrence of the greatest genetic diversity in *C. annuum* and *C. chinense*?

B. Pickersgill: We do not yet know. The diversity in fruit characters in cultivated *C. annuum* in Mexico and cultivated *C. chinense* in Amazonia is probably related to human selection. However, vegetative characters of *C. chinense* also vary a great deal in Amazonia. They are less likely to have been influenced by human selection and may possibly relate to ecological adaptation, but this needs further investigation. Allelic variation among isozyme-coding genes could provide a third measure of diversity, and could permit quantitative interspecific comparisons of genetic diversity, for which explanations might then be sought, but these isozyme data are not yet available.

2

Genetic Resources of Tomato and Pepper at AVRDC

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Abstract

The Asian Vegetable Research and Development Center (AVRDC) holds one of the largest collections of tomato genetic resources in the world. It presently contains 6,074 accessions from 84 countries/territories. Most accessions belong to the domesticated species, *Lycopersicon esculentum*. Other species include *L. cheesmanii*, *L. hirsutum*, *L. pennellii*, *L. peruvianum*, *L. peruvianum* ("glandulosum" race), *L. pimpinellifolium*, and some crosses of *L. esculentum* × *L. pimpinellifolium* and *L. cheesmanii* × *L. minutum*.

The tomato collection is being characterized in detail and the International Board for Plant Genetic Resources (IBPGR) descriptor list is being modified for this purpose. New lots of seeds are being produced for the base collection in the newly constructed AVRDC genebank. A computerized information management system has been established using the software package MINISIS on AVRDC's HP-3000 minicomputer.

From 1975 to 1987, a total of 48,723 tomato seed samples (both accessions and breeding lines) were distributed to 153 countries/territories for testing.

Pepper was made a principal crop in 1986. AVRDC has been designated by the IBPGR to store the world base collection of peppers. The *Capsicum* collection presently has 5,177 accessions from 81 countries/territories, including accessions from most of the world's major existing collections. Most of the diversity are variants of *Capsicum annuum*. Other species include *C. baccatum*, *C. chacoense*, *C. chinense*, *C. cardenasii*, *C. eximium*, *C. frutescens*, *C. galapagoense*, *C. microcarpum*, *C. pubescens* and *C. praetermissum*.

AVRDC, in cooperation with IBPGR presently revises the pepper descriptor list. The pepper accessions are being characterized and evaluated using the modified list. Seed multiplication for base and active collections is done in insect-proof net-houses to prevent out-pollination by insects. Other genebank processes are carried out as in tomato.

Introduction

The Asian Vegetable Research and Development Center (AVRDC) maintains one of the world's largest collections of tomato and pepper germplasm. The tomato collection, started in 1973, presently contains 6,074 accessions from 84 countries/territories. In 1986, pepper was chosen as one of AVRDC's principal crops (McLean, 1986). AVRDC has been designated by the International Board for Plant Genetic Resources (IBPGR) to keep the world base collection of peppers. The *Capsicum* collection presently comprises some 5,177 accessions from 81 countries/territories, including accessions from most of the world's major collections.

The general activities of the Genetic Resources and Seed Unit (GRSU) on tomato and pepper, which include collection, multiplication, conservation, characterization and evaluation, documentation and distribution, have been described elsewhere (Tay, 1988). The goal is to provide tomato and pepper scientists worldwide with the appropriate germplasm and the accompanying information necessary to exploit the material. This can be achieved through systematic germplasm

conservation of both landraces and related wild species in base and active collections, a well documented germplasm information system providing passport, characterization and evaluation data, and a worldwide distribution system with adequate quarantine standards.

This paper describes the different tomato and pepper germplasm activities and achievements to date.

The Collections

Tomato. The AVRDC tomato collection has been acquired mainly through donations and exchange with different institutions, seed companies and individual scientists from 84 countries/territories (Table 1). It includes 4,433 plant introductions (PIs) from the United States

Table 1. Countries of origin for *Lycopersicon* germplasm introduced to AVRDC (as of 1988).

Country/Territory	No. of entries	Country/Territory	No. of entries
1. Afghanistan	12	43. Korea, Rep. of	27
2. Argentina	59	44. Lebanon	2
3. Australia	47	45. Liberia	1
4. Bangladesh	8	46. Malaysia	28
5. Bolivia	77	47. Malawi	2
6. Brazil	112	48. Mauritius	3
7. Bulgaria	29	49. Mexico	225
8. Canada	142	50. Morocco	16
9. Chile	64	51. Nepal	2
10. China	458	52. Netherlands	95
11. Colombia	127	53. New Caledonia (France)	1
12. Cook Islands	2	54. New Zealand	4
13. Costa Rica	46	55. Nicaragua	31
14. Cuba	7	56. Nigeria	17
15. Czechoslovakia	68	57. Norway	1
16. Ecuador	163	58. Oman	0
17. Egypt	2	59. Pakistan	6
18. El Salvador	407	60. Panama	61
19. Ethiopia	17	61. Papua New Guinea	3
20. Fiji Islands	1	62. Peru	495
21. France	34	63. Philippines	126
22. Gambia	2	64. Puerto Rico (USA)	19
23. Germany, Federal Rep.	19	65. Poland	44
24. Ghana	8	66. Romania	5
25. Greece	5	67. Senegal	1
26. Guadeloupe (France)	14	68. South Africa	21
27. Guam (USA)	3	69. Sri Lanka	16
28. Guatemala	227	70. Spain	49
29. Guiana (France)	13	71. Switzerland	1
30. Guyana	1	72. Sweden	7
31. Honduras	97	73. Syrian Arab Republic	25
32. Hong Kong (UK)	10	74. Taiwan, China	135
33. Hungary	145	75. Thailand	45
34. India	114	76. Trinidad and Tobago	2
35. Indonesia	22	77. Turkey	194
36. Iran	63	78. United Kingdom	44
37. Iraq	2	79. Uruguay	1
38. Israel	27	80. USA	1,212
39. Italy	69	81. USSR	90
40. Japan	96	82. Venezuela	28
41. Jordan	2	83. Yugoslavia	118
42. Kenya	1	84. Zaire	1
		Unknown	48
Total			6,074

Department of Agriculture (USDA). Most accessions in the collection belong to the domesticated species, *Lycopersicon esculentum*. Other species represented are listed in Table 2. To date, 86 suspected duplicates have been identified by comparing passport information. These suspected duplicates will be confirmed by morphological characters and also by electrophoresis of isozymes and soluble proteins. The main weakness of the collection is the lack of proper passport information.

The only major gap in the collection is the lack of variation of the wild related species (602 accessions). However, a large collection of wild types exists at the Tomato Genetics Center (TGC), University of California, Davis, California (TGC, 1987) which is readily accessible to researchers.

Table 2. *Lycopersicon* species in the AVRDC collection.

Species	No. of accessions
L. esculentum	5,365
L. esculentum var. *cerasiforme*	31
L. pimpinellifolium	253
L. cheesmanii	5
L. hirsutum	25
L. hirsutum f. *glabratum*	4
L. esculentum × *L. pimpinellifolium*	180
L. esculentum x *L. hirsutum*	2
L. esculentum x *L. peruvianum*	3
L. peruvianum	80
L. peruvianum race "glandulosum"	11
L. peruvianum var. *humifusum*	2
L. pennellii	37
Unknown	76
Total	6,074

Pepper. The pepper collection, similarly to tomato has been acquired mainly through donation and exchange from 81 countries/territories (Table 3). It includes germplasm from many of the major national programs and seed companies, with 2,860 accessions from USDA (PI); 877 from the Zentralinstitut für Genetik und Kulturpflanzenforschung German Democratic Rep.; 395 from the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica; 136 from the Malaysian Agricultural Research and Development Institute, Malaysia; 97 from the Rural Development Administration, Korea; 51 from the National Plant Genetic Resources Laboratory, the Philippines; 40 from the Institut National de la Recherche Agronomique (INRA), France; and 248 from seed companies and universities. It is one of the most comprehensive collections presently available in the world. Most of the diversity is contributed by variants of *Capsicum annuum*. Other species included are *C. baccatum*, *C. chacoense*, *C. chinense*, *C. cardenasii*, *C. eximium*, *C. frutescens*, *C. galapagoense*, *C. microcarpum*, *C. pubescens*, and *C. praetermissum* (Table 4). The collection has 199 suspected duplicates according to passport information. This needs to be confirmed by morphology and chemical analysis as in tomato. Similarly, there is a lack of proper passport information as in the tomato collection.

In *Capsicum*, there are gaps in variation in the collection that necessitate further collecting. The *Capsicum* user group is not as active as the Tomato Genetic Cooperative for tomato. The working group on *Capsicum* genetic resources coordinated by the IBPGR, designated top priority to collect in Latin America, especially in Mexico, Central America and Panama, Ecuador and Peru (IBPGR, 1983). Presently, the large genetic diversity of the genus *Capsicum*, comprising some 20-30 species in Latin America is being actively collected by the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias (INIFAP), Mexico; and the Centro Nacional

Table 3. Countries of origin for *Capsicum* germplasm introduced to AVRDC (as of 1988).

Country/Territory	No. of entries	Country/Territory	No. of entries
1. Afghanistan	19	42. Kenya	4
2. Algeria	1	43. Korea, Rep. of	147
3. Angola	1	44. Lebanon	3
4. Argentina	50	45. Libya	10
5. Austria	22	46. Malaysia	186
6. Belgium	3	47. Marianas Islands	1
7. Belize	7	48. Mexico	270
8. Bolivia	75	49. Nepal	8
9. Brazil	208	50. Netherlands	104
10. British Indian Ocean Territory	1	51. Nicaragua	9
11. British Virgin Islands	2	52. Nigeria	13
12. Bulgaria	107	53. Pakistan	10
13. Canada	25	54. Panama	13
14. Chile	12	55. Paraguay	2
15. China	115	56. Peru	290
16. Colombia	89	57. Philippines	60
17. Costa Rica	235	58. Portugal	10
18. Cuba	15	59. Puerto Rico (USA)	20
19. Czechoslovakia	32	60. Romania	38
20. Denmark	5	61. Singapore	1
21. Ecuador	55	62. Solomon Islands	1
22. Egypt	10	63. South Africa	1
23. El Salvador	88	64. Spain	58
24. Ethiopia	66	65. Sri Lanka	1
25. Fiji Islands	3	66. Sudan	2
26. France	43	67. Surinam	10
27. Germany, Democratic Rep.	28	68. Switzerland	9
28. Germany, Federal Rep.	23	69. Syrian Arab Republic	7
29. Greece	5	70. Taiwan, China	33
30. Guatemala	143	71. Thailand	70
31. Guinea (French)	1	72. Trinidad and Tobago	5
32. Guyana	7	73. Tunisia	10
33. Honduras	87	74. Turkey	395
34. Hungary	245	75. United Kingdom	35
35. India	217	76. Uruguay	4
36. Indonesia	9	77. USA	320
37. Iran	52	78. USSR	56
38. Israel	8	79. Venezuela	27
39. Italy	116	80. Yugoslavia	493
40. Jamaica	1	81. Zambia	6
41. Japan	30	Unknown	174
Total			5,177

de Recursos Genéticos (CENARGEN), Brazil (Dr. Miguel Holle. IBPGR Field Officer in Latin America. personal communication. 1987).

Hot pepper, after initial introduction to a new environment, tends to naturalize itself, i.e. establish in the new environment after a period of time. Existing collections of these naturalized populations from most countries are limited, especially the cultivated landraces in South, Southeast and Central Asia, China, Africa, and the Mediterranean (IBPGR. 1983).

Table 4. *Capsicum* species in the AVRDC collection.

Species	No. of accessions
C. annuum	2,593[z]
C. baccatum	334[y]
C. chacoense	25
C. chinense	341
C. eximium	3
C. frutescens	269
C. galapagoense	1
C. microcarpum	6
C. praetermissum	4
C. pubescens	27
Unknown	1,574
Total	5,177

[z]Includes eight *C. annuum* var. *longum* and four *C. annuum* var. *grossum*. [y]Includes one *C. baccatum* var. *baccotum* and 206 *C. baccatum* var. *pendulum*.

Conservation

The collections are maintained under three different storage conditions: (1) in long-term permanent storage at -18°C in hermetically-sealed aluminum-polyethylene (Al-PE) pouches (base collection), (2) in medium-term storage at 2° ± 3°C and 40% ± 5% relative humidity (RH) in plastic screw-top bottles for distribution (active collection), and (3) in short-term storage at 15°C and 40% RH in nylon net or paper bags for seeds which are waiting to be further processed (working collection). There are currently 1,213 tomato and 452 pepper accessions in the base collections and 6,074 tomato and 5,177 pepper accessions in the active collections at AVRDC. Most of the tomato accessions have been duplicated in the National Plant Genetic Resources Laboratory, Philippines through arrangement with the IBPGR. The pepper collection which is presently being multiplied will also be duplicated in the genebank at CATIE, Costa Rica, the other IBPGR-designated genebank for *Capsicum*.

Before packaging in Al-PE pouches for long-term storage, seeds of both species are dried to 5%-6% moisture content using a slow dryer operating at 15°C and 15% RH. A minimum of 12,000 seeds per accession are kept in the base collection. The seed viability of each accession in long-term storage is assessed by determining the initial germination rate, followed by monitoring the viability every five years during the first ten years; the monitoring interval is adjusted according to the seed quality. Seeds are regenerated when the viability falls to 85% generation rate or when it drops by 15%.

Seed Multiplication

Seed multiplication is an important step in the conservation process. It is necessary to maintain the genetic integrity of the accessions during seed multiplication. Alteration of the genetic composition of an accession can be due to the following causes: genetic mishaps such as out-crossing, selection, genetic drift, mutation,and others; mechanical contamination with seeds of other accessions during harvesting or during seed cleaning, processing and packaging; and/or mistakes in labelling. The process, therefore, involves a series of steps and at any one of these steps an accession can be contaminated either through out-crossing or mechanical mixing. A proper seed production management system should, therefore, be followed.

Tomato. Most *Lycopersicon* accessions in the collection are self-pollinated except for a few belonging to certain wild, related species, namely *L. hirsutum*, *L. pennellii*, *L. peruvianum* and *L. pimpinellifolium*. However, in hot weather in the tropics the out-pollination rate in the normally

self-pollinating species may be as high as 25% (Esquinas-Alcazar, 1981). Seed multiplication at AVRDC is, therefore, conducted only in the winter season from November to February when the average day temperature is about 19°C. Isolation of accessions during seed multiplication is, however, implemented to prevent mechanical mixture.

Each accession is planted to double row beds of 1.5 × 7.5 m. The planting distance is 50 cm between rows and 50 cm within rows, resulting in 30 plants per plot per accession. The AVRDC recommended field management practices for tomato are followed during seedling preparation and field management (Kuo and Lai, 1979). Black plastic mulch is used to control weeds. Because of the vigorous vegetative growth of many of the landraces, special attention is taken to prune each plant into a single stem and to stake each up with bamboo poles to prevent overgrowth into the neighbouring plots. Definite off-types are rogued. However, many of the accessions are landraces and, therefore, have a range of variation within an accession. These accessions are maintained as bulk. In cases where definite different types are present in an accession they are harvested separately and maintained as different accession numbers but with the same passport data.

Each accession is harvested two to four times to obtain enough seed stock for storage. Seed is extracted by fermentation. Before drying, the freshly extracted seeds for the active collection are treated with trisodium phosphate solution (12.5%, 20 minutes) to control seedcoat-borne viruses. At the end of the season, the seed lots from different harvests of each accession are combined together and dried before packaging.

Pepper. *Capsicum* is a self-pollinating genus. However, an out-crossing rate of up to 46% is possible (Belletti and Quagliotti, in the proceedings). Seed multiplication is, therefore, done in insect-proof nylon net-houses which are partitioned into cages to accomodate 12 accessions/cage. The plot size is 1.2 × 6.0 m with 40 cm between rows and 40 cm within row resulting in 30 plants/plot. An extra 0.8 m space between the plots is kept in order to provide sufficient space to separate the plots from each other at a later growth stage.

Seed of each harvest of each accession is extracted using a small modified mince-meat grinder. This is followed by washing the seed with water to remove the pulp. Using this technique, extraction is fast and if carefully done it is free from mechanical contamination. Compared to the method of manually splitting and extracting the seeds from every fruit, the pungency of the hot pepper is far less bothersome to the workers. The clean seeds for the active collection are treated with 10% trisodium phosphate solution for 2 hours (Rast and Stijger, 1987).

There is more genetic variation and/or mixture within an accession of pepper than in the tomato because of the higher out-crossing rate of the species. The variations are managed as described above for tomato.

Characterization and Evaluation

Characterization and evaluation of tomato and pepper germplasm are emphasized at AVRDC to identify the subgroups within each species, specific traits and the duplicates. The climatic conditions at AVRDC provide a unique natural site for these activities. Most of the characterization on tomato is done during seed multiplication in the winter season, and heat tolerance and bacterial wilt resistance are evaluated in the hot wet season (summer).

The IBPGR tomato descriptors (Esquinas-Alcazar, 1981) are being modified to form 53 characters. A summary of the modified descriptors, according to the different plant parts, is given in Table 5. Since 1972, a series of accessions with desirable traits have been identified (Table 6). Some of these traits, such as heat tolerance, bacterial wilt resistance, TMV resistance, nematode resistance, and agronomic characteristics have been successfully combined by the breeders at AVRDC (Opeña et al. 1987; 1989 in the proceedings).

Presently, AVRDC in cooperation with IBPGR revises the *Capsicum* descriptor list (IBPGR, 1983) using 69 characters (Table 7). Using this list, characterization is an on-going activity in the summer season in the open field.

Table 5. Summary of tomato descriptors used at AVRDC.

Plant part	Numbers of characters	
	Qualitative	Quantitative
Seedling	1	2
Vegetative	7	1
Flowers	2	4
Fruit	24	12
Total	34	19

Table 6. Accessions with desirable traits from the AVRDC tomato collection.

Character	Accession (L)[z]	Origin	Country/Inst. reporting	Reference[y]
Bacterial spot resistance (*Xanthomonas campestris* pv. *vesicatoria*)	Hawaii 7998 (TL 263)	USA	AVRDC	1987a
Bacterial wilt resistance (*Pseudomonas solanacearum*)	1, 8, 15, 21, 29, 33, 34, 39, 80, 82, 88, 95, 96, 203, 213, 232, 233, 240, 246, 274, 283, 285, 366, 712, 969, 1629, 1737, 1822, 1937, 3690, 3705, 3880, 3972, 3987, 4045, 4066, 4410, 4540, 4670, 4679, 4681, 4712, 4841, 5327, 5331, 5336, 5338, 5509, TL 241	Czechoslovakia, Ecuador, El Salvador, France, India, Japan, Malaysia, Netherlands, Panama, Peru, Philippines, Puerto Rico, Sri Lanka, Taiwan	AVRDC	1974, 1975, 1976, 1977, 1978, 1979, 1981a, 1981b, 1985, 1987b
	274	USA	Hawaii	1977
	8, 39, 4045	India, Philippines	Philippines	1977
Cold tolerance and disease resistance	3841, 4004	Japan, New Zealand	Korea	1976
Flood tolerance	123, 125, 973, 3072, 3091, 4313, 4360, 4422	Ecuador, Japan, Philippines, Poland, USA	AVRDC	1981b
Fusarium wilt resistance (*Fusarium oxysporum* f.sp. *lycopersici*)	93, 94, 203, 272	USA	AVRDC	1985, 1987a
Gray leaf spot resistance (*Stemphylium solani*)	203, 224	Canada, USA	AVRDC	1975
Heat tolerance	1, 18, 33, 95, 96, 99, 125, 226, 229, 232, 243, 245, 246, 283, 285, 387, 492, 493, 1076, 1488, 1834, 2972, 2973, 2991, 3040, 3510, 3537, 3690, 3956, 3957, 3958, 4043, 4511, 4719, 4841, 4912, 4924, 4964, 4977, 5153, 5331, 5336, 5337, 5338	Canada, China, Ecuador, France, India, Malaysia, Philippines, South Africa, Taiwan, Thailand, USA, USSR	AVRDC	1975, 1976, 1977, 1978, 1979, 1981a, 1981b, 1984, 1985, 1987a
	1, 274	Philippines, USA	Honduras	1981b
High fresh market quality	21, 34, 202	Philippines, USA	AVRDC	1976
High germination rates of pollen at high temperature (34°C)	245, 283, 3692	Malaysia, Ecuador, USA	AVRDC	1979
High yield	123, 124, 319, 3855, 3926, 3953, 3978	Japan, USA	Taiwan	1977
	3841, 4004	Japan, New Zealand	Korea	1976
Late blight resistance (*Phytophthora infestans*)	1197, 1497, 1501, 1517	Argentina, USA	AVRDC	1977, 1985, 1987a, 1987b
	718, 1717	Costa Rica, Peru	Malaysia	1976

Table 6. Continued.

Character	Accession (L)[z]	Origin	Country/Inst. reporting	Reference[y]
Leaf mold resistance (*Fulvia fulva*)	95,96	USA	AVRDC	1975
Moisture tolerance	95, 96, 123, 166, 3972, 3987	Ecuador, France, Japan, Sri Lanka, USA	AVRDC	1978, 1979
Parthenocarpy	5471, TL 164	Netherlands	AVRDC	1984
Powdery mildew resistance (*Erysiphe polygoni*)	17, 30, 40	Philippines	AVRDC	1977
Processing type	80, 85, 124, 3857, 3874, 3907, 3975, 3976, 4012, 4093	Japan, Philippines, USA	AVRDC	1976, 1985
PVY resistance	3683, 5815	Ecuador, Peru	AVRDC	1987a, 1987b
Rootknot nematode resistance	97, 272, 274, 275, 313, 315, 345, 354, 373, 383, 640, 641, 671, 672, 673, 680, 688, 885, 887, 889, 890, 892, 3889, 3890, 3893, 3960, 4104, 4109, 4110, 4124, 4126, 4129	Chile, Taiwan, USA	AVRDC	1976, 1977, 1979, 1981a, 1981b, 1985
TMV resistance	127, 366, 5327, 5328, 5335, 5336, 5337, 5338, 5340, 5341, TL 16, TL 37, TL 38, TL 39	France, Netherlands, United Kingdom, USA	AVRDC	1975, 1982, 1984, 1985, 1987a
Tomato fruitworm resistance	139, 177, 181, 593, 632, 633, 667, 675, 677, 680, 690, 691, 697	Colombia, Ecuador, Peru, Philippines, USA	AVRDC	1985

Sources: AVRDC Annual/Progress Reports, 1974-87. [z]L-series: permanent AVRDC *Lycopersicon* collection; TL-series: temporary AVRDC *Lycopersicon* collection. [y]AVRDC Annual/Progress Reports.

Table 7. Summary of *Capsicum* descriptors used at AVRDC.

Plant part	Numbers of characters	
	Qualitative	Quantitative
Seedling	5	2
Vegetative	12	5
Flowers	9	4
Fruit	20	8
Seed	2	2
Total	48	21

Documentation

A computerized information management system has been established using the MINISIS software package which was developed by the International Development Research Centre (IDRC) of Canada on the HP 3000 minicomputer (Tay, 1989). The passport data of both crops are in one common data base which includes all species stored at AVRDC. Their characterization and evaluation data are organized in separate data bases which can be linked together and utilized as one big integrated data base by the users. Simultaneous on-line retrieval on the data base can be performed from any of the interactive terminals throughout headquarters.

Distribution

Since 1974, a total of 48,723 seed samples of tomato (both accessions and breeding lines) have been distributed to 163 countries/territories for testing, and 27,086 samples of the accessions have been tested by AVRDC's scientists. Germplasm is available for exchange with both public and private research organizations. The major recipients of this germplasm are shown in Table 8,

and the distribution by continent is summarized in Tables 9 and 10. The dissemination of AVRDC-improved lines has resulted in the official releases of 66 cultivars in 26 countries/territories (Opeña et al. 1988).

Table 8. Major recipients of AVRDC tomato germplasm and breeding lines, 1974-87.

Country	No. of seed samples
Philippines	10,132
Taiwan, China	5,348
Thailand	4,693
India	2,823
USA	2,192
Japan	1,988
Malaysia	1,597
Indonesia	1,217
Solomon Islands	1,049
Korea	949
Mexico	771
Nigeria	770
Saudi Arabia	664
Costa Rica	623
Ghana	502
Others[z]	13,405
Total	48,723

[z]Includes 148 countries and territories.

Table 9. Distribution of AVRDC tomato germplasm accessions and breeding lines by continents, 1974-87.

Continent	No. of seed samples
Asia	31,919
Africa	5,510
Latin America	5,155
Australia and the Pacific	2,777
North America	2,304
Europe	1,058
Total	48,723

Table 10. AVRDC tomato releases, June 1989.

Local name	AVRDC ID no.	Year	Country/ territory	Remarks[z]
-	CL 1131-0-38-4-0	1983	Barbados	BW, HT, TMV, FC
-	CL 1131-9-43-8-1	1983	Barbados	BW, HT, TMV, FC
-	CL 1131-0-43-8-1	1983	Barbados	BW, HT, TMV, FC
Belem-70	CL 5551(F_3)	-	Brazil	BW
Xina	CL 143-0-13-3 UG + local line	1989	Cape Verde Islands	HT, BW, FW (0,1), GLS, F
Tropiva 3	CLN BC_1F_2-26-3-3-15	1989	Cape Verde Islands	EM, CR, FM, HY, HPD
Xin	CL 143-0-13-3	1982	Congo	HT, BW, FW, GLW
-	CL 11d-0-2-2-0-3-0	1983	Cook Island	BW, HT
-	CL 1104-0-0-29-1-0	1983	Cook Island	BW, HT
-	CL 9-0-0-1-3-0	1983	Cook Island	BW, HT
-	CL 143-0-10-3-0-1-10	1983	Cook Island	BW, HT
Alton	CL 143-0-4-B-1	1979	Fiji	BW, HT

Table 10. Continued.

Local name	AVRDC ID no.	Year	Country/ territory	Remarks[z]
Sada Bahar	CL 8d-0-7-1	1983	Fiji	BW, HT
Xin	CL 143-0-13-3	1982	Gabon	HT, BW, FW, GLS
Tropiva 1	CL 949	1986	Gabon	BW
Lee's Plum	CL 143-0-4-B-1	1978	Guam	HT, BW
Royal Plum	CL 143-0-6-9	1978	Guam	BW, (HT)**
Intan	L 33 (VC 8-1-2-1)	1979	Indonesia	BW, HT
Ratna	L 21 (VC 11-1)	1979	Indonesia	BW, (HT)
Berlian	L 15 (VC 8-1-2-7)	1984	Indonesia	BW
Mutiara	(Gondol × Intan)	–	Indonesia	–
–	L 21 (VC 11-1)	1978	Malaysia	BW, HT
MST 20/13	CL 143-0-10-3	1981	Mauritius	HT, BW
MST 32/1	–	1981	Mauritius	HT, BW
MST 21/23	–	1981	Mauritius	HT, BW
MST 25/7	–	1981	Mauritius	HT, BW
MST 23/11	–	1981	Mauritius	HT, BW
BPI-Tm P-1 ("Mapula")	CL 2784-1-1-4	1987	Philippines	HY, MT, P, FC, W 43
–	CL 1145-5-0-0	1982	Panama	BW, HT
Chancellor	CL 555 (SSD)	1979	Papua New Guinea	BW, HT
–	CL 143-0-4-B-1 + local line	1983	Reunion	BW, HT
Bourbonna	MST 21-23	1986	Reunion	–
Xin	CL 143-0-13-3	1982	Senegal	HT, BW, FW, GLS
Xina	CL 143-0-13-3 UG + local line	1986	Senegal	HT, BW, FW (0,1), GLS, F
Canner	CL 143-0-4-B-1	1983	Seychelles	HT, BW
Big Red	CL 143-0-3-6	1983	Seychelles	HT, BW
Creeper	CL 8d-0-7-1	1983	Seychelles	HT, BW
Little Cherry	CL 11d-0-2-1	1983	Seychelles	HT, BW
Star	L 21 (VC 11-1)	1983	Seychelles	BW, (HT)
–	CL 1164 F5-1	1983	Seychelles	–
–	CL 1164 F5-4	1983	Seychelles	–
–	CL 1164 F5-29	1983	Seychelles	–
–	CL 1164 F5-37	1983	Seychelles	–
–	CL 1094 F5-10	1983	Seychelles	–
–	CL 1084 F5-48	1983	Seychelles	–
–	L 33 (VC 8-1-2-1)	1979	Singapore	BW, (HT)
–	L-33	1980	Singapore	BW, (HT)
T-146	C 32d-0-1-2-0	1982	Sri Lanka	HT, BW
Yeong-Mei #3	CL 1591-5-0-1-7-0	1979	Taiwan, China	HY, F, P
TSS1	TSS 557 (AVRDC parent)	1981	Taiwan, China	BW, HT
Tainan No. 2	CL 1561-1	1982	Taiwan, China	HY, F, P
Tainan No. 3	P.T. 3027	1986	Taiwan, China	HT, P, F(M), TMV, BW, N, W 65-75
–	CL 143-0-13-3	1982	Tanzania	BW, HT, FW, GLS
SVRDC-3	L 22 (VC 11-3-1-8)	1980	Thailand	BW, HT
SVRDC-4	CL 1131	1980	Thailand	BW, HT, possible TMV resistance
Seedathip I	CL 1131-0-0-13-0-6 × Seeda	1987	Thailand	HT, EM, W 25
Seedathip II	CL 1131 × Seeda	1988	Thailand	W 30, CLM, HT
CES No. 1	CL 1131-0-0-43-4-12	1987	Trinidad & Tobago	HT, BW, F, W 25-30, C

Table 10. Continued.

Local name	AVRDC ID no.	Year	Country/ territory	Remarks[z]
CES No. 2	CL 143-0-10-3-0-1-10	1987	Trinidad & Tobago	HT, BW, F, W 25-30, C
–	CL 143-0-10-3	1982	USA (Virgin Islands)*	HT, BW
Alufua Early	CL 2729-0-2-1-12-0	1988	Western Samoa	BW(H), FC, EM, W 25, HY, NP
Alafua Winner	CL 5915-93D4-1-0	1988	Western Samoa	BW(H), W 52, FC, NP
Alafua Large	CL 5915-206D4-2-2-0	1988	Western Samoa	BW(H), W 76, HY, FC, NP
–	CL 143-0-13-3	1982	Zaire	BW, HT, FW, GLS

*Unidentified, unofficial release to farmers by Water Isle Botanical Garden.
** Parenthesis indicates degree, e.g. (M) = moderate; (H) = high.
*** Adapted line bred from AVRDC parental stock.
[z]Symbols:
BW: Bacterial wilt resistance.
C: Cherry tomato.
CLM: Cercospora leaf mold resistant/tolerant.
CR: Cracking resistance.
EM: Early maturing.
F: Firm fruit.
FC: Good flavor and color
FM: Acceptable size for fresh market.
FW: Fusarium wilt resistance. Parenthesis indicates strains.
GLS: Gray leaf spot resistance.
HPD: High planting density.
HT: Heat tolerant.
HY: High yield.
N: Nematode resistant/tolerant
NP: No pruning required
P: Good processing qualities.
TMV: TMV-resistance.
W: Fruit weight (g).

Future Prospects

The germplasm activity on tomato at AVRDC has significantly enhanced the production and utilization of *Lycopersicon species* in the tropics. It is believed that the same trend will follow in peppers. Germplasm evaluation will be emphasized to identify new germplasm with specific traits. Crop catalogs will be developed. The distribution of diverse and well evaluated genetic materials to support research programs worldwide will, therefore, be strengthened.

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Symposium Discussion

R.T. Opeña: What is the status of *L. esculentum* as the valid scientific name for cultivated tomato? This was supposed to have been discussed in the last International Botanical Congress.

B. Pickersgill: The 14th International Botanical Congress (Berlin, 1987) agreed for the first time to the principle of conservation of specific names for species of major economic importance. Two such names were conserved: *Lycopersicon esculentum* Mill. and *Triticum aestum* L. The correct scientific name for the cultivated tomato is, therefore, *Lycopersicon esculentum* Mill. (Anonymous. 1988 International Code of Botanical Nomenclature: Adopted by the Fourteenth International Botanical Congress, Berlin, July-August 1987, Koeltz Scientific Books, Konigstein, Fed. Rep. of Germany. Pages 16, 288).

3

Genetic Resources of Tomato in India, Their Buildup, Evaluation, Maintenance and Utilization

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Abstract

Tomato is one of the most popular and versatile vegetables in India and is cultivated in almost all parts of the country because of its wide adaptability. The National Bureau of Plant Genetic Resources (NBPGR) of the Indian Council of Agricultural Research is the main center for germplasm maintenance of tomato, with duplicate centers at the Indian Institute of Horticultural Research, Bangalore and at the Punjab Agricultural University, Ludhiana. It has since 1946 systematically assembled a germplasm collection of 2659 entries including wild species from over 40 countries. Almost the entire germplasm collection has been evaluated for 39 different agrobotanical and economic characters. A catalogue is under preparation for the benefit of user agencies. Accessions showing high yield potential, good processing characteristics, heat tolerance, disease resistance, and the ability to withstand long distance transportation were sorted out for direct selection or exploitation as parental material in breeding programs. Improved Meeruti, HS-101, HS-102, KS-1, KS-2, S-11, CO-1, CO-2, S-120, and Punjab Tropic have been developed by selection from indigenous germplasm. Pusa Ruby and Pusa Early Dwarf, the most popular varieties under cultivation for the last three decades, have been developed by the NBPGR. A number of disease-resistant lines have been identified at various centers.

Introduction

Tomato (*Lycopersicon esculentum* L.) was introduced into India in the 18th century. Commercial scale cultivation began towards the close of last century. It has now become a popular vegetable and is grown widely throughout the country. It is cultivated on ca. 80,000 ha in different parts of the country and is well adapted to all regions. On the average, a normal crop of tomato yields 16,000 to 24,000 kg per hectare. Extensive efforts are under way to maintain old cultivars and the invaluable wild relatives (obtained from several countries) that have served as the progenitors of the present day tomato. Tomato germplasm from India and from foreign countries is maintained by the Germplasm Evaluation Division of the National Bureau of Plant Genetic Resources at New Delhi and is available to scientists/breeders working on tomato improvement on request.

Collection, Evaluation and Documentation

Although introduced over two centuries ago, tomato in India has attained commercial importance only with the introduction of several promising cultivars from the USA, Australia and Europe over the last four decades. In 1946 the erstwhile Plant Introduction Division of the Indian Agricultural Research Institute (the present NBPGR) initiated the building up of tomato germplasm, on a systematic basis, from various parts of the world. A total of 2,659 germplasm

lines (Table 1) has been assembled including wild species such as *L. pimpinellifolium*, *L. hirsutum*, *L. peruvianum*, *L. glandulosum*, *L. cheesmanii*, *L. chilense*, *L. esculentum* var. *cerasiforme* and *L. pissisi*.

The collection was evaluated systematically for 39 different agrobotanical and economic characters and found to vary in plant height (25-167 cm), number of branches per plant (3-19), number of clusters per plant (4-201), number of flowers per cluster (2-26), number of fruits per cluster (1-22), number of fruits per plant (8-790) and average weight of 10 marketable fruits (30-167 g) (Table 2). The characterization of tomato germplasm has helped breeders in the identification of donor types carrying characteristics (Table 3) some of which have been used in the breeding programs. A number of donors are yet to be utilized by the breeders (Paroda et al. 1987; Thomas and Umesh Chandra. 1987).

Wild relatives have been evaluated for high tolerance to poor soils, the ability to withstand drought or excessive moisture, and to resist diseases and insects.

The germplasm collection includes lines highly resistant to Fusarium wilt (Sel 673, EC 37192), TMV (breeding lines B 2247 and Holmes PI) (Choudhury et al. 1973) and leaf curl virus (*L. esculentum* lines P-13, XXXII-354-A-Silvestra, B 2247 and Sel 498), *L. peruvianum* (LP-6, LP-8) *L. chilense* and *L. hirsutum*.

Nematode-resistant accessions are Anahu, Florida, Hawaii Cross, Hawaii 55, Nemered, Nematex, Atkinson, VNF 8, 65 N-215-1, 65 N-255-1, and Pusa-120, a highly tolerant accession to rootknot nematode (Singh and Choudhury, 1972).

Lines with high yield potential, heat tolerance, suitability for processing and transportation, and resistance to Fusarium wilt, fruitrot and fruitborer were sorted out for their utilization as direct selection or for exploitation as parental material in hybridization program. A catalogue

Table 1. Tomato germplasm in India.

Sources of collections	Number of accessions
(i) From abroad	
Argentina, Australia, Brazil, Bulgaria, Burma, Canada, Chile, China, Colombia, Cyprus, Czechoslovakia, Denmark, Germany, Ghana, Hong Kong, Hungary, Iraq, Israel, Italy, Japan, Mauritius, Nepal, Netherlands, New Zealand, Nigeria, Philippines, Poland, Portugal, South Africa, South America, Spain, Switzerland, Taiwan, Tanzania, Trinidad, Turkey, United Kingdom, United Arab Republic, USA, and Yugoslavia.	2,229
(ii) From India	
West Bengal, Tamil Nadu, Madhya Pradesh, Maharashtra, Uttar Pradesh, Himachal Pradesh, Karnataka, Bihar, Jammu and Kashmir, Andhra Pradesh, Haryana, Gujarat, Mizoram, Sikkim and Manipur.	430
Total germplasm assembled	2,659

Table 2. Preliminary evaluation and range of variability in quantitative characters in tomato (both cultivated and wild).

Characters attributes	Values	
	Minimum	Maximum
Plant height (cm)	25	117
Number of branches per plant	3	19
Number of clusters per plant	4	201
Number of flowers per cluster	2	26
Number of fruits per cluster	1	22
Number of fruits per plant (incl. wild relatives)	8	790
Average weight (g) of 10 marketable fruits	30	1,675

Table 3. Donor types identified for breeders use.

Trait	Donor germplasm
High yield	EC Numbers: 1127, 1153, 3069, 4708, 6049, 6053, 7291, 9016, 9149, 11238, 10309, 27412, 16920, 17960, 27918, 42662, 35395, 54645, 66504, 101652, 110176, 125754, 126776, 128524, 128693, 128969, 129600, 129600-p^2-1, 129081, 129353, 129354, 129081, 129353, 129354, 129757, 129171-p^1-2, 130035, 130163, 130163-p^2-1, 141854-1, 145515, 161251 and DM83-12, DM83-21 and Bulgarian.
Heat tolerance	EC Numbers: 41824, 7764, 9149, 35211, 54315-1, 122963, 129666-p-1, 32611, 126955, 159979, 141832, 14073-p^2, 27936, 27929, 128964, 2599, 35220, 27251, 37264, 43225, 54027, 61691, 103595, 111085, 1139, 41025; PI Numbers: 126453, 126923, T30/47, MH 81-3, 78/81-13, IC 23571 & many more.
Processing type	Bulgarian, EC942, 1193, 2790, 480, 1132, 1154, 8822, 4229 p^2, 54628, 35461, 52062, 89258, 110578, 161252, 160187, 145623, 141814; Ont. 787; IC 15212; M28 81-12 etc.
Suitable for transportation	EC 4229 p^2, 19 81-6, 7167, 7352, 8822, 100845, 110268, 99184; DM Sel-3-1; EC 130049, 168541, 171072, and many more.
Resistance to Fusarium wilt and fruitrot	EC Numbers: 160195, 1149, 1184, 1151, 1136, 6589, 26108, 35401, 161[illegible], 122527, 21626, 103598, 116874, 117008, 115947, 37192, 117671, 117103, 119116, 5962, 4764, 54716, 455, 119187, 30366, 35488 p^2-1, 110116, 109181-2, 54716, 54628A, 54628B, 50366-1-1-1, 104162 p^2-1, 106261, 66504, 11662, 1265[illegible], 129757, 129380 and EC 128769.
Resistance to fruit borer	EC Numbers: 262, 2669, 490, 491, 6200, 7764, 59621, 129354, 6987, 16787-1, 23528, 110264, 101552, 1747, 57289, 65077, 11520-1, 124406, 129599, 129597, 129698, 129599 p^2-1, 129469, 128016, 119791, 43264, 66005, 65984, 2630, 121443, 86526, 20685, 121451, 2792, 85622, 160191, 21318, 161254, 9227, 18223, 118266, 1149-7, 114937, 119114, 119121; IC 59067; 51 81-3, 14 81-6, 78/81-8, 100/1-A, M 3 81-3 DM 83-14, DM-3, DM 83-7, 51 81-2, 28/81-3, 95/81-2, 51 81-3 and 14 81 6.

EC numbers represent exotic collections obtained from other countries and maintained at the National Bureau of Plant Genetic Resources, New Delhi-110012, India.

depicting all these characters is under preparation (Paroda et al. 1987; Thomas and Umesh Chandra, 1987).

Utilization

Tomato breeders in India over the past 30 years have made tremendous gains in yield, fruit-setting, quality, and ability to withstand the pressures of handling and storage, yet many of the genes that favor resistance to diseases and pests have not been fully exploited.

Several cultivars introduced from abroad, particularly from USA, have performed well in different parts of India. These include: Sioux (ex USA), Best of All, Fireball (ex Canada), Rutgers, Early Lathbridge, King Humbert, Roma (ex USA), La Bonita (ex USA), Dwarf Money Maker (ex Israel), Pan America, Early Chatham, Marglobe, Best of All, Italian Red Pear and Roma (Thomas et al. 1983). For growth at the high altitudes of Ladakh, Early Lethbridge, Fireball and Early North (Canadian lines) were found suitable (Singh and Mital, 1966).

Selection has played an important role in tomato improvement in India. Improved Meeruti was evolved from an Indian cultivar from Meerut in Uttar Pradesh (Singh and Sikka, 1955). Selections made from indigenous material are Meeruti, HS-101, HS-102, KS-2, S-11, CO-1 and CO-2. Selection-120, a large-fruited high yielding cultivar with nematode resistance, was selected from exotic breeding material (Helani numbers) received from Dr. Gilbert of Hawaii. This cultivar has been found to be promising for nematode resistance, heavy yields and large round fruits. Hybridization, utilizing exotic cultivars as one of the parents, resulted in cultivars like Pusa Ruby (Sioux × Improved Meeruti), Pusa Early Dwarf (Improved Meeruti × Red Cloud), Pusa Red Plum (*L. esculentum* × South American *L. pimpinellifolium*), Punjab Chhuhara (Israel Introduction EC 55055 × Punjab Tropic) and Sweet 72 (Pusa Red Plum × Sioux) which is rich in vitamin C and sugar (Pal and Singh, 1943). Mutation breeding was utilized in developing cultivars like S-12 and CO-3. Heterosis in tomato resulted in an increased yield of 20 to 50% (Pal and Singh, 1943; Choudhury et al. 1965). Two very promising combinations are Red Jacket × Meeruti using a closed anther mutant (Mital et al. 1962) and Pusa Ruby × Best of All (Choudhury et al. 1965). The advantage of such hybrids resulted in earliness, better yield potential, improved quality, uniformity and adaptation to adverse conditions. The most important tomato selections and their characteristics are listed in Table 4.

Large resources of germplasm are available and yet unexploited opportunities await investigation.

Table 4. Important tomato selections and their characteristics.

Variety, source and year of identification	Suitable growing zones[1]	Varietal characteristics
Pusa Ruby, IARI/NBPGR (1975)	II, IV, VI, VII and VIII	Plant height 80-85 cm, indeterminate growth habit, spreading, less branched and hardy. Fruits flat, round, small to medium, uniform deep red, slightly lobed (4-5 locules), slightly acidic. 25-30 fruits per plant, maturity 60-65 days. Suitable for autumn, winter and spring summer seasons in the plains. Good for juice and ketchup. It is an old variety derived from the Cross Improved Meeruti × Sioux.
HS-101, Hisar (1975)	I, II, IV, VII, and VIII	Plant height 50 cm, dwarf multi-branched, sturdy and determinate in growth habit. Fruits borne in clusters of 2-3, round, small to medium in size, 3-4 locules. Fruits ripen uniformly, 40-50 fruits per plant. Suitable for winter season.
HS-102, Hisar	I, II, IV, VII, and VIII	Early cultivar, determinate, fruits with yellow stem end, medium to small size, smooth, attractive, round.
S-12, Ludhiana (1975)	I, II, IV, VII, and VIII	Plants are dwarf, bushy, vigorous; fruits are medium sized, compressed round. Uniformly colored red at maturity, juicy, highly acidic. Average yield 175-230 t/ha. Suitable for fresh market.
Pusa 120, IARI/NBPGR (1975)	I, IV, VI, VII, and VIII	Semi-determinate, spreading type, foliage, dark green, good coverage, fruits and attractive round to flattish round, medium to large, smooth, uniform, red in color, less acidic and less seeded. Resistant to nematodes. Suitable for summer and winter.
T-1, Pantnagar (1975)	I, II, IV, VII, and VIII	Plant height 100-120 cm tall, erect and indeterminate in growth habit, foliage, green in color. Fruit round, slightly, pointed at the stigmatic end, 4-5 locules, 4-5 fruits per tree, non-cracking, red on ripening, susceptible to TMV.

Table 4. Continued.

Variety, source and year of identification	Suitable growing zones[z]	Varietal characteristics
Sweet-72, Gwalior (1975)	I, IV and VII	Plants determinate type, fruit flattish round green stem end, slightly furrowed. Uniform maturity. Heavy yielder.
Pusa Early Dwarf, NBPGR	I, IV and VIII	Plant typical dwarf 50-55 cm in height with determinate growth (1975) habit. Fruit roundish slightly flattish, medium large, uniform red, ribbed, obscure furrow, 5-6 locules; 30-40 fruits per plant. Maturity in 55-60 days after transplanting.
Sioux, IARI (1977)	II, IV, VI and VII	Plants with indeterminate growth habit, fruits round, smooth, medium to large, attractive red on ripening, less seeded. Maturity 60-70 days after transplanting. Suitable for summer and spring in plains and hills.
Pusa Gaurav (Sel-152) IARI (1983)	I, II, IV, VI, VII and VIII	Determinate growth habit, cut leaves with light green foliage, yellow fruits, smooth, oblong, two locules, uniform ripening, maturity 80-85 days after sowing. Excellent for processing and suitable for long transportation.
Punjab Chhuhara, Ludhiana	I, II, IV, VI, VII and VIII	Plants dwarf, bushy and determinate growth habit with dense and luxuriant foliage. Fruits are medium sized, pear shaped, firm, fleshy, usually bilocular, not very seedy, not very sour, thick walled, uniformly colored, red at maturity, retain marketable quality for a week after harvesting under ordinary conditions during summer. Most suitable for long transportation. Average yield 30-32 t/ha.
KS-2, Kalianpur (1985)	I, II, IV and VI	Plants determinate, foliage light green, fruit flattish round, slightly furrowed with 4-5 locules moderate yield.
Pant Bahar (AC-238), Pantnagar (1985)	I, II, IV and V	Plant height 90 cm, bushy indeterminate in growth habit and branched. Light green foliage, stem relatively thin, leaflets small in size. Seventy-eight days to first ripening. Fruits flattish round, medium in size, 5-6 locules, slightly ridged, red on maturity. Resistant to Verticillium and Fusarium wilt under field conditions. Good storage and processing qualities.

[z]Zones: I Humid Western Himalayan Region; II Humid Bengal-Assam Basin; III Humid Eastern Himalayan Zone and Bay Islands; IV Subhumid Satluj-Ganga Alluvial Plains; V Subhumid to Humid Eastern and Southeastern Uplands, VI Arid Western Plains; VII Semiarid Lava Plateau and Central Highlands; VIII Humid to semiarid Western Ghats and Karnataka Plateau

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28

4

Problems of Seed Production and Storage of Pepper

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Abstract

Results of pepper research conducted at the Institute of Plant Breeding and Seed Production (IPBSP), and information collected from literature, are presented. (1) Pollination: although pepper displays autogamous behavior, the percentage of natural cross-pollination can be high, an important fact that must be considered for maintaining purity of lines. Natural cross-pollination (NCP) was found to vary between 1% and 46% in trials carried out by the IPBSP. Higher values were obtained under particularly favorable environmental conditions. (2) Morphology: variability in seed size, color and shape is very high, both at the inter- and intra-specific level. (3) Plant and postharvest ripening: the best ripening stage of the fruits for obtaining the highest seed yield per plant and the highest percentage of seed germination is that of the full colored (red or yellow) berries (market-ripeness in Italy). (4) Germination: parameters that can express the vigor of the seed lot better than the simple percentage of germination are the mean germination time and the uniformity of germination. A viability colorimetric test (2-3-5 TTC) proved useful to differentiate at the end of germination tests between ungerminated and dead seeds. (5) Embryoculture: this technique can be very useful for shortening the reproductive cycle of plants. (6) Storage and viability: the effects of different storage conditions on seed storability are described. (7) Presowing treatments: osmo-priming, particularly with KNO_3, appears to be a useful technique for reducing germination time and improving uniformity of germination. (8) Genetic resources: the IBPGR has identified pepper as one of the vegetables to be given high priority in programs for genetic resources conservation. Since 1981 the IPBSP has collected over 200 accessions, both local and foreign. The most important genebanks of pepper are listed and conditions for seed storage, aspects of evaluation, multiplication and rejuvenation of collected material are discussed. (9) Seedborne diseases: the most important seedborne pepper diseases are reviewed and the effectiveness of some seed treatments are discussed. (10) Characteristics of commercial seeds: in Europe the open-pollinated cultivars are decreasing both in number and in quantity in favor of F_1 hybrid seeds.

Pollination

Capsicum annuum is a prevalently autogamous species. However, cross-pollination by insects (mainly *Apis* sp., *Bombus* sp. and *Tripetidae*) and to a lesser extent by wind, is not infrequent. Information on the rate of natural cross-pollination (NCP) is important for determining the genetic composition of the population, and for identifying the most appropriate breeding methods (Lorenzetti and Cirica 1974). Moreover this information is very useful for the maintenance of the purity of cultivars and lines and for the production of commercial seed, both of open-pollinated cultivars and of F_1 hybrids.

The frequencies of NCP in pepper reported in the literature, although hardly comparable because of the differences in environmental conditions, vary widely. In many cases there is almost

no cross-pollination, whereas values of 91% have been reported (Tanksley, 1984). The most important causes of variability have been found to be: the genotypes of the male and the female parents; the presence of pollinating insects (quantity and species); the climatic conditions; the presence of other species more attractive to the pollinators; the way the plants are set out; and possibly the interaction of two or more of these factors.

Four cultivars and two experimental conditions, favorable and unfavorable to cross-pollination, were tested (Franceschetti, 1972) at the Institute of Plant Breeding and Seed Production (IPBSP) of the University of Turin: The NCP differed widely between the two treatments and an interaction genotype x condition is evident (Table 1). Similar results were obtained by other workers (Csillery et al. 1986a, 1986b).

Table 1. Natural cross-pollination in pepper in northern Italy (Franceschetti, 1972)[z].

Cultivar Year	A[y] (%)	B[x] (%)
Giallo di Nocera (1968)	46	9
Corno di bue giallo (1968)	22	14
Corno di bue giallo (1969)	17	4
Braidese giallo (1969)	15	1
Quadrato d'Asti giallo (1969)	18	10

[z]Marker character: color (red vs yellow) and pungency (pungent vs sweet) of the berry; Tester cv. Caloro (red and pungent); Plant to plant distance 0.6 × 0.6 m. [y]A = optimal conditions for cross-pollination (each tested plant among 24 tester plants) [x]B = difficult conditions for cross-pollination (tester plants placed round the perimeter of the plots and the remaining area planted with 121 tested plants; only the three central plants of the central row taken into consideration)

It is known that the same experiments, repeated in the same way and the same place for several years in a row, can sometimes give very different NCP frequencies, indicating the influence of environmental factors. Different NCP can also be obtained when different marker characters are chosen. One of the most commonly used is the color of the berries, which, since it appears rather late, requires a great deal of space and time for the growing and assessment of the progeny.

A more precocious feature, by which a greater number of seedlings can be assessed in a short time and restricted space, is hypocotyl color. This character is however related to the purple color of the stigma and of the filaments, which may induce anomalous behavior in the pollinating bees, characterized by their high flower constancy. Pollinating bees might give preference to flowers with purple stigma color.

The fact that the marker character may influence the behavior of the pollinators becomes important in cases where the presence or absence of this feature determines morphological differences between the tester lines under examination (for example the height of the plants or the level at which the flowers are set). The same problem may arise when male-sterile lines are used (Csillery et al. 1986a; Corella et al. 1986).

At present, the most suitable characters for pollination studies seem to be the isozymes. They do not induce morphological differences in the tester lines and can be assessed on seeds immediately after the harvest. One of the most commonly used isozyme markers is phosphoglucomutase – 2 (Pgm-2), for which there is a high degree of natural variability (Tanksley, 1984).

As far as the maintenance breeding of the varieties and the practical aspects of seed production are concerned, pepper must be treated as a typically allogamous species.

Seed Morphology

Pepper seeds are usually straw-colored. The exception are seeds of the *C. pubescens* species, which are of a darker color.

The size of the seeds, although a genetically controlled feature, is found to be very variable. The causes of variability are the environmental conditions in which the seed ripens, the general condition of the mother plant, the position of the berry on the mother plant, the number of seeds per fruit, the time of harvesting and the time of extraction of the seeds from the fruit. The 1,000 seed weight varies widely. In the IPBSP collection of germplasm the extremes were 2.49 g and 10.55 g. However 80% of the 1000 seed weights lie in a range between 5 and 8 g.

Plant and Postharvest Ripening

The highest seed yield per plant and the highest percentage of seed germination can be obtained from full (red or yellow) colored fruit (market-ripeness in Italy) rather than from green berries. In summer time in the field, it takes about one to two weeks for each fruit to turn from green to full color.

The effects of postharvest ripening of the seed within the fruit was studied (Quagliotti, 1969; Quagliotti et al. 1981) and it was found that the average number of seed harvested from each berry is very similar: 128 in the berries harvested at green ripeness (A) and 121 in the berries harvested at market ripeness (B). There is, however, a significant difference in the total weight of the seeds removed from the berries (0.6 g in A and 1.0 g in B) since the weight of 1,000 seeds in group A was 4.8017 g versus 7.9811 g in group B. The viability of the seeds is noticeably improved by postharvest ripening (Table 2). If the storage of the A berries is at 20°C instead of 10°C, the growth of the seeds within the harvested fruit is definitely favored.

Postharvest ripening of the berries before seed removal seems to be useful if the fruits have to be picked early, and seeds have to be saved for genetic improvement.

Table 2. Effects of the ripening stage and postharvest ripening on the seed production and quality in Yolo Wonder pepper (Quagliotti et al. 1981).

	Ao[z]	A1[z]	A2[z]	A3[z]	B[y]
Fruits with viable seeds (%)	12 a[x]	40 b	71 c	86 c	100 d
Viable seeds per plant (no.)	6 a	40 ab	191 bc	266 c	243 c
Weight of 1,000 seeds (g)	3.8 a	4 a	4.2 a	4.5 a	8.7 b
Germination (%)	1 a	7 a	32 b	56 c	81 d

[z]A = Berries harvested at green ripeness; Ao seeds removed from the fruit immediately after harvest; A1 seeds removed from the fruit 10 days after harvest; A2 seeds removed from the fruit 20 days after harvest; A3 seeds removed from the fruit 30 days after harvest. [y]B = Berries harvested at market ripeness and seeds removed from the fruit immediately after harvest. [x]Means followed by different letters in rows are significantly different by Duncan's multiple range test (P = 0.05).

Germination

The ISTA (1985) recommended methods for *Capsicum* sp. seed germination are: permissible substrata: top of paper or between paper; temperature: alternating 20% 30%; counting: first counting after 6 days and final counting after 14; and breaking of dormancy: light and KNO_3.

In some seed lots, particularly of less selected cultivars and local populations, a high frequency (25-30%) of fresh ungerminated seeds (FUS) can be found on the 14th day, some of which later germinate while others evolve to dead seeds (DS). Thus it could be useful to conduct germination tests for more than 14 days up to 45 days in order to ascertain exactly the viability of the lot (Table 3).

It is also useful to evaluate seed viability by the topographical tetrazolium method shortly after the end of the standard germination test. The soaked seeds are longitudinally bisected and stained in a 1% water solution of 2, 3, 5-triphenyl tetrazolium chloride at 30°C, in the dark, for 24 h. In the viable seeds at least the entire embryo is stained bright red.

Table 3. Germination tests of commercial pepper seeds, according to the method recommended by ISTA.

Cultivar	PG[z]		FUS		DS		AS[x]	
	14[y]	45	14	45	14	45	14	45
	%							
Trottola di Cuneo	71	76	21	7	7	16	1	1
Lungo rosso Rubens	87	89	8	3	5	7	0	1
Quadrato d'Asti giallo	76	81	16	5	4	9	4	5
Cajenna	75	79	24	16	0	4	1	1
Yolo Wonder	91	92	8	6	0	1	1	1
Gildor	93	93	6	5	1	2	0	0
Grecor	83	88	14	1	2	10	1	1
Heldor	92	94	7	1	1	4	0	1
Lamuyo	99	99	1	0	0	1	0	0

[z]PG = percentage of germination; FUS = fresh ungerminated seeds; DS = dead seeds. [y]Days after the beginning of the germination test. [x]AS = Abnormal seedlings.

Seed vigor can be tested through one or more of the following procedures:

(a) Percentage of the germinated (PG) seeds at the first count (6th day);
(b) Mean germination time (MGT):

$$\frac{\Sigma\, ni \times d}{N_1}$$

where ni = number of germinated seeds on each day, d = number of days counted from the beginning of the test, and N_1 = total number of germinated seeds.

(c) Velocity of germination (VG):

$$\frac{\Sigma\, ni \frac{1}{d} \times 100}{N_2}$$

where N_2 = total number of seeds set to germinate which is quite different from N_1 (b) when PG is far from 100%.

(d) Precocity of germination (PrG): number of days in which 50% of the germinated seeds germinate;
(e) Uniformity of germination (UG): number of days between the germination of 15 and 85% of the germinated seeds (Figure 1);
(f) Percentage and mean emergence time (PE; MET) in controlled environment with other than optimum temperature conditions, in order to evaluate the vigor and not only the viability of the seeds.
(g) Measurement of ionic release from each seed (the electrical current level of the solution indicates the amount of leakage through interior seed membranes).

It is possible to calculate (b), (c), (d), and (e) if the germination test is checked daily and the seeds germinated in the previous 24 hours are counted and removed. Examples are shown in Figure 1.

Light and temperature affect germination. The effect of constant light or darkness on germination depends very much on the genotype and on the temperature of germination (Figure 2)

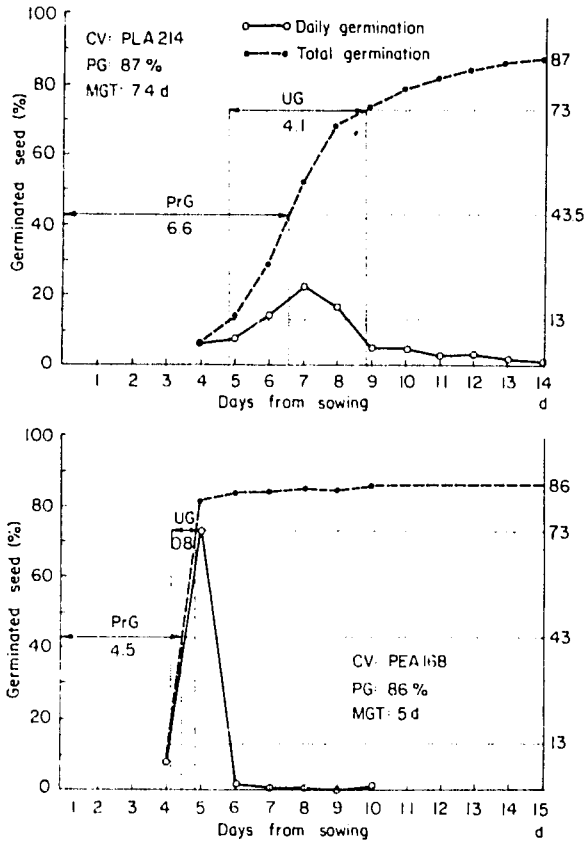


Figure 1.
Uniformity (UG) and Precocity of Germination (PrG) in two cultivars of pepper. Germination trials carried out at 20°-30°C, light 8 h.

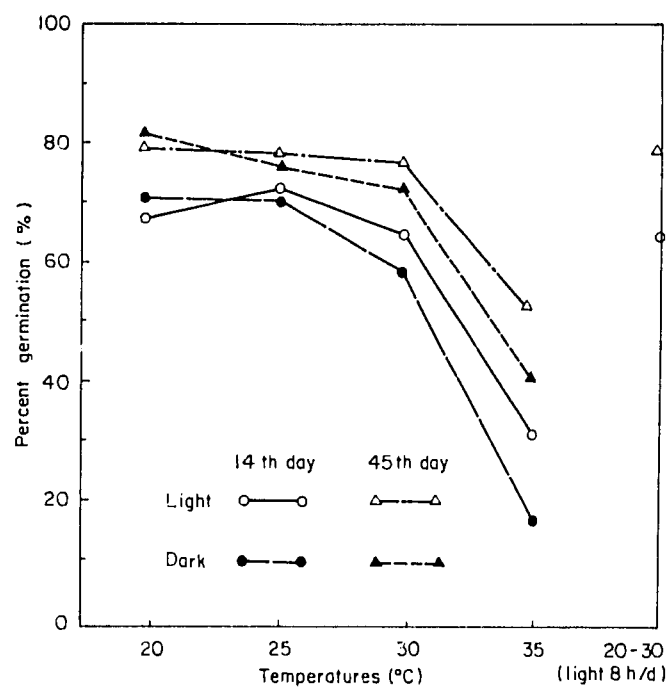


Figure 2.
Effect of light on germination different temperatures.

(Accossato and Quagliotti, 1983). In many cases the mean germination time is found to be slightly longer in the light.

The best temperature for germination is usually an alternation of 20° (16 h) and 30°C (8 h/day); or a constant temperature of 25°C (night). On the other hand, high temperatures such as 30°C and 35°C discourage germination, reducing PG and significantly increasing the percentage both of FUS and of abnormal seeds (AS); this happens particularly in seed lots with low vigor.

Knowledge of the germination capacity at low temperatures (< 20°C) may be of interest, in view of possible direct sowing in the field and complete mechanization of the crop. Results obtained from tests using a large number of cultivars of *C. annuum*, *C. frutescens*, *C. pubescens*, *C. chinense*, *C. chacoense*, *C. baccatum* v. *baccatum*, *C. baccatum* v. *microcarpum* and *C. baccatum* v. *pendulum* indicate a considerable difference in time of emergence in the greenhouse at 10°C and 13°C and between genotypes of the same or different species (Honma and Gerson, 1977; Randle and Honma, 1980). The cv. 2033 of *Capsicum baccatum* v. *pendulum* showed the minimal time of emergence both at 13°C and 16°C (24.5 and 16.9 days, respectively).

Pepper seeds, like those of tomato and eggplant and unlike those of pea and bean, are very sensitive to salinity during germination (Table 4). It was shown that germination of pepper seeds is reduced practically to nil on a substrate soaked with a solution of 100 mM of NaCl (Guerrier, 1983). The fresh weight of pepper seedlings on the fifth day from the emission of the rootlet was significantly lower on a substrate with 50 mM of NaCl than on the salt-free controls.

On the other hand, peas and beans are able to germinate (40% and 10%, respectively) on substrates containing as much as 500 mM of NaCl.

The absorption of sodium by the seedlings does not seem to indicate the extent of their sensitivity or tolerance to salinity. Tolerance rather seems to be associated with the ion content of the seed (Table 4). It is a complex mechanism involving the capacity to absorb minerals and the effect of osmo-regulating substances such as sugar, electrolytes, etc. Species sensitive to salinity are those with a lower level of potassium or calcium.

Table 4. Chemical characteristics of some seeds sensitive (S) or tolerant (T) towards NaCl.

	Water content (%)	Content of elements (μq/gdm)		
		Na^+	K^+	Ca^{++}
Phaseolus vulgaris L. (T) cv. Bagnolet	10.7	1.15	495.60	3.79
Solanum melongena L. (S) cv. Violetta di Barbentane	9.5	42.55	132.12	32.11
Capsicum annuum L. (S) cv. Piment doux d'Espagne	5.5	7.53	32.62	6.58
Lycopersicon lycopersicum L. (S) cv. Monalbo	10.4	87.90	127.50	25.50
Pisum sativum L. (T) cv. Dolce di Provenza	6.9	1.30	343.38	2.07
Allium cepa L. (T) cv. Janne d'Espagne	9.7	11.12	45.64	29.48

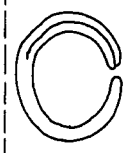
Source: Guerrier, 1983.

Embryoculture

Embryoculture can be applied to overcome barriers of interspecific incompatibility and to study physiological characters in a controlled environment. It is widely used by seed firms to shorten the reproductive cycle of the plants from about five months required under normal field conditions to about three to four months, to grow a greater number of generations per year, and to obtain the final product of the breeding work earlier.

The most important factor for ensuring the development of viable plants from embryoculture appears to be the time of embryo removal. For pepper, this can be from 20-40 days after fertilization. During this period the embryo passes from its initial globular shape to take on first the shape of a heart, then of a torpedo, then of a walking stick and, lastly, of a ring. The length of the immature embryo varies from 50 to 800 μ (Figure 3) (Fari et al. 1983).

The use of media containing auxin and cytokinin for early-removed pepper embryos (globular and heart phases) is suggested, while for more developed embryos (torpedo, walking-stick and ring phases) cytokinin alone would appear to be sufficient (Fari et al. 1983). Once the autotrophic phase has been reached, the embryo can be placed on a medium without hormones. The percentage of flowering plants obtained from excised embryos was high and can certainly be increased by refinement of the technique.

Number of day from pollination	20-22	22-25	25-30	30-35	35-40
Embryo shape					
Length of embryo (μ)	50	100-200	500-2000	3000	8000
Embryo phase	Globular	Heart	Torpedo	Walking stick	Ring

Source: Fari et al. 1983.

Figure 3. Characteristics of the pepper embryos suitable for excision.

Storage and Viability

The length of seed storage depends on the initial germination percentage, the vigor of the sample, and the storage conditions.

In temperate climates, storage of pepper seed under natural conditions (room temperature, low relative humidity) for up to three years does not normally present any problems. However conservation even for a few months in the tropics or for periods above three years in temperate climates requires: initial lowering of the seed moisture level to values not above 5% to 6%; the artificial regulation of room temperature; and the use of waterproof containers (glass, metal or plastic) in order to prevent the seeds from readsorption of moisture during seed storage.

Pepper seed, which is of the orthodox type, can be dried with hot air at 30° to 32°C for seven to 10 days without any harmful effects. The hygroscopic nature of these seeds, which have mostly lipid reserves, is such that samples with an initial moisture content of 6% will revert to a dangerous moisture level (> 8-10%) in 40-50 days if storage temperatures are between 25° or 35°C and if the relative humidity in the storage environment is above 55-60%.

Prolonged storage temperatures of above 20°C can reduce germination by 50% in about three months and cause total death in about six months if the samples are stored in an environment with high relative humidity (> 70%).

Environmental humidity affects the moisture content in the seed and thus has a greater effect on the aging of these seeds than temperature. Only a very slight difference in the percentage of germination was observed after 24 months of storage at 20% relative humidity (RH) whether at 25°C or at 35°C (84% and 74%, respectively).

With 20% environmental RH, which corresponds to a moisture content of about 5% in the seed and an average storage temperature not above 25°C, a PG above 80% was maintained for five years (Quagliotti and Trucchi 1984; Quagliotti, 1986).

Since in practice it is costly and difficult to reduce the moisture in the environment and keep it constant at a low level, it is advisable to dry seed carefully to about 5% moisture content and store it in waterproof containers or wrappings.

The most evident symptoms of aging in the pepper besides rapid reduction in PG are increase of the MGT and in the frequency of AS.

After only one or a few months of storage in an unsuitable environment the MGT provides a considerable amount of information on the differences in the viability of the seeds induced by different levels of RH. After 20 days, MGT was found to be lengthened by at least one to three days, if samples were stored at 55% or 76% R.H. compared to samples kept at the same temperature but at an RH below 35%. Although seeds are still kept alive, a great variation is observed in the MGT.

Abnormal seedlings are malformed seedlings which are unable to develop into normal plants even under the most favorable conditions. They are usually not found in samples of vigorous seeds, but they appear increasingly as the seeds age, particularly when the aging process is slow. For example, more than 10% of abnormal seedlings were found in a sample of seeds stored for two years at 35°C and 20% RH.

If the seed sample ages rapidly the seeds soon lose not only vigor but viability as well.

Besides the loss of precious material and the reduction of the physiological value of the lot, seed storage in less than optimal conditions may cause a selection of genotypes on the basis of longevity, and hence a reduction of genetic variability and an accumulation of non-lethal mutations. Rota's enquiry (1986) into the frequency of chromosome aberrations in late anaphase configurations of root tips of germinated *Capsicum* seeds aged under various conditions, show that there is a growing tendency to produce more frequent aberrant cells as the PG becomes lower. In general, however, the slower the deterioration, the higher the frequency of aberrant cells. In many of the aging treatments, aberrations were found most frequently where there was a PG between 40% and 50%. The aberrant formations most commonly found are single or double bridges and chromosome segments without a centromere.

Presowing Treatments

For satisfactory germination, pepper seed requires high temperatures (> 20°C), a considerable difference between the day and night temperatures (30°C light-20°C darkness) and a fairly long period (10-20 days), during which the individual seeds germinate rather unevenly (Accossato and Quagliotti 1983).

Hence it can be very useful for growers to have seeds with a more rapid and concentrated germination, suitable for germination at lower temperatures or under stress conditions (salinity, shortage of water, etc). The loss of seed and variability in time of emergence could be reduced when sowing directly in the field. It would also reduce energy costs of greenhouse production of plantlets.

Several presowing treatments for the increase of seed vigor and for improvement of germination when conditions are not of the most favorable have given satisfactory results.

The following osmo-priming technique was developed at the IPBSP (Hennart, 1983, 1984):

- disinfection of the seed for five minutes in sodium hypoclorite (6% NaOCl in water)followed by washing in running water. This treatment, besides having an excellent effect in eliminating the micro-organisms (Dempsey and Walker 1973), exerts a stimulating effect, causing earlier and more concentrated germination (Fieldhouse and Sasser 1975);
- treatment with KNO_3 or with PEG (-6, -8 bars, 11 days, at 15°C, photoperiod of 8h/day) followed by washing in running water;
- dehydration at 30°C for one to two days, to bring the seeds back to their initial moisture level of 6-7%.

These treatments reduce the MGT considerably (from more than 6 days to 2-2.5 days) and give greater UG (from 3-6 days to 2-3 days). Best results can be obtained with KNO_3, although this does cause a reduction in the PG, especially if the sample did not have very good germination capability. These treated and dehydrated seeds can be stored for at least four months without any decrease in the invigorating effect.

Therefore it seems that in pepper seeds, the complex biological reactions that constitute the longest and most delicate phase of the germination process before rootlet protrusion can be induced in an artificial environment, perfectly conditioned and repeatable, by a preliminary and effective blocking of the emission of the root tip with osmotic agents (KNO_3) which prevent cell extension and division.

Another procedure for invigoration of the pepper seed using a slow wetting process to induce pre-germination activities (TPGA) has been developed (Perl and Feder, 1981). The method consists of aeration of the seeds at 95% RH and 20°C for several days followed by dehydration at room temperature (22° to 25°C) to the initial level of moisture. Seeds thus treated can be kept for at least two months before sowing.

The greatest effect on germination (measured in terms of rootlet emergence) was with a seven-day treatment, when the seeds had reached 30% of moisture; in terms of seedling development, after 12 days. The effects of invigoration varies not so much from cultivar to cultivar as from seed lot to seed lot: it is very small in seeds with low viability and in those with already strong vigor.

Genetic Resources

Pepper is subject to a very high degree of loss of natural variability. In 1979, at a meeting held in Wellesbourne, UK, pepper was proposed as a species to which absolute priority should be given in programs for the preservation of genetic resources (IBPGR, 1983). Consequently pepper has been added to the other species accorded this kind of priority such as *Abelmoschus esculentus*, *Allium* spp., *Amaranthus* spp., *Brassica* spp., *Cucurbita* spp., *Lycopersicon esculentum*, *Momordica* spp., *Raphanus* spp., *Solanum melongena*.

In 1980, the CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) at Turrialba, Costa Rica, presented a global plan encompassing guidelines for the preservation of the genetic variability of this species (IBPGR, 1983).

A major difficulty connected with the preservation of the genetic resources of pepper is the taxonomic complexity of the genus *Capsicum* which consists of many species, all originating in Central and South America. The cultivated forms belong to five species: *C. annuum*, *C. baccatum*, *C. chinense*, *C. frutescens* and *C. pubescens*. To these, however, a dozen wild species should be added which are more or less closely related to these five. Their importance as a source of useful genes still has to be verified. It is certain, however, that some genetic sources of adaptability to unfavorable climatic conditions and of resistance to various diseases are present in the wild species which may be useful in breeding programs of the cultivated species hence the efforts for the collection and preservation of the genetic resources of wild species as well.

There are institutions in almost all parts of the world that deal with the preservation of pepper germplasm. The International Board for Plant Genetic Resources (IBPGR) listed 25 major

collections in 1983. In addition there are at least an equal number of small collections of local interest (IBPGR. 1983).

The most important pepper germplasm collections are in Costa Rica (CATIE, Turrialba), France (Institut National de la Recherche Agronomique, Montfavet), German Democratic Republic (Zentralinstitut für Genetik und Kulturpflanzenforschung, Gatersleben), Mexico (Instituto Nacional de Investigaciones Agricola, Celaya), the Netherlands (Institute for Horticultural Plant Breeding, Wageningen), USSR (Vavilov Institute of Plant Industry, Leningrad), United Kingdom (University of Reading, Reading) and USA (United States Department of Agriculture, Fort Collins; Experiment; Geneva; Davis; and Oxford).

The IBPGR has assigned grade 2 priority to the Mediterranean area, second only to that of Latin America. Germplasm collections are found in Greece (North Greece Agricultural Research Center, Thessaloniki), Spain (Instituto Nacional de Investigaciones Agraria, Zaragoza; Valencian Institute for Agricultural Research, Valencia; Genetics Department, Valencia; and Regional Agricultural Research Center, Murcia), Tunisia (Institut National de la Recherche Agronomique de Tunisie, Ariana), Turkey (Aegean Regional Agricultural Research Institute, Izmir) and Italy (Institute of Germplasm, Bari; Experimental Institute of Vegetable Crops, Salerno; ENEA, Rome; and Institute of Plant Breeding and Seed Production (IPBSP), Turin).

The IPBSP germplasm bank was established in 1981 and now holds over 200 accessions. Most of the material collected belong to *Capsicum annuum*. There are, however, some accessions belonging to *C. chinense*, *C. frutescens* and *C. baccatum* species.

The accessions preserved at IPBSP fall into three large groups: (1) material of local origin, often not widely grown and on the decrease, obtained directly from the growers in the principal areas were they are cultivated (mainly Piedmont, northwest Italy); (2) commercial material obtained directly from seed firms; and (3) foreign material obtained by exchange of samples (Thailand, Japan, Korea, Morocco, Egypt, Tunisia, Puerto Rico, Brazil and Hungary).

One major problem of accessions of local origin which belong to the *C. annuum* species is to identify the various populations known by the same name, and the cultivars known by different names, in various areas. Another problem is the great variability within accessions, which is often comparable to that existing between different accessions.

When the amount of seed is not sufficient (less than 30 g) to guarantee good preservation it is first multiplied. This is done by growing, where possible, 20 plants under a plastic net (isolator) which prevents free pollination. It is expected that an analogous method will be used when the phase of regeneration the material is started.

Before storage in freezers at a temperature of -20°C the seeds are dried for several days at 30° to 32°C, reaching a moisture content of 5% to 6% at the end of the treatment. Presently the seeds are kept in polyethylene containers. However, since this material does not guarantee perfect waterproofing, it will be replaced by some other material (glass, metal, etc.) in the future.

The management of pepper accessions is conducted as follows:

1. After reaching the Institute, the seed sample is given an inventory number consistingof three letters (the first indicating the genus, the second indicating the type of material and the third the generation of multiplication) and of three figures (progressive).
2. The sample is dried for about one week at 30°-32°C.
3. Selection by removing the broken seeds and those obviously incapable of producing a normal plant.
4. Routine tests for moisture content, percentage of germination and 1000 seed weight.
5. Data collection on cards and in the computer.
6. Weighing: if the sample is less than 30 g (approximately 5,000 seeds) steps are taken for its multiplication; the product of this process is then treated as a separate accession.
7. Storage of seeds in long-storage freezers.
8. Characterization: the data are stored in the computer.

For characterization, 10 plants per accession are grown and observed for the characters suggested by the IBPGR (1983). This is a rather critical phase, because of the high degree of variability which is often present in local accessions. Other assessments, particularly of resistance to diseases, are made in the laboratory.

Seedborne Diseases

Many pepper pathogens are seed-transmitted (Table 5) (Richardson, 1979, 1981, 1983; Park and Kim, 1986; Ibe and Ike, 1982) and cause serious damage to the crop, particularly when they are not detected on the seed and if sowing is done in unfavorable conditions of temperature and moisture. The pathogens are either carried on the seed surface, or in the inner tissues.

Table 5. Seed-borne pathogens of *Capsicum* sp.

Fungi	
Alternaria alternata	*Fusarium semitectum*
Alternaria capsici-annui	*Fusarium solani*
Alternaria solani	*Gibberella fujikuroi*
Botryodiplodia palmarum	*Helminthosporium* spp.
Candida tropicalis	*Macrophomina phasealina*
Cercospora capsici	*Myrothecium roridum*
Cladosporium herbarum	*Myrothecium verrucaria*
Colletatrichum capsici	*Nigrospora oryzae*
Colletotrichum piperatum	*Phaeoramularia capsicicola*
Curvularie spp.	*Phoma destructiva*
Diaporthe capsici	*Phytophthora capsici*
Diaporthe phasealorum	*Pichia membranaefaciens*
Drechslera spp.	*Rhizoctonia solani*
Fusarium equiseti	*Sclerotinia sclerotiorum*
Fusarium oxysparum	*Verticillium albo-atrum*
Bacteria	**Viruses**
Pseudomonas solcnacearum	*Alfalfa mosaic virus*
Erwinia carotovora	*Cucumber mosaic virus*
Xanthomonas campestris pv. *vesicatoria*	*Tobacco mosaic virus*

The best control of seedborne diseases is prevention, by using seed produced from healthy mother plants.

TMV, the most important seed-transmitted pathogen, causes enormous damage, particularly to greenhouse-grown peppers, following operations such as transplanting which cause small lacerations in the plants through which the virus can penetrate. Transmission of TMV can be kept under control to a satisfactory extent by treating the seed with various chemicals, such as $Ca(OCl)_2$, Na_3PO_4, NaOCl, and HCl (Demski, 1981).

Treatment of seeds with dry heat (85°C for 5 days) keeps *Colletotrichum capsici* completely under control, but considerably reduces the germination of the seeds treated (Takano et al. 1985). *Rhizoctonia solani* can be eliminated from infected seed by hot water treatment for 30 minutes at 52°C (Richardson, 1979).

Many chemical products are utilized for the control of seedborne diseases of pepper. Thiram has been found to be active against many seedborne diseases such as *Colletotrichum piperatum*, *Helminthosporium* spp. (Richardson, 1979, 1981) and *Colletotrichum capsici*. Good results have

also been obtained against the latter parasite by using captafol and carbendazim (Kumar and Mahamod. 1986). Carbendazim was also found to be very active against infection by *Fusarium oxysporum* (Richardson. 1983) and *Cercospora capsici*, especially if the seed treatment is followed by whole plant treatment in the field (Sharma and Sohi. 1984).

Characteristics of Commercial Seeds

The EC Catalogue of Vegetable Species (Anon. 1986) lists 299 varieties of *Capsicum annuum* L. officially recognized for marketing in the 12 EC member countries: of these 119 are in Group A (Group A seed can be certified as 'basic seed' or 'certified seed' or checked as 'standard seed'), and 180 in Group B (seeds which can only be checked as 'standard seed'). Italy with 107, Spain with 86, the Netherlands with 81, and France with 50 varieties are the countries most represented in the Catalogue. Forty-seven percent of all varieties allowed on the EC market are F_1 hybrids. It can be seen from the seed companies' catalogues that there are fewer and fewer open-pollinated cultivars and more F_1 hybrids. The seed firms do not consider it worthwhile to produce seed from open pollinated cultivars, which cost as much to multiply as F_1 hybrid seed, but sell at a prices 50-100 times lower. This means that the great genetic variability that should be present in the large number of varieties in the EC Catalogue is illusory; many of these varieties are not available any more on the market.

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Symposium Discussion

Y. Haile: Did you investigate the life span of pepper seed at room temperature?

L. Quagliotti: At room temperatures (20° to 25°C) good viability of pepper seed can be maintained for two or three years provided that seed moisture is low (5% to 6%). The relative humidity of the storage room must be controlled or the dried seeds have to be stored in sealed and waterproof containers.

C.H. Huang: Materials for F_1 sweet pepper seed production are mostly from Europe or the USA. Seed is normally golden but we find many dark seeds (poor quality seed) in berries produced in Taiwan. Do you know what could cause this condition?
P. Belletti: In species with tan-colored seed, dark seeds usually result from irregular establishment of fertilization and/or embryo and endosperm development. In fact most of them are empty or contain nonviable embryos. Under our conditions, the amount of dark seeds is usually high when environmental conditions during flowering of plants are unfavorable (i.e. too humid or too warm and dry). A certain percentage of dark seed may also be present in normal seeds, but it is not very difficult to eliminate them, because of their lower weight and bulk. It is also possible that dark seed result from infection with certain pathogens.

H.I. Wien: Parthenocarpic tomato lines show considerable promise for fruit-setting under cool greenhouse conditions. Are parthenocarpic pepper lines available to improve fruit set?
L. Quagliotti: In Italy, seed companies are working on parthenocarpic sweet pepper varieties (for winter cropping under plastic for instance in Sicily). So far it seems that in these crops some problems can still arise in connection with the abnormal shape of bell pepper berries.

43

Varietal Improvement

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44

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Tissue Culture of Tomato and Pepper: New Tools for Plant Breeding

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Abstract

Two biotechnology tools, somaclonal variation and anther culture, have directly impacted tomato and pepper breeding programs. Somaclonal variation can be used for incremental improvement of elite breeding lines without affecting overall agronomic habit. Anther culture can be used to induce gametoclonal variation and generate pure breeding lines via hybrid sorting. Specific improvements achieved through these technologies, and integration of biotechnology into a conventional breeding program, are discussed.

Introduction

Plant biotechnology is the application of molecular biology and cellular genetics for the development of novel and improved crop varieties and plant products. It should be noted, however, that these new techniques of genetic engineering and tissue culture complement, rather than replace, plant breeding as a method of crop improvement. Novel gene combinations and genetic variation produced through cell and tissue culture require plant breeding and field trialing to select for improvements. Similarly, transgenic plants could not have been produced without prior establishment of cell culture protocols for tissue and protoplast regeneration. By extension, plant biotechnology is only an effective method of crop improvement when integrated into an intensive breeding/trialing program.

The first application of plant biotechnology has been in crops which are highly amenable to *in vitro* regeneration, and which are of major economic importance. A crop which fulfills both criteria is tomato (*Lycopersicon esculentum* Mill.). More limited success has been achieved with pepper (*Capsicum annuum* L.). However, the growing commercial importance of pepper should stimulate increased research in this crop in the near future. This paper will focus on two biotechnologies, somaclonal variation and anther culture, which are applicable to tomato and pepper improvement.

In vitro culture of tissue has been exploited in a range of scientific disciplines, including basic biochemistry and physiology, production of secondary compounds, gene expression and oncogenicity. Tissues from virtually all free-living organisms can be maintained *in vitro*. However, cultured plant cells are distinguished by their totipotency. That is, cells derived from diverse plant tissue sources, such as roots, leaves, stem, and so on, can be induced to develop into intact plants in culture.

While not all plant species demonstrate this capability, tomato has become a model system because of the ease with which plants can be regenerated from many tissue sources, and because of its importance as an economic crop. Regeneration among various tomato cultivars is ubiquitous through the genus *Lycopersicon* (Kut and Evans, 1982). Koorneef et al. (1987) reported that the high regeneration capacity conferred by interspecific hybridization with *L. peruvianum* is controlled by two dominant genes with high heritability.

It is generally thought that plants regenerated from tissue cultures originate from single cells (Carlson and Polacco, 1975). A histological examination of tomato cotyledon explants cultured *in vitro* showed that several neocambial cells contributed to the formation of plantlets (Monacelli et al. 1988). Evans and Sharp (1983) reported, however, that the segregation ratios among progeny of regenerated tomato plants conformed with simple Mendelian inheritance patterns. Thus the regenerated plants originated from individual mutant cells rather than from a collection of cell types.

In contrast, plant regeneration from somatic tissues of pepper (*Capsicum* spp.) is not routine, although a number of workers have reported success (Agrawal et al. 1988; Diaz et al. 1988; Morrison et al. 1986a; Agrawal and Chandra, 1983). Critical variables for success in regeneration of plants from somatic cells of pepper include genotype, explant source, and the particular hormone mixture used in the culture medium.

Anther culture is a method for culturing male gametes to generate haploid plants. Following chromosome doubling, homozygous, true breeding lines are produced without recurrent selfing. Plant regeneration from gametic cells of tomato has been reported (Varghese and Yadav, 1986; Sharp et al. 1972). To avoid callus proliferation from somatic tissues in the anther wall, isolated microspores were cultured instead. Although Varghese and Yadav (1986) reported embryo development from isolated microspores, there have been no reports of regeneration of haploid tomato plants.

Far more progress has been achieved in recovering haploid pepper plants from anther culture (Morrison et al. 1986a). A critical variable in the culture procedure is the treatment of anthers at elevated temperatures during the early stages of culture (Dumas DeVaulx et al. 1982). Subsequent work described the importance of genotype, cold treatment of flower buds prior to culture and the use of activated charcoal in a specialized culture system (Morrison et al. 1986b). An added benefit of pepper anther culture is the frequency at which dihaploids occur. Chromosome doubling is otherwise difficult to induce and may cause deleterious changes in doubled haploid plants.

Tomato and Pepper Tissue Culture

Somatic Tissue

The protocols for culturing explants of tomato and pepper are similar in terms of aseptic technique, growth of donor plants, and culture media (Morrison et al. 1986b; Kut and Evans, 1982). Differences between the two methods include the type of explant and plant growth regulator (PGR) supplements (Table 1).

Prior to culture, the donor tissue is sterilized in 20% bleach for 10 minutes and rinsed with sterile water. The surface sterilized explants are then placed on an autoclaved culture medium. Shoots begin to appear on pepper explants in about three weeks and on tomato in four weeks. An additional two weeks is required for the development of shoots into small plantlets. The plantlets are then excised and placed onto hormone-free media to facilitate root formation. Rooted plantlets are transferred to soil under high humidity to acclimate the plants gradually to the greenhouse environment. Seeds are then collected from mature fruit for genetic analysis.

Table 1. Somatic tissue culture of tomato and pepper.

	Tomato	Pepper[z]
Explant	Leaf	Embryo
Medium	MS	MS
PGR	5 μM 6BA, 2 μM IAA	10 μM 6BA

[z]MS = Murashige and Skoog (1962). 6BA = N-6 Benzyladenine. IAA = indoleacetic acid.

Gametic Tissues

No technique has been reported for production of tomato haploids from anther culture on a reproducible basis. In contrast, pepper haploids have been readily regenerated (Morrison et al. 1986a). The critical factor for haploid production from pepper anthers is the physiological condition of the donor plants from which anthers are explanted. The donor plants must be maintained under optimum illumination, fertilization, temperature, and humidity. The optimal level of each varies with the cultivar. The stage of microspore development is also important for haploid production. The highest frequency of haploid plant regeneration is achieved by culturing anthers in which the majority of the microspores are uninucleate, just prior to the first pollen mitosis.

Anthers are isolated from flower buds pre-conditioned in the cold (4°C) for several days (cultivar-dependent), and inoculated in the medium as described by Sibi et al. (1979) with 6% sucrose. MS basal medium with 10^{-8} M 2,4-D has also been used successfully. The anther cultures are incubated at 35°C in the dark for eight days. The anthers remain on the original medium for an additional four days at which time they are transferred to hormone-free media with 3% sucrose. Haploid and dihaploid embryos and plants develop within 3-4 weeks. Regenerated plants are handled identical to regenerants from somatic tissues.

Somaclonal Variation

Plants regenerated from somatic tissue should, in theory, be identical (clones) to the genotype of the explant tissue. In practice, genetic variants have been recovered for many crops following tissue culture (Larkin and Scowcroft, 1981). Somaclonal variation describes the occurrence of both Mendelian and non-Mendelian genetic changes in plants recovered from cell culture. The genetically stable changes derive from two sources: (1) transmission of pre-existing somatic mutations in the explant tissue, and (2) induction of new mutations during the cell culture plant regeneration process. Somatic mutations occur at extremely high frequencies in the plant genome. However, unless the germ line cells are mutated, such mutations are not transmitted to succeeding generations. Somatic mutations are propagated and rescued when complete plants are regenerated. In addition to preserving and amplifying pre-existing variation, chromosome abnormalities are induced in tissue cultured cells and regenerated plants. These include gene amplification, aneuploidy, polyploidy, translocation and mitotic crossing over (Evans and Sharp, 1986). Other changes in gene expression may result from methylation, late replication of heterochromatin and activation of transposable elements (Peschke et al. 1987).

Mitotic crossing over (MCO), including both symmetric and asymmetric recombinations, also accounts for some of the variation detected in regenerated plants. The occurrence of MCO explains the recovery of homozygous recessive single gene mutations among regenerated plants. Plants regenerated from a tomato genotype heterozygous at five marked loci on Chromosome 6 demonstrated a high frequency of mitotic recombination among the marker loci (Loh et al. 1987). Surprisingly, the MCO frequency is enhanced in regions adjacent to the centromene. Thus somaclonal variation offers the potential for breaking up deleterious gene linkages near the centromene, where mitotic recombination is suppressed.

Somaclonal variation offers significant advantages over mutation breeding beyond mutagenesis. When seeds or plant parts are treated with chemical and/or physical mutagens, only those mutations in the germ line are transmitted to the next generation. As most mutations are deleterious, mutation breeding often produces plants with reduced fertility and low yield. Even if the change is beneficial, the mutation will not be transmitted to the next generation unless it occurs in the germ line. In contrast, since plants may arise from single cells in culture, mutations induced by somaclonal variation in the original cell are propagated throughout the plant. Chimeras, which are common to mutation breeding, appear to occur at a low frequency among plants generated *in vitro*.

Both beneficial and deleterious mutations are generated by somaclonal variation. However, the number of genetic changes is low with somaclonal variation as compared with plant breeding. Most of the genome of the somaclonal variant remains unchanged. Thus, if elite breeding lines are utilized as the starting point, overall agronomic performance is seldom affected. When combined with a screening program, somaclonal variation can be employed to generate small, incremental improvements in elite lines without disrupting the gene combinations responsible for good agronomic performance.

Since it is an *in vitro* process, somaclonal variation also acts as a sieve to screen out major deleterious mutations commonly found in a mutation breeding program. As cells in culture regenerate to give rise to intact plants, those cells which carry deletions in major gene functions would never be recovered. Somaclonal variation may be combined with mutagen treatment to increase the frequency of mutation. Regenerated plants, termed mutaclones, will still go through the sieving process of plant regeneration and behave as somaclones.

One interesting mutant with yellow-fruited progeny was selected from somaclones of red-fruited progeny donor plants. The inheritance of yellow fruit color indicated that the mutation is recessive to red fruit color (Table 2). Known yellow-fruited mutants were crossed with the somaclonal mutant to further characterize the *in vitro*-induced mutation. Progeny from the cross to a line homozygous for tangerine-colored fruit (x x) were red-fruited, indicative of complementation. Crosses between the somaclonal variant and a line homozygous for yellow fruit (r-2 r-2) gave only yellow-fruited progeny. Thus, the mutation derived by somaclonal variation resided at the same yellow-fruit locus on Chromosome 3.

Both qualitative and quantitative genetic improvements in tomato have been generated through somaclonal variation. DNA Plant Technology Corporation has produced a processing tomato variety with a 20% increase in soluble solids from UC82B. DNAP 9, derived from somaclonal variation, maintains the yield of UC82B, and resembles the donor material in every way except for higher soluble solids. Somaclones resistant to tobacco mosaic virus (TMV) have also been recovered (Barden et al. 1986). Both high solids and TMV resistance have been shown to be stable in subsequent generations. Other improvements identified by the DNA Plant Technology Corporation's tomato somaclonal variation program include increased yield, fruit pigmentation and disease resistance.

Table 2. Genetic analysis of yellow-fruited somaclonal variant.

Progeny	Red	Yellow
R_0	15	0
R_1	15	4
R_2 from Yellow R	0	99
R_2 from Homozygous Red R	132	0
R_2 from Heterozygous Red R	227	68
Yellow R_2 × r-2 r-2	0	24
Yellow R_2 × t t	15	0

Anther Culture

Variation induced in plants regenerated from culture of gametic tissue is termed gametoclonal variation. Since plants regenerated from anther culture are haploid, gametoclones would be expected to behave differently from somaclones. A unique feature of gametoclonal variation is the expression of recessive mutations induced by the culture process direct in the regenerated plant (R_0). When anthers of F_1 hybrids are cultured, the population of regenerated plants represents segregation and independent assortment events from the preceding meiosis. Hybrid sorting describes anther culture of heterozygous plants or F_1 hybrids to produce an array of stable, homozygous genotypes. Doubled-haploid peppers have been recovered in large numbers through anther culture (Morrison, 1987). Gametoclonal variation was detected among doubled

haploids (DHs) of the bell pepper (*C. annuum*) inbred Emerald Giant. The majority of the DHs were significantly shorter than the donor material, although several plants were significantly taller (Figure 1). Variation was also observed for yield (Figure 2). While deleterious variants were also recovered, several DH lines outperformed Emerald Giant for yield and quality. In contrast, no segregation was seen in the selfed progeny of Emerald Giant.

In a separate study, DH lines of bell peppers were generated from anther culture of an F_1 hybrid between parents that were light green and dark green. Out of 85 DH lines, 44 lines had dark green fruit, while 41 had light green fruit. Since inheritance of this trait is conferred by two loci, four phenotypic classes would be expected. The DH lines had a spectrum of fruit colors, from dark to intermediate to light, indicating the occurrence of these classes. The spectrum of fruit color from light or dark demonstrates a gametic array for this trait. Several lines exhibiting the desired fruit color have been incorporated into the breeding program, while others were selected for large-scale field trials prior to release.

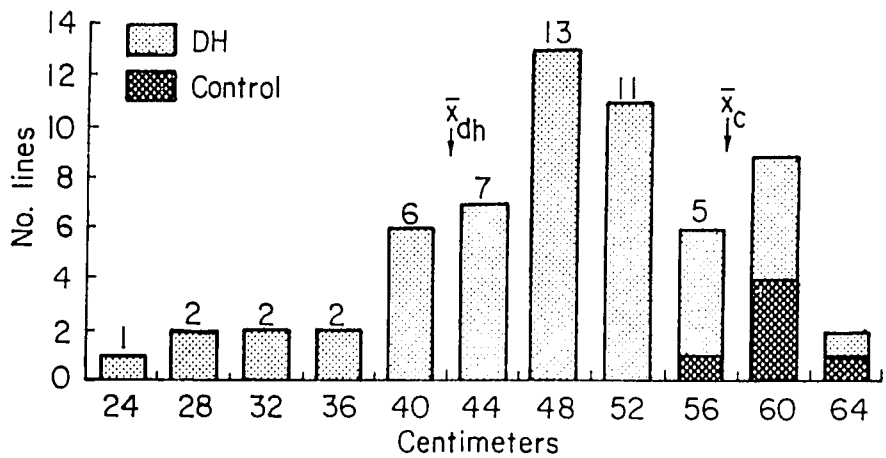

Figure 1. Distribution of plant height among DH and control lines of Emerald Giant. Numbers above bars represent the number of DH lines with individual means significantly different than the grand mean of the control lines ($p < 0.05$)

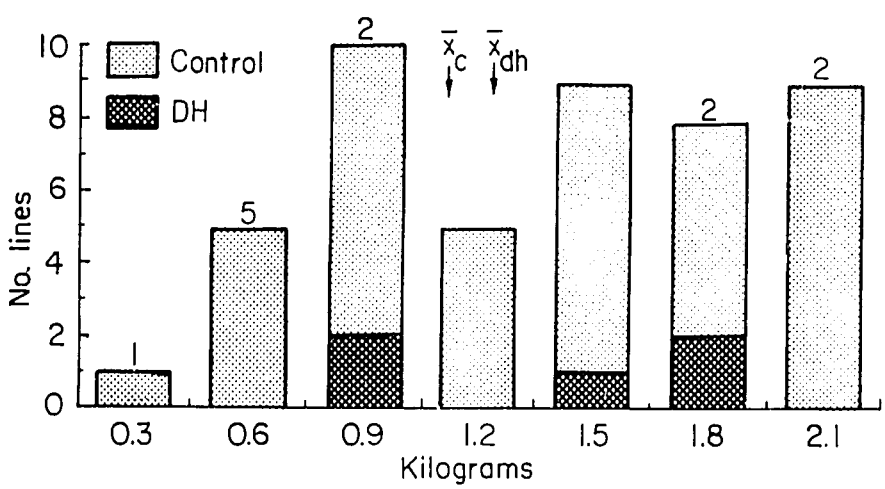

Figure 2. Distribution of single plant yield among DH and control lines of Emerald Giant. Numbers above bars represent the number of DH lines with individual means significantly different from the grand mean of the control lines ($p < 0.05$).

Conclusion

Two technologies derived from cellular genetics directly impact tomato and pepper improvement. Somaclonal variation has been successfully applied to make small, incremental improvements in elite breeding material without disrupting the gene combinations which control overall agronomic habit. Anther culture has been used to induce gametoclonal variation and to generate a gametic array of pure breeding lines through hybrid sorting. Each discipline presents additional tools to the plant breeder. While these tools are not essential to plant breeding, they can provide novel genes and gene combinations and significantly reduce the time to variety development.

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Symposium Discussion

L.C. Chang: There are some reports that the autodiploids derived by haploid chromosome doubling from anther culture are not stable and of low fertility after several generations. What are your experiences in the practical use of such haploids?
W.H.T. Loh: Genetic unstability may occur if chimeras are regenerated from a cell mixture. Regeneration from single microspores is favored by protocols which reduce culture time. Dihaploids produced under these conditions do not exhibit segregation in subsequent generations. DNA Plant Technology Corporation has obtained a patent under the Plant Variety Protection Act on a nearly seedless variety of sweet pepper developed through anther culture-derived gametoclonal variation. This is the first patent to be issued for a variety developed through anther culture.

S. Green: Considering the fact that resistance genes for CMV are not available in cultivated or wild tomatoes, do you envisage that a biotechnology approach might be possible, or is one already underway to solve that problem?
W.H.T. Loh: Viral resistance may be engineered by inserting the gene with the appropriate regulatory sequences for the viral coat protein. Expression of the coat protein confers viral resistance akin to cross-protection. Synthesis of viral coat protein may lead to yield reductions, but may be the only solution where natural resistance does not exist.

J. Hallard: Did you observe any spontaneous chromosome doubling in the regenerated pepper plants?
W.H.T. Loh: Spontaneous chromosome doubling in haploid peppers regenerated from anther culture occurs at very high frequencies. Thus, colchicine treatment, which often produces deleterious changes to the plants, is often not necessary.

R.T. Opeña: One of the serious criticisms that have been leveled at the technology of somaclonal variation is the low frequency of novel variation derived through this method. Is this true?
W.H.T. Loh: The level of somaclonal variation varies from crop to crop. In tomato, somaclonal variation occurs at a high frequency, such that some somaclones accumulate too many mutations and have lost utility. We try to reduce the incidence of somaclonal variation in tomato by minimizing culture time.

R.L. Villareal: Can you give one example of a commercial tomato/pepper hybrid or variety which has been developed using inbred line(s) derived through hybrid sorting?
W.H.T. Loh: Tomato cannot be regenerated from anther culture. DNA Plant Technology Corp. has produced several pepper lines from anther culture (hybrid sorting), both processing and fresh-market types, which are in advanced grower trials.

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Pepper Breeding and Genetics at New Mexico State University

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Abstract

Capsicum annuum is the most important horticultural crop in New Mexico. The majority of New Mexico's pepper acreage, 86%, is planted to the long green (Anaheim) type commonly called chile pepper. Most of the chile pepper produced is used as a processed product and can be separated into three major commodities: green chile, red chile, and paprika. Single plant selection with pedigree breeding has been used successfully to obtain lines that are unique and uniform in horticulturai traits needed by the chile industry. Most important to the chile pepper industry in New Mexico is disease resistance. The diseases of immediate concern are *Phytophthora capsici* (root rot), *Verticillium dahliae*, pepper mottle virus, tobacco etch virus, and *Meloidogyne incognita*. In breeding for disease resistance, our research has focused on identifying sources of resistance and the development of a multiple disease resistance seedling screen. Pungency level has become very important in chile peppers, because of the increased consumption of southwestern ethnic food products in the United States. Currently, the most accurate measurement of pungency is with high performance liquid chromatography (HPLC). We are investigating the capsaicinoids within *Capsicum* species, varieties, and cultivars. In the hope of expediting the research on pepper genetics, a *Capsicum* Genetics Cooperative (CaGC) was established in the Department of Agronomy and Horticulture at New Mexico State University (NMSU). Unique genetic stock material is requested from *Capsicum* researchers and is kept in a repository.

Introduction

Pepper, *Capsicum annuum*, is the most important horticultural crop in New Mexico which produces more chile pepper than all other states in the United States combined (Cotter, 1980). It is New Mexico's largest cash food crop and has been grown in the Rio Grande Valley of New Mexico for at least 400 years. Chile pepper is not native to New Mexico, but was probably introduced during the Spanish conquest by Don Juan de Ornate in 1598. By 1600, colonists were raising chile peppers with irrigation from the Rio Grande River.

Studies on peppers, including breeding, began with the founding in 1888 of New Mexico State University. Fabian Garcia, the first chile pepper researcher, began in 1907 to investigate ways in which to improve chile pepper production methods and cultivars for New Mexico (Garcia, 1908). Two of his most significant accomplishments were the 'raised bed' method of growing peppers to reduce the incidence of Phytophthora root rot, and the selection and propagation of less pungent chile peppers. This allowed for greater production and wider acceptance of chile peppers, especially the long green (Anaheim) types. Today, the majority of the 56,790 chile pepper hectares planted in New Mexico are used to produce chile for processing and can be separated into three major commodities: green chile, red chile, and paprika. Research on improving these pepper types has continued at New Mexico State University in the Agronomy and

Horticulture Department (Bosland et al. 1988; Harper. 1950; Matta and Nakayama. 1984; Nakayama. 1975; Nakayama and Matta 1985). Table 1 lists the pepper cultivars developed at New Mexico State University, with their originators and year of development.

Table 1. Important pepper cultivars developed at New Mexico State University.

Originator	Year	Cultivar
Garcia	1921	'New Mexico No. 9'
Harper	1950	'New Mexico No. 6-4'
Harper and Nakayama	1967	'Rio Grande'
Harper	1956	'Sandia'
Nakayama	1975	'NuMex Big Jim'
Nakayama	1984	'NuMex Espanola Improved'
Nakayama	1985	'NuMex R Naky'
Bosland et al.	1988	'NuMex Sunset'
Bosland et al.	1988	'NuMex Sunrise'
Bosland et al.	1988	'NuMex Eclipse'

Methods

Breeding for disease resistance is foremost in our breeding program. In breeding for disease resistance, our research has focused on identifying sources of resistance and the development of a multiple-disease-resistance seedling screen. We are designing inoculation techniques which allow for the multiple inoculation of several pepper pathogens onto a pepper seedling. The diseases of immediate concern in New Mexico are *Phytophthora capsici* (root rot), *Verticillium dahliae*, pepper mottle virus, tobacco etch virus, and the rootknot nematode, *Meloidogyne incognita*.

Pepper is thought to be a self-pollinating species, but in New Mexico outcrossing rates as high as 70% have been recorded. Therefore, breeding strategies to develop improved cultivars have taken this phenomenon into account. Since both pest resistance and horticultural traits can have varying genetic action (e.g. dominant, recessive, quantitative, or qualitative) different breeding methods are employed depending on the gene action. The most successful breeding methods have been the backcross, a modified single seed descent method, and the pedigree method.

Results

Improvement of horticultural traits for green chile, red chile, and paprika is being conducted at the same time as disease resistance is being introgressed. An ideotype for green chile has been developed (Bosland. 1988). Figure 1 is a stylized drawing of the green chile ideotype. The major features of the green chile ideotype are uniformity of pod length, pungency, fruit width, and wall thickness. Since green chile plants are also used to produce the red chile, the fruits must have high extractable red color and high dry matter. In the United States, paprika is defined as a nonpungent red pepper powder. Therefore, very mild or nonpungent chile peppers are also used to produce paprika. In New Mexico, all peppers are still hand-picked, but machine harvesting of red chile would be desirable. Preliminary steps toward the development of a plant type suitable for machine harvesting have been accomplished. Pungency is another horticultural trait towards which considerable effort is being directed. Pungency level has become very important in chile peppers, due to the increased consumption of southwestern ethnic food products in the United States. The genetic control of pungency is through a single recessive gene. However, once pungency is present, the range of pungency levels is controlled by a quantitative gene system. Currently, the most accurate measurement of pungency is with high performance liquid

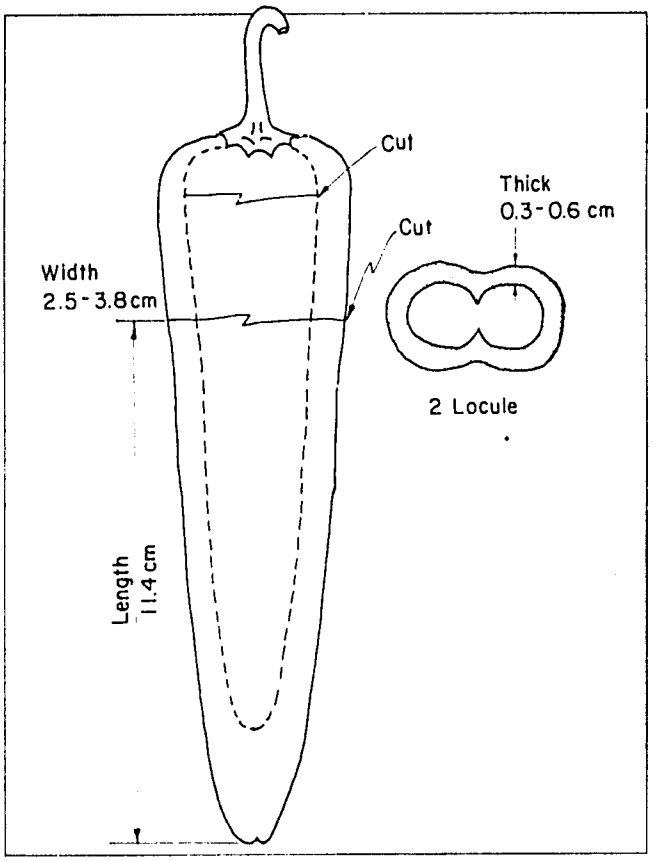

Figure 1.
A stylized drawing of the green chile fruit ideotype for processing needs.

chromatography, HPLC. The HPLC system is capable of detecting the seven capsaicinoids which differ by species, variety, and cultivar.

Conclusions

The New Mexico State University pepper program has been, and will continue to be, involved internationally in *Capsicum* research. Cooperation with other researchers in the world is welcomed. In the hope of expediting research on pepper genetics, a *Capsicum* Genetics Cooperative (CaGC) has been established in the Department of Agronomy and Horticulture at New Mexico State University. Unique genetic stock material is requested from *Capsicum* researchers and is deposited into a repository. All persons providing genes and stocks to the CaGC will be recognized as the source of those traits in the Eucarpia Capsicum Newsletter.

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Symposium Discussion

B.H. Chew: Do you find that the color of the netting used in caging the pepper plants for seed increase affects fruit-set?
P.W. Bosland: The coloring does not seem to have an effect, but the shading causes the peppers to grow more vigorously. This suggests that pepper grown in southern New Mexico is in a stressed environment.

Y. Haile: How do you determine the oleoresin content of the tested cultivars?
P.W. Bosland: Extractable red color, oleoresin, is a major characteristic for red chile production. Color is assayed using the American Spice Trade Association (ASTA) methods. It is generally felt that an ASTA of 140 is sufficient for red chile grown in New Mexico.

R.L. Villareal: Would pepper be more susceptible to *Verticillium dahliae* than to *V. albo-atrum*?
P.W. Bosland: *V. albo-atrum* of pepper is now considered to be *V. dahliae*. The Verticillium colonizing pepper has microsclerotia, therefore is classified as *V. dahliae*. *V. dahliae* occurs mostly in the southern USA and may produce symptoms at soil temperature approaching 30°C. *V. albo-atrum* produces no symptoms above 28°C.

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The Use of *Capsicum chinense* as Sweet Pepper Cultivars and Sources for Gene Transfer

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Abstract

The common *Capsicum annuum* sweet pepper cultivars do not thrive under humid tropical conditions in the Amazon Basin because of disease problems such as bacterial wilt, anthracnose leafspot, bacterial spot, Erwinia rot and viral diseases. Most sweet peppers of the Amazon are imported from thousands of kilometers away because of the very high cost of local production. However, because of the need for transport over long distances under hot and humid conditions, the peppers imported from northeast and southern Brazil are always of poor quality, and are expensive. The Amazon Basin is the center of origin for *C. chinense* species. Many cultivars were domesticated by the Amazon natives for flavor and/or pungency. Some of the cultivars have sweet pepper properties and can be used as such. These cultivars are naturally adapted and disease-free under humid tropical conditions. This paper reports the collection, evaluation and development of *C. chinense* materials in the Amazon region as substitute for *C. annuum* sweet pepper for humid tropical regions. The advantages of *C. chinense* cultivation are the longer harvest periods, no pesticide application requirement, and low production cost. A breeding program is under way to transfer fruit quality traits from *C. annuum* to *C. chinense*.

Introduction

Sweet pepper is the solanaceous fruit most widely cultivated in the east Amazon region where tomato is difficult to produce. Currently 95% of tomato and more than 50% of sweet pepper (*C. annuum*) are imported from northeast and southern Brazil some 2,000 to 3,000 km away. Neither sweet peppers nor tomatoes are commercially produced in the west Amazon region. There is no paved highway system to connect Amazonian cities and vegetables are transported without refrigeration on dirt roads and rivers. The trip takes 4 to 12 days in the dry season, and even then some cities can only be supplied by air. During the wet season, when ground transport is cut by water, air transport is always needed. High prices and low quality of the imported produce is responsible for the sharp reduction of consumption of these vegetables in Pará State, and especially in other inner states and territories of the Amazon Basin (Cheng, 1987).

Vegetables in Brazil are mostly produced by Japanese immigrants, who arrived at the Atlantic coast and currently have settled up to the middle Amazon River city of Santarem (Figure 1). Sweet pepper cropping goes with Japanese immigration, but remains expensive to produce. No commercial sweet pepper is produced to the west of Santarém. (Prof. R.R. Lima, 1988, personal communication)

The Amazon Basin is a center of origin of *C. chinense*, and a huge variety of hot peppers, flavoring peppers and ornamental peppers of this species occur there (Casali and Couto, 1984; Souza and Casali, 1984). Many have a sweet and dark-green pericarp similar to common sweet pepper, although smaller in size (10 to 30 g) and different in shape. They are grown under humid conditions, under half-shade in backyards as perennials for two to four years, without disease or pest control.

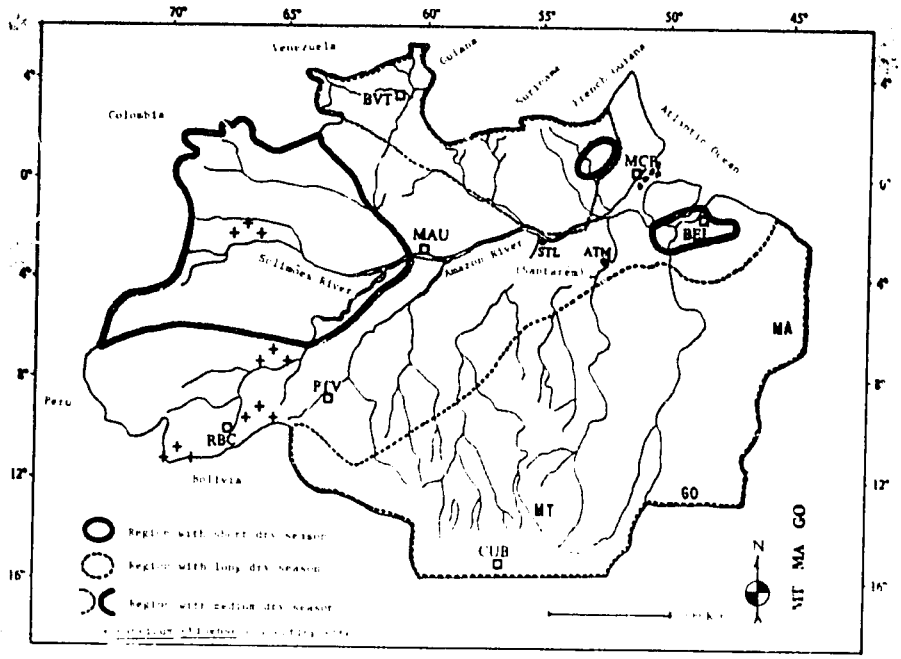

Figure 1. Humid tropics of Brazil with three types of climate and *Capsicum chinense* collecting sites.

There are several advantages in using *C. chinense* as sweet pepper in the humid tropics. *C. chinense* is affected by few pests and diseases and spraying of chemicals is not required. It produces fruit over a long period. Under half-shade or light shading, *C. chinense* can produce fruit continuously for several years. Its fruits are crispy and sweet without the bitterness which is a characteristic common to many *C. annuum* cultivars. However, the domesticated forms are still at a backyard stage and little is known about their behavior under open field commercial scale production. Also unknown is the consumers' acceptance of these small peppers instead of the traditional common sweet pepper.

Two approaches to improve fruit size and shape of *C. chinense* peppers have been adopted: wide collection of domesticated forms and selection for size and shape as near to those of common sweet pepper as possible; and transfer of size and shape from *C. annuum* to *C. chinense* peppers.

Materials and Methods

A collection of *C. chinense* germplasm with sweet pepper characteristics was made under the leadership of Professor Rubens R. Lima, of the College of Agricultural Sciences of Pará, through the Amazon Pre-Columbian Useful Plant Collection Project. The major collecting site was along the Solimões River to the Bolivian border in the west. Mature fruit samples were sent to the Laboratory for Vegetable Research and Development, UEPAE/EMBRAPA (Brazilian Institute of Agricultural Research) in Belém, for evaluation and multiplication.

The collection was planted under full shade under passion fruit vines; under half-shade against a wall; and in the open unshaded field, for two seasons: dry season, from July to November 1987, and rainy season, from December to April 1988. The objective was to obtain information about fruiting potential under different environments, particularly for the open field conditions of commercial growers. Fruit number, weight of the first fruiting, and fruit quality in terms

of pericarp thickness and color, were recorded. Refractometer readings were taken from green and red fruit.

Potato virus Y (PVY) is the most serious disease of sweet pepper in Brazil. Several mild strains belonging to the Y^0 group and several strains of the virulent Y^w group are recorded in Brazil (Nagai, 1984). To test the reaction of PVY, eight selected lines of *C. chinense* were sent to AVRDC for testing by artificial mechanical inoculation followed by an ELISA test. The PVY used for the inoculations had been previously isolated from peppers in Taiwan and was classified as pathotype O. Marketability was evaluated in relation to the price of imported common sweet peppers.

The breeding program started with a cross of California Wonder × AMA-3 to improve fruit size and pericarp thickness. The F_1 was backcrossed to AMA-3 and selected for high fruiting capacity, long production cycle, and disease resistance. Two promising lines were then crossed to the *C. annuum* hybrid Miyoshi to increase yield and to improve fruit shape and size in subsequent generations.

Results and Discussion

About 20 lines have been collected. Shapes vary from sausage (AMA 10), conic (AMA 3) to long square (AMA 6). Under open field conditions without supplemental irrigation, normal yield was obtained in the rainy season, from January to April. During this period, showers occurred every afternoon and monthly rainfall was 570, 305, 542, 442 mm for January, February, March, and April respectively. During the dry months of July, August, September, October and November, monthly rainfall was 145, 182, 86, 86 and 55 mm respectively.

In the dry season, both fruit yield and fruit weight were sharply reduced (Table 1), despite supplemental irrigation. In the rainy season, AMA 3, AMA 6 and AMA 7 lines produced about 100 fruits per plant during the first fruiting, but only 30 to 40 fruits were picked in the first fruiting in the dry season. Flower drop and young fruit drop under water stress conditions was observed in all *C. chinense* lines during the dry season. *C. chinense* species evolved in the humid and half-shade conditions of the Amazon forest. Lack of water stress was an important condition under which this species was developed. Consequently *C. chinense* does not have the mechanism to resist water stress.

Table 1. Fruit weight distribution (%) of three pure lines of *Capsicum chinense* sweet pepper during the dry season (August to November 1987) and rainy season (January to April 1988), and a breeding line selected from three-way cross Miyoshi × (California Wonder × AMA-3) × AMA 3.

Line	Fruit weight class (g)[1]						Average[2]
	6-10	11-15	16-20	21-25	26-30	31-35	(g)
AMA 3							
Dry season	15.0	63.4	20.3	1.1	–	–	12.69
Rainy season			6.0	37.0	57.0		26.37
AMA 6							
Dry season	37.4	57.8	4.6	–	–	–	10.79
Rainy season	8.0	–	71.0	21.0			18.72
AMA 7							
Dry season	39.4	60.5	–	–	–	–	10.92
Rainy season		9.0	30.0	46.0	15.0		20.99
Tricross-G							
Dry season	–	6.3	8.2	25.0	34.6	25.6	23.81

[1]Sample size varied from 13 to 143 fruits per line. [2]For reference, the fruit weight of California Wonder in the rainy season generally ranges from 41.6 to 50.5 g, that of Miyoshi from 34 to 89 g.

C. chinense plants grown under half-shade against a wall proved to be the best for year-round fruit production. Since the afternoon sunshine was blocked by the wall, no water stress conditions occurred and normal fruit yield was produced in both seasons. Full shading was too dark for fruit-set of *C. chinense*. Although the plants thrived very well, fruit-setting never exceeded 10 per plant in both dry and rainy season. The fruiting capacity is apparently dependent on water balance rather than light intensity.

Probably because of natural resistance, *C. chinense* plants were not found affected by bacterial wilt (*Pseudomonas solanacearum*). This species is also resistant to bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) and has been used by Noda (1986) in Manaus (west Amazon) as a source to transfer this resistance to *C. annuum* sweet pepper. During the rainy season, the stems and leaves were found to be free from anthracnose spot (*Colletotrichum gloeosporioides*) and no *Erwinia carotovora* rot was observed. Tomato spotted wilt virus and PVY are common on *C. annuum* sweet pepper in the Amazon. However, typical symptoms of these two virus diseases were not observed in *C. chinense* lines grown under natural conditions.

Two disorders most frequently observed on these lines were Sclerotium wilt (*Sclerotium rolfsii*) and yellowing caused by nutrient deficiency. Growers who are planting *C. chinense* line AMA 3 in southern Brazil have observed that this line is susceptible to late blight (*Phytophthora capsici*), a disease which is not important in the Amazon Basin.

The above results indicated that seeding and transplanting for commercial production are best done in the last month of the dry season (November, in the Amazon region). Fruit picking can be done through the rainy season (January to April). After May, supplemental irrigation is needed to avoid water stress during the dry season. On dry land soil, weekly side-dressing of chemical fertilizers is required to maintain soil fertility under intensive leaching. Some growers reported that on valley soil of the Amazon River bank, neither supplemental irrigation nor fertilizer side-dressing was needed because of natural humidity and fertility, even in the dry season under strong sunshine. Full fruiting capacity was apparently obtained there through water balance at a high level of absorption-transpiration.

However, for commercial scale production, the uncertainty of popular acceptance has to be considered. Because *C. chinense* cultivar AMA 3 has smaller fruit than the imported *C. annuum* peppers, and a strange shape (imperfect cone), the initial wholesale price was only half that of the imported peppers. Recently the popularity of this pepper increased considerably because the country's economic problems reduced the purchasing power of Brazilian consumers for imported peppers, and also because of improved production techniques adopted by the growers, and the recognition of the better quality of *C. chinense* fruits. Some growers have obtained heavy fruit-set and yields of 10 kg fruit per plant per year with *C. chinense* pepper on Amazon River Valley soil, without any input, not even pesticide application. Stems and leaves were free of anthracnose spot (Figures 2 and 3). Fruit of AMA 3 pepper in the full green stage had about 4.5 Brix index and reached 6.5 Brix at the red stage, indicating that the mature pepper of AMA 3 cultivar is sweet.

The high adaptability of *C. chinense* sweet pepper to half-shade environment indicates that it can be used for home garden production in the humid tropical regions to improve the nutritional status of the people in this region who generally have poor vitamin A and C intake. The low cost of production and the absence of need for pesticide application will make production very easy.

The AMA 3 line is best in terms of fruit weight (Table 1), pericarp thickness and fruit color. It is believed that crossing between the AMA lines can produce fruits of even better shape and size. Since the flowers of young fruits drop easily, the crossing should be done in the rainy season. Currently only AMA 3 was released as a cultivar with seeds multiplied and packed by the Brazilian Center of Vegetable Research at the Brazilian Institute of Agricultural Research in Brasilia. The seeds were distributed through the extension network of the Amazon region. With its small, crispy and dark-green fruits, AMA 3 peppers are promising for the pickle industry. Furthermore, the results of the virus screening at AVRDC (S.K. Green, 1988, personal communication) showed that line AMA 3 was resistant to PVY, the major virus in Brazil.

Figure 2. A *C. chinense* sweet pepper cultivar, AMA 3, 80 days after planting in Belem, Pará, Brazil, (dry season).

Figure 3. A *C. chinense* sweet pepper cultivar, AMA 6, 80 days after planting in Belém, Para, Brazil, (dry season)

A breeding program to improve fruit quality of AMA 3 was initiated in 1985, and was aimed at transferring the thick pericarp and large fruit size of California Wonder and the high yield of *C. annuum* Miyoshi to AMA 3. During the first cross, the average fruit weights of

California Wonder, AMA 3 and the F_1 hybrid were 46 g, 15 g, and 27 g respectively. Seedset was normal either using AMA 3 as male or female parent. However, a higher number of seed (200 per fruit) was obtained using California Wonder as female parent. The F_1 hybrid from California Wonder × AMA 3 cross was highly sterile, with 93% empty pollen grains. Although both of the parents have sweet fruit, peppers of the F_1 hybrid were very pungent, suggesting that different genes were involved in each species to block capsaicin synthesis. Each parent carries a different recessive gene pair. The F_1 plant synthesizes capsaicin through gene complementation.

About 10 seeds per fruit were obtained in the backcross with AMA 3 pollen to the F_1 hybrid. From the backcross population, plants producing sweet fruit, having high fruiting capacity, long lifecycle and absence of disease, were selected for four generations. To increase yield, two promising lines were crossed to the *C. annuum* hybrid Miyoshi (Figures 4, 5). Promising lines were obtained after this cross. The fruit weight of these lines is now twice that of AMA 3 pepper, i.e. approximately 23 g in the dry season and 36 g in the rainy season. The fruits have normal *C. annuum* shape. Other characters are those of AMA 3: high yield, long life cycle, sensitivity to water stress, no symptoms of anthracnose or viral diseases. Their final canopy reached 2 × 2 meters. Seed multiplication and regional tests will be carried out before their release to the growers of Amazonia.

In conclusion, the use of *C. chinense* cultivars such as AMA 3, can supply the lowland tropics with low-cost, pesticide-free, high-quality sweet pepper year-round. Even in high altitude tropical regions, as in most of South America, cheap peppers can be produced during the hot and rainy season by utilizing AMA 3. It is hoped that as a result of the present breeding program (Figure 6) the new generation of *C. chinense* sweet pepper would be perennial trees bearing fruits with characteristics similar to the common sweet pepper.

Acknowledgments

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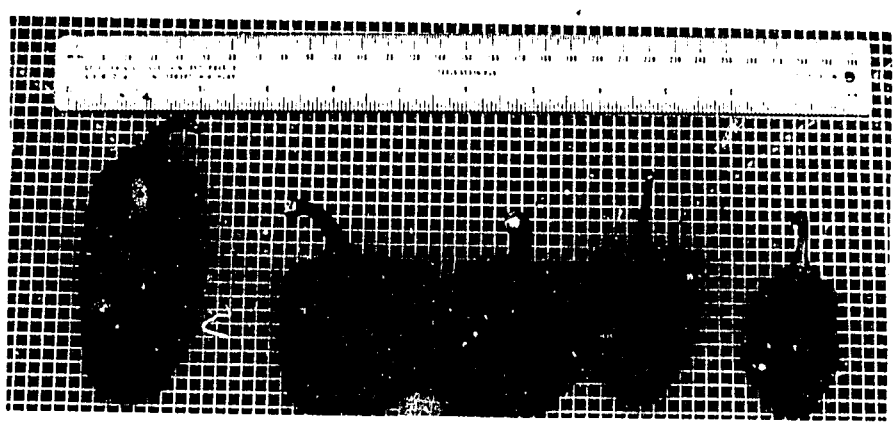

Figure 4. Fruit from the original *C. chinense* cultivar and selected breeding lines. From right to left: AMA 6, AMA 3, Miyoshi × {California Wonder × AMA 3 × AMA 3}, Miyoshi × {California Wonder × AMA 3 × AMA 3} and (California Wonder × AMA 3) × AMA 3.

Figure 5.
A breeding line from Miyoshi × {California Wonder × AMA 3 × AMA 3}.

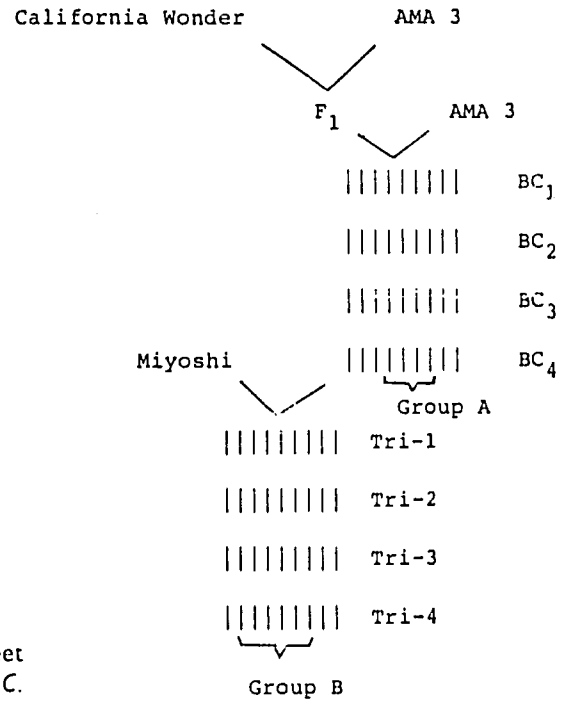

Figure 6.
Breeding program to create perennial sweet pepper cultivars involving *C. chinense* and *C. annuum*.

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Symposium Discussion

L. Black: You stated that the *Capsicum chinense* lines with which you are working possess virus disease resistance. Do you know specifically some of the viruses to which these lines are resistant?

S.S. Cheng: Rating for virus resistance was generally done visually in the field only. As mentioned, typical virus symptoms were never observed under field conditions. Screening of AMA lines by artificial inoculation with a PVY virus isolate from Taiwan showed that AMA 3 possesses resistance to this virus. Since none of the *C. chinense* lines grown in the Amazon region ever exhibited any virus-like symptoms even when grown in proximity to severely virus-infected plants, they may be tolerant to or perhaps resistant to the isolates of PVY occurring there.

A. Hibberd: Do your breeding progenies involving *C. annuum* as parents suffer increased disease susceptibilities?

S.S. Cheng: In the backcross population of F_1 × cv. California Wonder, severe Pseudomonas wilt occurred, although good fruit shape and size were observed. This fact made us approach from F_1 × *C. chinense* to increase fruit size at a slower pace but with higher resistance.

R.L. Villareal: How long can a perennial *C. chinense* be productive under a normal growing environment? Under cultivated condition? What spacing do you use under the latter condition?

S.S. Cheng: The oldest population we have now is three years old and the productivity is still the same, under shade conditions. Under cultivated conditions, high yields were obtained during the first 18 months. Nutritional deficiency began to show up at later stage. Under commercial production, with an 18-month cycle, a spacing of 1.0 m × 1.5 m is recommended. Shading always prolongs the lifecycle of *C. chinense* sweet pepper.

63

8

Evaluation of Tomato Materials for Use in the Processing Tomato Breeding Program in Martinique

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Abstract

A breeding program was initiated in 1985 at IRAT/CIRAD in Martinique (French West Indies) to improve processing tomato for the lowland humid tropical areas. The most important required characters are resistance to *Pseudomonas solanacearum*, heat tolerance and firm fruit with high soluble solids contents, and a pH of 4.5. As the first step, this program evaluated, under Martinique conditions, two groups of accessions: those with reported bacterial-wilt resistance; and those susceptible to bacterial wilt but with good agronomic characteristics during the cool season, or with good fruit-set during the hot and wet season. Vanguard, King Kong, Dynamo and Caraibo were selected from bacterial wilt-resistant accessions because of large fruit size; Nema 1200, Rio Grande, Petomech, Europeel and F_1 Count II for good marketable yield and high soluble solids contents; All Star and PSX 1994 for best yield; King Kong and entries from AVRDC for heat tolerance and good bacterial wilt resistance. From bacterial wilt-susceptible accessions , Tulena and PSX 1994 were chosen for their high fruit-set. The best varieties in each category will be intercrossed to pool those characters in each parent.

Introduction

Most processing tomato varieties are unsuited to lowland humid conditions in the tropics because of two major limiting factors: bacterial wilt (*Pseudomonas solanacearum*), and adaptation to environmental conditions prevailing in the hot wet season. Fruit-set is often low because of high day and night temperatures and excessive moisture (Villareal, 1980). Incidence of pests, diseases and weeds is also high.

The table cultivar Caraïbo can be grown in lowland humid tropic areas, because of its resistance to bacterial wilt. However its low fruit-set during the hot wet season, its low firmness, and its susceptibility to cracking, make it unsuitable for processing. Therefore a breeding program was initiated in 1985 at IRAT/CIRAD to improve processing tomato for tropical countries of Africa, including Burkina Faso and the Congo, and for Reunion (Indian Ocean) and the French West Indies.

The most important characteristics required are resistance to heat and bacterial wilt, good fruit-set during the hot wet season, determinate growth habit, medium fruit size, good color, firmness, crack resistance, high soluble solids content, and a pH of 4.5. The French West Indies were chosen as a location to carry out this project for four reasons. Firstly, *P. solanacearum* is endemic and widely distributed. Secondly, the bacterial wilt-resistant line Caraïbo (developed in the French West Indies) remains resistant when grown in the areas listed above where bacterial wilt is damaging (D'Arondel, personal communication; IRAT Reunion, 1986; IRAT Polynesie Francaise, 1986). Thirdly, two types of soils are present, vertisols in which bacterial wilt normally

does not occur (this permits testing of bacterial wilt-susceptible varieties) and oxisols, in which resistance to bacterial wilt can be screened by either natural infection alone or additional artificial inoculation. Fourthly, climatic conditions represent those of lowland tropical humid areas. Temperatures are 26°-27°C night/32°C day and 18°-20°C night/30°C day during the hot wet season and cool season, respectively, and rainfall is 2-3 m/year at 0-100 m above sea level on the coast which is exposed to wind.

Materials and Methods

Accessions Resistant to Bacterial Wilt

Thirty-three varieties reportedly resistant to bacterial wilt were collected worldwide and evaluated for bacterial wilt resistance in Martinique on oxisols which are highly conducive to *P. solanacearum*, all year round. Seeds were planted in a greenhouse in raised beds of heat-sterilized soil. After 10 days, seedlings were transplanted into 10 cm pots or into benches. When plants were five weeks old, they were transplanted to the field, at a spacing of 1.60 m × 0.50 m between and within rows. Plants were trellised between strings at 50 cm height. Plots consisted one row of 10 plants per line and were not replicated. Three local strains of *P. solanacearum*, PS6, PS8, and PS11, isolated from different areas in Martinique, were used for artificial inoculation of five-week-old-plants. Inoculum consisted of a mixture of suspensions of each of the three bacteria strains, grown on tetrazolium chloride medium (TZC) (Kelman, 1954) and adjusted to 10^7 CFU's/ml. Roots were wounded with a knife and 2 milliliters of the bacterial suspension were poured onto the soil surface at the base of the plant. Caraïbo and Floradel were used as resistant and susceptible checks respectively. Several plants with typical bacterial wilt symptoms were randomly taken and individually tested to confirm the presence of *P. solanacearum* in the vascular tissue. All plants without characteristic symptoms were tested by streaking on Kelman's medium. Disease severity was assessed, based on the percentage of dead plants: R (resistant): no dead plants; MR (moderately resistant): 1% to 10% dead plants; S (susceptible): 11% to 100% dead plants.

A selected number of varieties were also evaluated for fruit-set during the hot wet season by recording fruit-set on the first three inflorescences.

Accessions Susceptible to *P. solanacearum*

Bacterial wilt-susceptible lines, consisting of commercial processing cultivars or determinate fresh-market cultivars with good agronomic characteristics or with good fruit-set, were maintained on naturally suppressive vertisols where they are usually not affected by bacterial wilt (Bereau et al. 1975; Messiaen et al. 1972; Prior et al. 1987).

Fifty-three varieties were subjected to a preliminary evaluation for agronomic characteristics in the cool season (December 1986). Plots consisted of 10 plants per variety using a completely randomized block design and two replications.

Fruit weight, marketable yield, pH and soluble solids content were recorded. Individual fruit weight was calculated from the total sum of the marketable fruits. The twenty-seven best varieties selected from the first screening were evaluated for the same characters. Firmness was also evaluated in 1987. The lines were grown as described above, but using three or five replications.

Fruit-set was evaluated during the hot wet season in 1986 and 1987. Fruit size and marketable yield were observed only during 1987 randomized block design with five replications and ten plants per plot. Firmness was assessed manually, using a scale from 1 (soft) to 3 (very firm). For evaluating processing characters, fifteen tomato fruits with uniform ripeness were obtained from each variety at the third harvest; half of the fruits were blended to give a 'puree' which was tested for pH and soluble solids content (by refractometry) (Taillebois, 1979). Harvesting was at weekly intervals and usually started about two months after transplanting. The percentage of fruit-set (number fruit set/total number of flowers) was determined on the first three trusses.

Results

Evaluation of Bacterial Wilt-Resistant Lines

Twenty-three varieties were found to be as resistant as Caraïbo. These were the large-fruited Vanguard (F_1), King Kong (F_1), and Dynamo (F_1), and the small-fruited IRAT L3, CRA66, Hawaii 7996 and sixteen AVRDC lines (Table 1). Five lines were classified as moderately resistant

Table 1. Evaluation of selected tomato genotypes for bacterial wilt resistance in the cool season on oxisols in lowland Martinique.

Genotype	Origin	Plant habit[z]	Fruit weight (g)	Firmness[y]	% of dead plants 1985	1986 trial 1	1986 trial 2	Bacterial wilt rating[z]
L 366	AVRDC	D	50	S	0	NT[v]	NT	R
L 285	AVRDC	D	15	F	0	NT	NT	R
CL 8d-0-7-1	AVRDC	D	50	S	0	NT	NT	R
CL 9-0-0-1-3	AVRDC	D	50	S	0	0	0	R
CL 143-0-10-3-0-1-10	AVRDC	D	35	S	0	NT	NT	R
CL 1104-0-0-71-4-0-1A	AVRDC	D	45	MF	NT	NT	0	R
CL 1131-0-0-38-4-0-1A	AVRDC	D	35	–w	NT	NT	0	R
CL 1131-0-0-43-8-1	AVRDC	D	30	S	0	NT	NT	R
CL 1131-43-8-1	AVRDC	D	30	S	NT	NT	0	R
CL 1219-0-8-0	AVRDC	D	45	F	0	0	0	R
CL 1351-1-9-10-0	AVRDC	D	30	MF	0	NT	NT	R
CL 5915-39D_4-1-2-0	AVRDC	I	45	S	NT	NT	0	R
CL 5915-93D_4-1-0	AVRDC	D	55	MF	NT	NT	0	R
CL 5915-553D_4-3-0	AVRDC	D	35	S	NT	NT	0	R
CL 5915-206D_4-2-4-0	AVRDC	I	70	S	NT	NT	0	R
CL N 65-349D_5-2-0	AVRDC	D	50	MF	NT	NT	0	R
F1 Vanguard	Known You	I	115	F	NT	0	0	R
F1 King Kong	Known You	SD	150	MF	NT	0	0	R
F1 Dynamo	Sakata	I	85	F	NT	0	0	R
CRA 66	INRA	D	30	F	NT	0	NT	R
IRAT L3	IRAT	I	45	MF	NT	0	NT	R
Hawaii 7996	U. Florida	D	30	MF	NT	0	NT	R
CL 949-0-8-0	AVRDC	D	45	F	8	NT	NT	MR
CL 1131-0-0-7-2-0-9	AVRDC	D	35	MF	5	10	5	MR
CL 5915-206D4-2-3	AVRDC	I	90	F	5	0	NT	MR
CL 5915-206D4-2-5	AVRDC	I	95	F	5	NT	NT	MR
Hawaii 7997	U. Florida	I	5	0	MF	NT	50	MR
CL 5915-136D_4-1-0	AVRDC	D	30	S	NT	60	NT	S
CL 5915-206D_4-2-2	AVRDC	I	95	S	NT	15	0	S
(H7996 × C.28)F2	INRA	(I)	50	MF	NT	15	NT	S
Rodade	Inst. Res. Hort. (South Africa)	D	110	MF	NT	25	10	S
8SCR-15-14-42	IRAT	D	55	S	90	NT	NT	S
8SCR-15-6-40	IRAT	D	60	S	85	NT	NT	S
Floradel (susceptible check)	Petoseed	I	–	–	100	100	100	S
Caraibo (resistant check)	INRA	D	115	MF	0	0	0	R

[z] D = determinate, I = indeterminate, SD = semi-determinate. [y] S = soft fruits, MF = moderately firm fruits; F = firm fruits.
[z] S = susceptible; MR = moderately resistant; R = resistant. [w]no data. [v]NT = Not tested.

to the same degree as Hawaii 7997, and five lines were as susceptible as Floradel. Several entries from AVRDC, and King Kong (F_1), had a high percentage of fruit-set during the hot season; Rodade, a variety previously found to perform well during the cool season, had a low fruit-set.

Evaluation of Agronomic Characters of Bacterial Wilt Susceptible Lines

Cool season trials. The good performance (defined as high soluble solids content and a marketable yield superior to or equal to Caraïbo) of varieties All Star, Nema 1200, Europeel and Florida in the cool season 1986 trial was confirmed in 1987. The lines PSX 1994, Tulena and Count II were selected for high yield and satisfactory soluble solids content (Table 2).

Hot wet season trials. In the hot wet season, Heinz 822 and Saladette had the best average fruit-set (more than 60%) among bacterial wilt-susceptible lines, compared to an average of 40-60% for L3957. This entry from AVRDC had good results in Taiwan in 1983 (AVRDC, 1985) (Table 3). Accessions from Brazil (IPA 1, 2 and 3) which are heat-tolerant in their country of origin (Da Costa et al. 1978) were found to have low fruit-set under Martinique conditions.

Tulena and PSX1994 had the best fruit-set (Table 4). The cultivars Chico III and Heinz 822 showed good fruit-set, but the marketable yield was low because a large number of fruits were affected by blossom end rot. The two populations Xina and Lignon, which had been improved for high fruit-set in Senegal and in Cuba (CDH, 1986; Gomez and Laterrot, 1988), showed a high variation for fruit-set; plants with high fruit-set were selected. Fruit-set of the local check cultivar Caraïbo was very low in the two trials.

Discussion and Conclusion

Our results indicate that resistance to bacterial wilt differs locally. Several AVRDC lines, two lines from Burkina Faso, (8SCR 15 14 42 , 8SCR 15 6 40,) and the cultivar Rodade from South Africa are all reported to be resistant in their countries of origin (Bosh et al. 1985; D'Arondel, personal communication) but were found to be susceptible when planted in the French West Indies. This discrepancy might be explained in terms of different environmental conditions, such as air or soil temperatures (Mew et al. 1977); different inoculation techniques; or by the presence of different strains of *P. solanacearum* (Rao et al. 1975).

Four virulence groups of *P. solanacearum* with different effects on three tomato varieties (resistant, moderately susceptible and susceptible) (Prior et al. 1988) were shown to be present in the French West Indies. This emphasizes the need for careful screening of resistant lines against local isolates of the wilt pathogen under local climatic conditions. It may be advantageous to choose resistant parental materials from different countries to pool different patterns of bacterial wilt resistance where these exist. However, lines chosen for the breeding program in the French West Indies should still be assessed in other countries because of the variability of *P. solanacearum*.

Several lines have been chosen for bacterial wilt resistance, fruit characteristics or heat tolerance. The best will be selected as parents and intercrossed to create a population with improved performance for those characters. After several cycles of intercrosses, this population will be introduced into each country to obtain varieties well adapted to local conditions.

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Table 2. Evaluation of selected tomato lines for processing characteristics, cool season, 1987.

Cultivar	Fruit size (g)	Marketable yield (kg/plant)	Soluble solids content (%)	pH	Firmness[z]
		Trial 1			
Florida	115 d[y]	2.36 b,c (w)[y]	4.8	4.4	2
Campbell	137 c	2.55 a,b,c	5.1	4.5	2
Caraibo	173 a	2.66 a,b,c	4.7	4.3	2
Duke	163 a,b	2.10 c	4.6	4.4	2
VF 10	103 d	2.50 a,b,c	4.8	4.4	2
Floradade	133 c	2.94 b,c	4.2	4.3	3
AVX 5715	57 e	2.42 a,b,c	4.1	4.3	3
Tulena	106 d	3.10 a,b,c	4.7	4.2	2
Pacesetter 616	66 e	3.02 a,b,c	4.2	4.3	–
Count II	155 b	3.56 a,b	4.2	4.3	3
All Star	139 c	3.64 a	4.7	4.3	2
PSX 1994	104 d	3.26 a,b,c	4.3	4.3	2
Luxor	159 a,b	2.84 a,b,c	4.9	4.4	1
Caraibo	108 d	2.97 a,b,c	4.3	4.3	2
		Trial 2			
Roma	43 e (w)	1.04	4.7	4.4	1
Florida	109 b	1.72	5.3	4.3	3
Campbell	146 a	1.60	4.8	4.5	2
Rio Grande	76 c,d	2.23	5	4.4	3
Castle More	79 c,d	2.81	4.4	4.8	2
UC 82 B	58 d,e	2.6	4.2	4.3	3
AVX 5131	57 d,e	2.55	4.3	4.3	–[x]
VF 145B	83 c	2.47	4.6	4.3	2
M82.18	58 d,e	2.68	4.3	4.3	3
Hofit	63 c,d	2.31	4.4	4.7	3
Cannery Row	66 c,d	1.83	4.6	4.4	3
Petomech	67 c,d	2.11	4.8	4.3	3
Europeel	39 e	2.66	5	4.4	2
Count II	154 a	1.69	5	4.3	2
Luxor	156 a	1.96	5.1	4.4	2
Nema 1200	65 c,d	2.64	5.1	4.4	3
Caraibo	111 b	2.61	4.6	4.3	2

[z]1 = soft fruit; 2 = moderately firm fruit; 3 = firm fruit. [y]Means in column not followed by the same letter are significantly different at the 5% level by Newman-Keuls test (Keuls 1952; Newman 1939). [x] = no data.

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Table 3. Fruit set of bacterial wilt-susceptible and bacterial wilt-resistant tomato lines during the hot wet season (1986).

Accessions	Fruit-set		
	-60%	60% to 40%	40% to 0%
Susceptible to bacterial wilt	Heinz 822 Saladette	Chico III Tipton Sunny L 3957	Ontario 823 PM 91446 Caraibo VX 5715 IPA 3 IPA 1 Vista UC 82 B IPA 2
Resistant to bacterial wilt	CL 1131-0-0-38-4-0-1A CL 5915-206D$_4$-2-2 CL 1131-43-8-1 CL 5915-553D$_4$-3-0 King Kong CL 9-0-0-1-3 CL 1131-0-0-7-2-0-9 CL 1219-0-8-0	CL N65-349$_5$-2-0 CL 5915-206D$_4$-2-4-0 Hawai 7997 CL 5915-93D$_4$-1-0 CL 5915-39D$_4$-1-2-0	Vanguard CL 1104-0-0-71-4-0 1A Dynamo Caraibo Rodade

Table 4. Evaluation of bacterial wilt-susceptible tomato during the hot wet season, (1987).

Trial 1				Trial 2			
Line or cultivar	Marketable yield (kg plant)	Fruit size (g)	Fruit set[z] (%)	Line or cultivar	Marketable yield (kg plant)	Fruit size (g)	Fruit set[z] (%)
Nema 1200	3 14 a[y]	47 c,d	22	PSX 1994	3 14 a	73 c,d,e	63
Xina	2.68 a,b	25 f	33	Walter	3 05 c,d	92 a,b	43
Miexin	2.53 a,b	36 e	39	Tulena	2.91 a,b	74 c,d,e	61
Lignon	2.46 a,b	58 b	20	Caraibo	2.57 a,b,c	67 d,e	17
Caraibo	2 3 b,c	68 a	8	Sunny	2.1 b,c,d	87 a,b,c	46
Chico III	1.74 c,d	42 d,e	60	Luxor	1 76 c,d	99 a 10	
VF 145-B	1 73 c,d	52 b,c	42	All Star	1.61 c,d	91 a,b	38
M 82 1 8	1.54 d	40 d,e	7	Chico III	1 53 c,d	38 d	75
Heinz 822	1 4 d,e	27 f	89	Floradade	1.31 d	75 c,d,e	50
Indiana 812	1.37 d,e	28 f	47	Vista	1 27 d	84 b,c	54
Liliana	1.35 d,e	45 c,d,e	7	Count II	1.14 d	81 b,c,d	35
AVX 5131	1.27 d,e	40 d,e	6				
Heinz 722	1.14 d,e	27 f	42				
Castle More	0.74 e	44 c,d,e	33				

[z]Average of fruit-set on the first three trusses [y]Means within columns followed by different letters are significantly different by Newman-Keuls test, 5% level

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Genetic Improvement of Tomato Adaptability to the Tropics: Progress and Future Prospects

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Abstract

The first stage (1973-80) of the AVRDC tropical tomato breeding program emphasized the development of heat tolerant and bacterial wilt-resistant breeding lines. In the second stage the most promising of these "pioneering" lines were further improved, mainly through backcross breeding. The most important attributes that were added are: resistance to diseases such as tomato mosaic virus (ToMV) and common rootknot nematode; improved fruit size and yield; improved fruit firmness; and, resistance to fruit cracking. For ToMV resistance, we used mainly the gene *Tm2*[2] which gives a high level of resistance to strains ToMV-0 and ToMV-1, the two most common strains found in Taiwan and throughout tropical Asia based on a survey by AVRDC virologists. Breeding for resistance to rootknot nematode made wide use of firm-fruited parent stocks to simultaneously improve the fruit firmness of the progenies. Contrary to previous reports, heat tolerance appears to be conditioned by a few but undefined number of quasi-quantitative genes which can be easily recovered in the early backcross generations. Further studies also revealed that additive and nonadditively acting genes are both important in regulating heat tolerance and resistance to bacterial wilt. Using near-isogenic lines varying in growth habit, our studies show that indeterminate tropical lines have consistently better fruit quality than their determinate counterparts; therefore, our attempt to breed an indeterminate tropical cultivar is justified from the standpoint of developing tropical lines with improved quality. Future prospects for improving tropical tomato for additional traits such as disease resistance, stress tolerance and quality are discussed.

Introduction

Tomato cultivation in the tropics is beset by many problems. These production constraints may be generally classified as follows: biotic stresses, such as debilitating diseases[1] and insect pests[2]; and abiotic stresses, such as high temperature, high humidity, excessive rainfall, low light intensity and poor soil conditions. Both types of stresses provoke drastic effects on the productivity and quality of tomatoes in the tropics.

In 1972, the Asian Vegetable Research and Development Center (AVRDC) started its tomato breeding program with the aim of enhancing the adaptation of this vegetable to the hot humid

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[1] At least 9 of 51 tomato diseases are important in the humid tropics (Villareal 1979, Yang 1979). These are bacterial wilt (*Pseudomonas solanacearum*), rootknot nematode (*Meloidogyne incognita*), tomato mosaic virus, leafmold (*Fulvia fulva*), gray leafspot (*Stemphylium solani*), Septoria leafspot (*Septoria lycopersici*) southern blight (*Sclerotium rolfsii*), early blight (*Alternaria solani*), late blight (*Phytophthora infestans*) and powdery mildew (*Leveillula taurica*). Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) has also become a severe problem in recent years (Opeña et al. 1987a).

[2] Of the tomato insect pests, fruitworm (*Heliothis armigera*) has received the most attention. As vectors for virus diseases, some sap-sucking insects, such as aphids and whiteflies, are just as important (Vattanatungum and Ruchtapakornchai 1978).

tropics. The first stage of the program (1973-80) emphasized the development of breeding lines carrying heat tolerance[3] and bacterial wilt resistance, the two most fundamental traits required for tropical adaptation (Villareal and Lai, 1979). The most promising of these "pioneering" tropical lines were released later by a number of national vegetable programs (Opeña et al. 1987a; Opeña et al. 1988).

Since 1980, the tropical tomato has undergone further improvements in the following traits — additional resistance to diseases, improved fruit size and yield, and better external fruit quality such as firmness and resistance to cracking.

This paper reviews the breeding and breeding-related activities that characterized the second-stage genetic adjustments of the tropical tomato.

High Temperature Tolerance

The tomato improvement research at AVRDC has been sharply focused from the outset on heat tolerance because this trait, along with resistance to bacterial wilt, is crucial for tropical adaptation.

Genetic Resources for Heat Tolerance

A review of previous evaluation studies for heat tolerance reveals that only 39 tomato accessions, or about 1% of the 4,616 screened, are heat tolerant (Villareal and Lai, 1978). Although this type of screening continued through the years, no significant addition to the heat tolerant gene pool has been found since. The most widely used heat tolerant stocks in the AVRDC tomato breeding program are given in Table 1.

Table 1. Genetic resources for heat tolerance in tomato and frequency of their utilization in the AVRDC breeding program

Accession	Varietal name	No. of times used in crosses	Percent	Source
L 4841	L22 (VC 11-3-1-8)	80	12.9	Philippines
L 3958	PI 289309	69	11.1	USA (Texas)
L 125	Divisoria-2	56	8.9	Philippines
L 283	Tamu Chico III	47	7.5	USA (Texas)
L 232	Nagcarlan	45	7.2	Philippines
L 2972	PI 289296	47	7.5	Hungary
L 1488	PI 203232[2]	36	5.8	South Africa
L 18	VC 11-2-5	34	5.4	Philippines

[2]Also reported as frost tolerant

Genetic Basis of Heat Tolerance

In the process of incorporating monogenic disease resistances, such as tomato mosaic virus and rootknot nematode, to the tropical tomato via the backcross method, cursory observations indicated that a sizeable proportion of the BC_1F_2 progenies already possessed heat tolerance levels comparable to, if not better than, recurrent heat tolerant parents (AVRDC, 1988a). Thus, genetically this circumstantial evidence indicates that heat tolerance may not be as complex as had been previously reported (Villareal and Lai, 1979).

[3]Heat tolerance in tomato is defined as "the ability to set fruits under night temperatures not lower than 21°C" (Villareal and Lai, 1978).

To substantiate the above hypothesis, genetic analysis of high temperature fruit-set in one cross, CL 5915-223-2-1-0/L 345, was analyzed during the 1986 hot summer season. A pronounced bimodality of distribution in the F_2 and BC_1F_2 generations was observed (Figure 1). A similar discreteness tendency was evident in the F_1 and BC_1F_1 families. Constructing a 95% confidence interval about the mean of the heat tolerant parent enabled the scoring of the segregants into discrete fruit-set category (Figure 2). As may be noted, there is a preponderance of heat sensitive and intermediate types vs. heat tolerant types in the F_2 generation. However, their relative proportions were reversed in the BC_1F_2 generation. Based on the relative proportion of selectable (heat tolerant) and nonselectable (heat sensitive and intermediate) progenies in the F_2 and BC_1F_2 generations, a single backcross appeared adequate to obtain many individuals with fruit-setting ability at least equal to or better than the recurrent heat tolerant parent (Figure 3).

Genetic analysis of another cross, CL 5915-153-3-3-0/BL 267, grown in the 1987 summer season, did not readily show the characteristic bimodality of distribution that was evident in the 1986 materials. The unexpected heterozygosity of the "heat sensitive" parent, BL 267, blurred

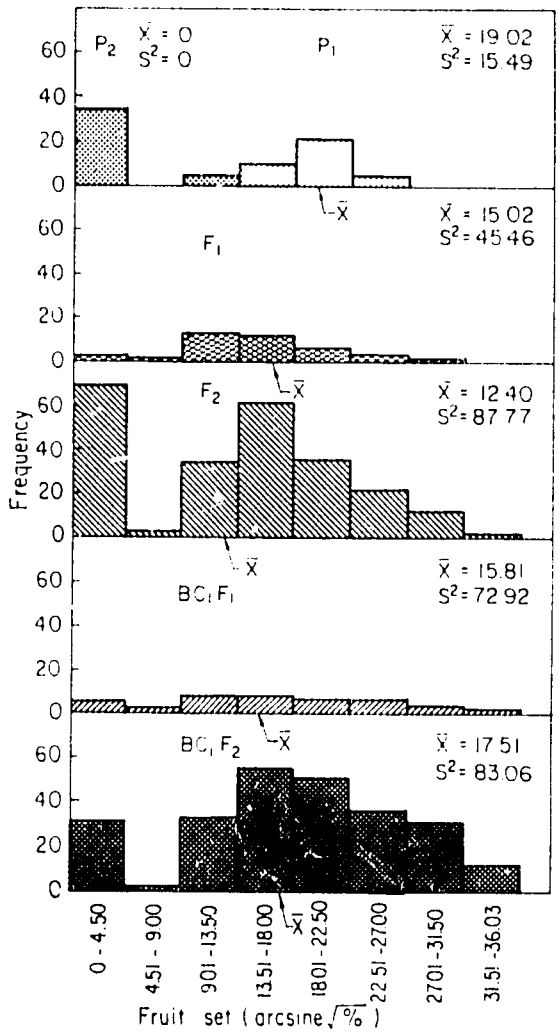


Figure 1. Distribution of fruit-set at high temperatures among parents, F_1, F_2 and backcross families of CL 5915-223-2-1-0/L 345.

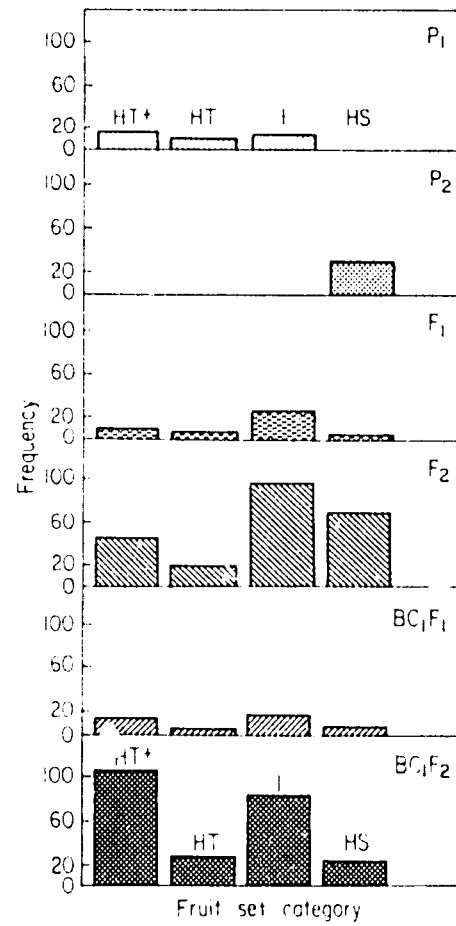


Figure 2. Distribution of fruit-set categories among parents, F_1, F_2 and backcross families of CL 5915-223-2-1-0/L 345. (HT⁺ = fruit set better than HT parent; HT = fruit set equal to HT parent; HS = heat sensitive; I = intermediate.)

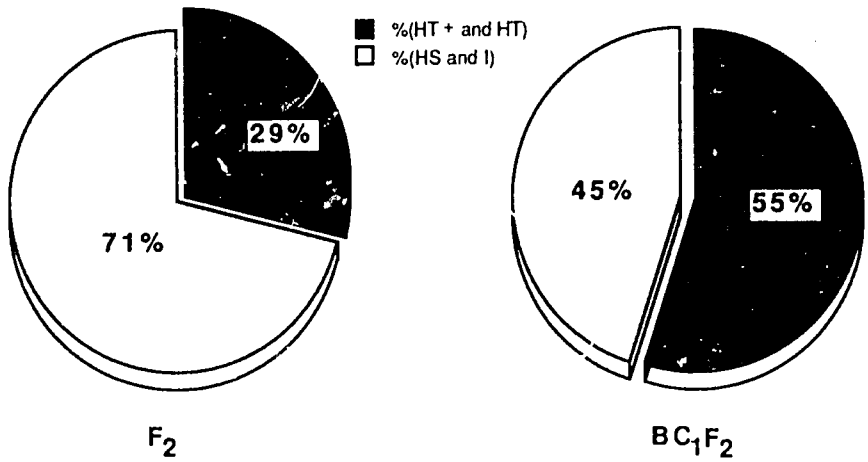


Figure 3. Relative proportion of selectable (HT⁺ and HT) and nonselectable (HS and I) classes in the F_2 and BC_1F_2 generations of the cross CL 5915-223-2-1-0/L 345. Note: HT⁺ = fruit set better than HT parent; HT = fruit set equal to HT parent; HS = heat sensitive; I = intermediate.

the segregation for high temperature fruit-set in this cross. Nonetheless, there were compelling reasons to assume that the number of heat tolerance genes in this cross are also as few as had been previously concluded in the 1986 study (AVRDC, 1988b).

It appears that the number of heat tolerant genes differentiating the parents in the crosses studied are few, possibly comprised of a limited number of genetic factors with major effects on the trait, and an effectively undefinable number of minor gene modifiers.

Mode of Gene Action for Heat Tolerance

Heat tolerance in tomato reportedly gave strong indications of genetical complexity — variation was continuous and heritability values were low, with a range of only 5% to 19% (Villareal and Lai, 1978).

Further studies of a genetically diverse seven-parent diallel set showed that both additive and nonadditive genes are important in regulating fruit-set at high temperature (AVRDC, 1988a). A similar genetic behavior was noted for the splitting of the antheridial cone, a common reaction of tomato flowers to high temperature.

Based on the above study, it was concluded that both conventional breeding methods, which take advantage of additively acting genes, and hybrid breeding, which relies primarily on genetic interactions, should be effective in breeding for heat tolerance. In support of the latter, about one-third of the diallel hybrid progenies from the foregoing study had better fruit-set than the better heat tolerant parents (AVRDC, 1988a).

In a related study, crosses between heat tolerant stocks were noted to have better fruit-setting ability and yield than their crosses with heat sensitive parents (Figure 4). However, it was apparent from the range of F_1 means (Table 2) that some hybrids between heat tolerant and heat sensitive stocks could equal, if not surpass, the performance of hybrids among heat tolerant stocks, further supporting the results from the diallel experiment (Opeña et al. 1987a).

Resistance to Major Tropical Diseases

A number of major diseases limit the productivity of tomatoes in the tropics. AVRDC's research on these diseases has been traditionally focused on the identification of resistance sources and their utilization in the breeding of resistant cultivars.

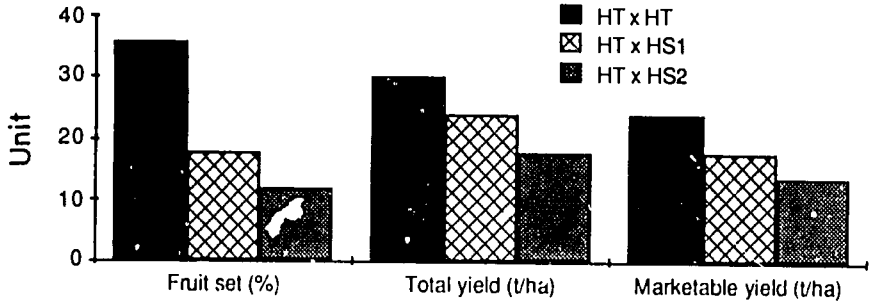


Figure 4. Comparative fruit-set and yield of F_1 hybrid progenies derived from crosses among parents with varying levels of heat tolerance (abbreviations in the legend footnoted in Table 2).

Table 2. Range of values for different characters among tomato hybrids with differing levels of heat tolerance.

Type of cross[z]	No. of crosses	Fruit-set (%)	Yield (t/ha)		Fruit size (g)
			Total	Marketable	
HT/HT	8	26-52	15.4-37.5	12.3-29.0	41-63
HT/HS1	11	5-30	15.9-28.8[y]	9.8-23.2	57-83
HT/HS2	10	2-32	6.3-33.2	5.9-27.6	59-92

[z]HT = heat tolerant parent, HS1 = heat sensitive parent (less than 10% fruit-set); HS2 = heat sensitive parent (no fruit-set) [y]Exceptional upper range values are underscored

Bacterial Wilt

Bacterial wilt, possibly the most important disease of tomato in the tropics, has received the highest priority in the breeding program (Opeña, 1985; Opeña et al. 1987a). Several resistance screening methods were tested by pathologists and the leaf clipping of young seedlings with a pair of scissors dipped in a bacterial suspension became the standard screening method for many years (Opeña et al. 1987a). Since 1986 field screening has completely replaced leaf clipping because of its relative accuracy (AVRDC, 1985; Opeña and Tschanz, 1987).

The most widely used bacterial wilt stocks in the breeding program are: Venus (USA), Saturn (USA), L366 (unknown origin), VC 11-3-1-8 (Philippines), VC 48-1 (Philippines), PI 406994 (Panama) and a few more, mostly coming from the tropical Southeast Asian countries (Table 3).

Although there are contrasting theories on the genetics of BW resistance (Acosta et al. 1964; Bosch et al. 1985; S.K. Tikoo, personal communication), AVRDC breeders have proceeded through the years with the encompassing assumption that BW resistance is polygenic. Materials from Hawaii and North Carolina for which polygenic inheritance was implicated, have been used in the AVRDC program, circumstantially justifying this assumption.

Bacterial wilt-resistant stocks vary in their ability to transmit resistance to their progenies (AVRDC, 1985). In a seven-parent diallel experiment, resistant stocks such as L 96 (cv. Saturn from North Carolina) and L 285, a local collection from Taiwan, produced hybrid progenies with better average resistance than others. Some stocks, such as CL 1351-1-9-10, tended to show high resistance in some crosses but not in others. It seems that nonadditive gene action may also be an important feature of the bacterial wilt genetic system. The reactions of F_1 hybrids among parent stocks with differing resistance levels provide further proof of this hypothesis (AVRDC, 1988b; AVRDC, 1989). Among these materials, hybrids between resistant parents generally tended to have higher levels of resistance; however, there were hybrids between resistant and susceptible parents that were equally resistant though the frequency was low (Figure 5).

Table 3. Genetic resources for bacterial wilt resistance in tomato and frequency of utilization in the AVRDC breeding program.

Accession	Varietal name	No. of times used in crosses	Percent	Source
L 96	Saturn	135	21.8	USA (North Carolina)
L 95	Venus	109	17.6	USA (North Carolina)
L 366	Unknown	85	13.7	Unknown
L 4841	L 22	80	12.9	Philippines
L 1	VC 48-1	34	5.5	Philippines
L 15	VC 8-1-2-7	34	5.5	Philippines

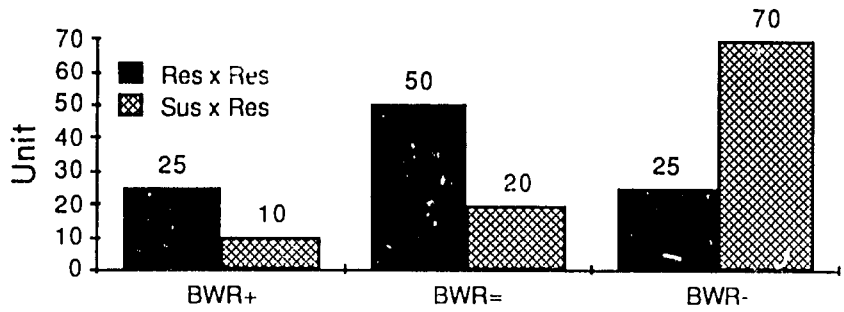


Figure 5. Comparative frequency (%) of resistant F_1's derived from crosses among resistant stocks vs. crosses among susceptible with resistant parents (Note: BWR + resistance is higher than the better resistant parent; BWR = resistance is equal to the better parent; BWR- resistance is lower than the better parent.)

Viruses

In surveys conducted from 1981 to 1985 in Taiwan, it was found that cucumber mosaic virus (CMV), tomato mosaic virus (ToMV) and potato virus Y (PVY) are the viruses with the highest incidence on tomato (AVRDC. 1984; AVRDC. 1985; AVRDC. 1987b; Green. 1986). Recently, a new aphid-transmitted potyvirus was also detected which is serologically unrelated to PVY, TEV and other potyviruses commonly occurring on tomato (AVRDC. 1987a; AVRDC. 1987b; Green and Kuo. 1985) and has a host range which is confined to the Solanaceae but apparently excluding *Capsicum annuum* and *Capsicum frutescens*. The virus is not seed-transmitted and produces only mild symptoms on tomato. A gemini-type virus causing leafcurl disease has also been isolated in Taiwan (AVRDC. 1984; Green et al. 1985; Green et al. 1987) but is neither endemic nor widespread. The virus has also been found on tomato in Indonesia and the Philippines (AVRDC. 1985). In Thailand, it is considered the most important virus on tomato and causes considerable yield loss (Chandrasikul and Patrakosol. 1986; Attathom and Sutabutra. 1985).

All of the above-mentioned viruses, with the exception of the new potyvirus, seem to be widespread and important in Southeast Asian countries, such as Indonesia, Malaysia, the Philippines and Thailand (AVRDC. 1985); (Abu Kassim. 1986; Chandrasikul and Patrakosol. 1986; Giatgong. 1980). The tomato spotted wilt virus (TSWV) has been reported in Malaysia and Japan (Fujisawa et al. 1986; Kobatake and Inouye. 1984). AVRDC has given priority to further characterize and include these viruses in the resistance screening program.

Tomato Mosaic Virus (ToMV)

Strains 0, 1 and 2 are the only naturally occurring ToMV strains detected on tomato during surveys conducted between 1980 and 1982 in the major tomato-producing areas of Taiwan. Strains 0 and 1 were most frequently found. ToMV 2 was only present in 1.4% of the samples tested positively for tomato mosaic virus whereas strain 0 and strain 2 were detected in 50% of the ToMV-positive samples (AVRDC. 1984; Green. 1986; Green et al. 1986). Contrary to observations in many temperate countries, ToMV did not appear to survive long in the soil in Taiwan. ToMV was detected in soil samples from infected fields only up to five months after the tomato harvest, even when tomato was followed by a rice crop (AVRDC. 1984; AVRDC. 1987b; Green et al. 1986).

Three genes for resistance, *Tm-1*, *Tm2* and $Tm2^2$, originally from the green-fruited species, *Lycopersicon peruvianum* and *L. hirsutum*, but also *L. glandulosum* and *L. pennellii* (Pelham. 1966) have already been transferred to *L. esculentum* and are available in many commercial cultivars bred for the temperate areas. Gene $Tm2^2$ gives a high level of resistance to the two most commonly occurring strains 0 and 1; therefore, it was chosen by the AVRDC tomato breeders for further breeding. The mode of action of gene $Tm2^2$ is not clearly understood, but it is thought to either limit ToMV multiplication within cells or to prevent viral movement from cell to cell.

AVRDC virologists have identified several stocks carrying resistance to tomato mosaic virus (Opeña et al. 1988). Some of the $Tm2^2$-donor stocks that have been utilized in the AVRDC tomato breeding program are L 127 (*an-Tm2a*) (USA), Ohio MR-12 (USA), Ohio MR-13 (USA), and a number of recently released commercial cultivars with superior characters (Opeña et al. 1988).

Segregating populations are regularly screened at the seedling stage by inoculation with ToMV-1 using a Paasch airbrush at 3.5 kg/m^3 at 10 cm distance and 0.5 ml inoculum (1 : 50 dilution of ToMV-infected plant tissue in phosphate buffer pH 7, 2% Celite added) per plant.

Cucumber Mosaic Virus (CMV)

A search for possible sources of resistance in the AVRDC germplasm collection was initiated in 1984 (AVRDC. 1987b; Green. 1986). More than 200 wild relatives of tomato, such as *L. pimpinellifolium*, *L. peruvianum*, *L. hirsutum*, and *L. pennellii*, were screened by two subsequent mechanical inoculations with an isolate that produces severe shoestring symptoms on tomato (isolate CMV-Peet).

Since no accessions were found with resistance, six hairy tomato lines were evaluated as a possible source of nonpreference or deterrence to aphids, the vectors of CMV. Depending on the leaf position, these lines had from 6 to 10 times more hair than the normal hairy tomatoes. In a laboratory study, it was found that the total probe time and the total probe number, although not the average probe duration, were significantly reduced on the hairy tomato lines (Table 4) (AVRDC. 1985; AVRDC. 1987a). This led to the assumption that utilizing these hairy tomato lines might slow down CMV development in the field. In the 1984 spring season, they were planted in the field and exposed to conditions of natural infection. By the end of the growing season (90 days), incidence had reached almost 100% in the normal hairy check, whereas it ranged from only 34% to 76% for the hairy lines. A cross between hairy and normal hairy line had 79% CMV incidence. The infection rate, i.e. the rate of disease increase per unit time *sensu* van der Plank, of the hairy tomato lines were also significantly lower than those of the nonhairy lines (Table 5) (AVRDC. 1987a). However, in a second field test using the same lines in the 1985 spring season, these findings could not be confirmed although significantly lower levels of aphid populations were detected on the hairy tomatoes throughout the growing period. The disease incidence on the hairy lines at the end of the growing period (96 days after transplanting to the field) ranged from 81% to 91% which was not significantly lower than those of the nonhairy lines which ranged from 89% to 100% (AVRDC. 1987b). Initially, however,

Table 4. Hair density of hairy and nonhairy tomato and its relation to the feeding behavior of aphids.

Leaf position	Hair no. (per 44.18 mm^2)	Total probe time (min.)	Probe no.	Average probe duration[z] (min.)
Leaf 1				
Hairy	523	1.85	0.97	1.97
Nonhairy	56	4.16	2.04	1.90
Leaf 4				
Hairy	545	1.03	1.61	1.60
Nonhairy	89	2.60	3.74	1.50
Leaf 6				
Hairy	378	0.47	1.03	1.53
Nonhairy	32	1.67	2.53	1.50
Factor	Total value of difference between hairy and nonhairy leaves significance for each parameter[y]			
Leaf 1	12.91***	3.92***	3.99***	0.41 NS
Leaf 4	12.60***	3.61***	5.82***	0.22 NS
Leaf 6	9.54***	2.53*	4.46***	0.03 NS
df.	59	179	179	17

[z]Values are weighted average for each of the three groups of 10 aphids. [y]NS = $P \geq 0.10$. * = $P < 0.05$; *** = $P < 0.001$.

Table 5. Progress of disease by days and infection rate of CMV.

	Disease progress (logit)	Infection rate
Nonhairy check	-9.18318+0.14643 days	0.1463
Hairy 1 × nonhairy	5.77563+0.093519 days	0.093519
Hairy 1 (22-2)-1-2-1	-3.1155 +0.030715 days	0.030715
Hairy 2 (30-8)-1-1-1	-4.48224+0.0664766 days	0.0664766
Hairy 3 (30-8)-3-4-1	-5.17444+0.0816049 days	0.0816049
Hairy 4 (30-8)-2-5-1	-3.45798+0.0548405 days	0.0548405

at 41 days after transplanting, the percentage of CMV-infected plants was significantly lower on the hairy tomatoes. It is evident, therefore, that the CMV incidence cannot be effectively reduced under natural epiphytotic condition despite the reduction in number of aphid vectors.

It is unlikely that CMV resistance genes which can protect against the many different strains of CMV known to occur in nature will be found in tomato or its wild relatives. The only possible solution for CMV resistance thus remains the production of transgenic plants, such as for example by inserting into tomato plants a gene that expresses CMV coat protein, or one that expresses CMV satellite RNA. Both methods have shown to protect plants from viral infection in other systems (Baulcombe et al. 1986; Tien et al. 1987) and will be pursued by AVRDC.

Potato Virus Y (PVY)

This virus was generally not considered of importance on tomato in the past because of its generally mild symptoms. However, considerable yield losses have been associated with its presence (Cox. 1965). Simultaneous infections by other viruses such as TMV can result in severe necrotic symptoms that can lead to the death of the entire plant (Clark et al. 1980).

In Taiwan, PVY was first isolated and purified from tomato in 1979 (Yeh. 1979). The incidence of PVY on tomato in Taiwan was found to be as high as that of CMV (AVRDC. 1985). The virus was recovered from each of the five major tomato production areas and in

34% of a total of 1,608 leaf samples. Grouping of the PVY isolates on different *Capsicum annuum* cultivars (Gebre Selassie et al. 1982) indicated that pathotype PVY-0 was the most prominent in Taiwan (AVRDC. 1988a).

A search for sources of resistance to PVY in the AVRDC germplasm collection was initiated in 1984. Because of the mild symptoms on tomato, a screening method which enhances symptom expression, thus facilitating the evaluation and rating, was developed. This method consists of two inoculations, the first on the newly expanded primary leaves and the second on newly emerging side branches, after cutting the stem at the three-leaf stage. Symptomless plants or those with mild symptoms are usually tested by the enzyme-linked immunosorbent assay (ELISA) method (AVRDC. 1987a).

None out of 72 randomly chosen accessions, comprising *Lycopersicon esculentum*, *L. pimpinellifolium*, *L. hirsutum*, *L. glandulosum*, *L. cheesmanii*, and *L. peruvianum*, was resistant. Out of 22 other accessions selected for their reported resistance to PVY, only one, *L. hirsutum* PI 247084, was found to be resistant (AVRDC. 1987b). This line was also found resistant by others (Thomas. 1981). Resistance from this accession was found to be recessive (AVRDC. 1988a). The incorporation of this resistance into AVRDC breeding lines has already been initiated.

Tomato Leafcurl Virus (TLCV)

This virus is not endemic in Taiwan and occurs only sporadically. Screening is done in the greenhouse by the double grafting method, by which the material to be screened is first grafted onto TLCV-infected tomato, excised after four weeks and grafted onto healthy *Nicotiana benthamiana* (AVRDC. 1988). In the absence of antiserum and serological detection methods, grafting onto *N. benthamiana* allows for the detection of the virus which produces prominent leafcurl symptoms after 7 to 10 days. Using this method, nineteen resistant lines with reported resistance have been screened, including *L. pimpinellifolium* LA 121 which has been used in resistance breeding for tomato yellow leafcurl virus (TYLCV), a serious problem in the Near East (Czosnek. 1988. personal communication) and which appears to be related to the virus causing leafcurl on tomato in Taiwan (AVRDC 1989). None was found resistant (AVRDC. 1988). However, one line (VL 215) produced only 50% infected plants. Seeds of resistant plants were saved for confirmation screening at AVRDC by the method described above and at AVRDC's Thailand Outreach Program.

It seems appropriate that both field screening under natural epiphytotic conditions and screening by grafting method should be conducted, firstly, to detect tolerant plants (slow, mild or no symptom development) and secondly, to determine possible immunity. If resistance is not found, the use of genetic engineering will be considered.

Rootknot Nematode

The most important species causing rootknot in tomato is *Meloidogyne incognita*. The stocks that were used initially in the AVRDC tomato breeding program are Healani, Kewalo, Cal-Mart and 72T6, obtained from various breeding programs in the United States. In recent years, several newly released nematode-resistant cultivars have found greater use in the AVRDC program because of their improved features such as large fruit size and better fruit firmness (Opeña et al. 1988).

Resistance to common rootknot nematode is controlled by a single dominant gene, *Mi*. This gene is tightly linked to the gene *Aps-1*, an isozymic locus for acid phosphatase (Rick and Fobes. 1974) whose unique electrophoretic banding pattern can be used as a marker to screen tomato seedlings for nematode resistance. Unfortunately, the tight linkage appears to have been broken in some stocks, notably those from Hawaii (Medina-Filho and Stevens. 1980); therefore, the nematode egg inoculation method is also used at AVRDC as an alternative screening technique (Opeña et al. 1987b).

Resistance to Fruitworm

Tomato fruitworm (TFW), *Heliothis armigera* Hübner (Lepidoptera: Noctuidae), causes considerable damage to tomatoes in Asia (Srinivasan, 1959; Singh and Singh, 1975; Esguerra and Gabriel, 1969; Vattanatungum and Ruchtapakornchai, 1978; Talekar et al. 1983). The insect lays eggs on the foliage and the newly hatched larvae, after initial feeding on the foliage, bore into the fruits and feed inside.

A tomato germplasm screening program was initiated at AVRDC in 1981 to identify sources of resistance to TFW. In the first test, 800 tomato accessions, including several wild species, were screened in the field where the natural TFW population was augmented by occasional releases of laboratory-reared larvae. Resistance was evaluated based on the percentage of damaged fruits.

Ten wild tomato accessions were free of TFW damage. These accessions included 76W-PI 134417-A and 77W-PI 134417-1, two *Lycopersicon hirsutum* f. *glabratum* accessions from North Carolina State University which showed high levels of resistance to tobacco hornworm, *Manduca sexta*, which also attacks the tomato foliage and fruits in North America (Kennedy and Henderson, 1978). Studies on the mechanism of resistance indicated that the glandular trichomes on the foliage of these wild accessions contain a toxic chemical which kills the young larvae feeding on the foliage (Kennedy and Yamamoto, 1979; Williams et al. 1980). A similar mechanism of resistance was observed with TFW at AVRDC.

Since PI 134417 showed a high level of resistance and the fact that the resistance mechanism is already known, this accession is being actively used at AVRDC to breed TFW-resistant tomatoes. The segregating progenies are screened in the field for TFW damage to the fruit whereas the foliage is exposed to larvae in the laboratory to judge the level of antibiosis. Resistant plants thus selected are then evaluated by the plant breeder for horticultural characters, especially fruit size and yield, and backcrosses to the *L. esculentum* parents are then made to further improve the horticultural characters. As of the end of 1987, four BC_4 families have been screened and selected in this manner. At each screening, plants with bigger fruit size and at least a moderate level of TFW resistance are retained.

Some BC_4F_6 selections have already shown acceptable horticultural features. Therefore, a preliminary trial of TFW-resistant BC_4F_6 lines is being planned for autumn 1988. They will be compared with commercial cultivars for horticultural attributes and fruitworm resistance.

Quality of Tropical Tomatoes

The AVRDC tomato breeders aimed mainly at developing determinate tropical lines at the outset. Economic factors clearly provided the rationale for this choice: bush tomatoes are cheaper to grow as they do not need staking. However, there have also been persistent requests from other countries for tropical lines which have better quality such as sweeter, better flavor, larger size, firmer and with attractive external appearance, to supply their quality-conscious tourist sector.

AVRDC breeders started, therefore, the selection of indeterminate tropical lines in 1981. It is generally known that fruit size can be improved by pruning the lateral shoots and regulating the number of fruits per truss. The indeterminate cultivars are more amenable to pruning than the bushy, determinate tomato. Moreover, there have been studies in temperate countries which showed that certain components of fruit quality, such as soluble solids, do attain better levels in the indeterminate than in the bush tomatoes (Emery and Munger, 1970).

To determine whether the above observations apply equally well to the tropical lines, we extracted two near-isogenic lines varying in growth habit (*sp* vs. *sp*+) from one BC_3F_2 population of the cross CL 6046 (CL 1131/Moperou) with CL 1131, a tropical line, as the recurrent parent and studied their quality attributes. Theoretically, the isolines share only 94% common genetic background and may not be the most ideal genetic material for the study; however, a good preliminary indication for various quality parameters was necessary.

The quality attributes of the isolines were compared in a split plot experiment, replicated thrice, with isolines as main plot and pruning as subplot. Pruning involved maintaining only two branches per plant, each allowed to develop only 5 fruit clusters, or a total of 10 trusses per plant. This treatment was included to determine if quality can also be regulated by constraining the fruit load per plant. Quality attributes such as β-carotene, vitamin C, pH, Brix, titratable acidity, Hunter color, total solids, and sugar-acid ratio (SAR) were measured.

Figure 6 shows the quality attributes of determinate vs. indeterminate isolines. The indeterminate isoline showed superiority in all important quality parameters such as soluble solids (Brix), color, total solids, and sugar-acid ratio. High sugar-acid ratio, in particular, is known to impart good overall tomato flavor (Stevens et al. 1979). In addition, the indeterminate line also showed significantly higher vitamin C content than the determinate line.

The effect of regulating the number of fruits per plant on fruit quality is depicted in Figure 7. Pruning resulted in higher contents of vitamins C and A (β-carotene), more acidic fruits, and higher sugar-acid ratio (for better flavor) than when all fruits were allowed to develop.

From the above results, it can be safely assumed that the development of indeterminate tropical lines should likely lead to new genotypes with better quality than could possibly be obtained with determinate tropical tomatoes. The use of indeterminate varieties may also be combined with traditional pruning practices to obtain further quality improvement.

General Breeding Strategies

The enormity of factors affecting the production of tomatoes in the humid tropics called for a stepwise approach to genetic improvement (Opeña. 1985). In the early years, the bringing

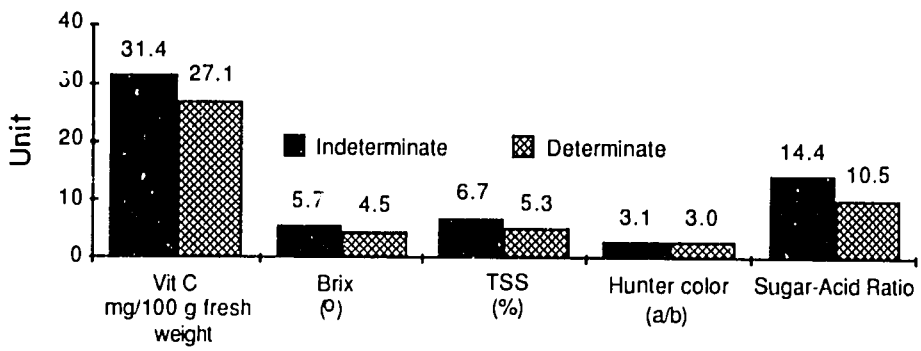


Figure 6. Comparative fruit quality parameters of indeterminate vs. determinate isolines.

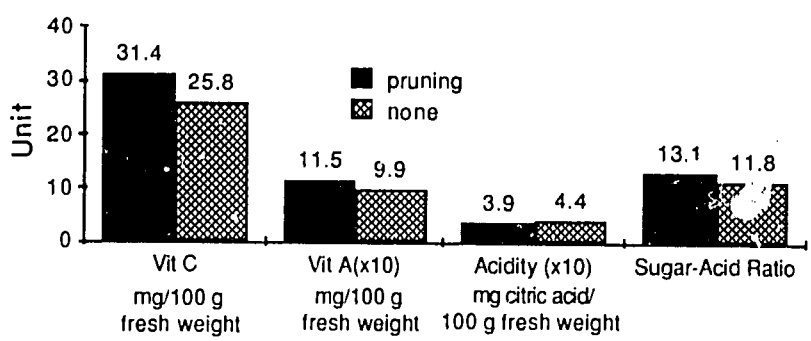


Figure 7. Comparative fruit quality parameters between pruned vs. no pruning treatments.

together of heat tolerance and BW resistance among the advanced breeding lines was emphasized because these features are fundamental to grow a successful tomato crop in the tropics (AVRDC. 1974; Opeña et al. 1987a).

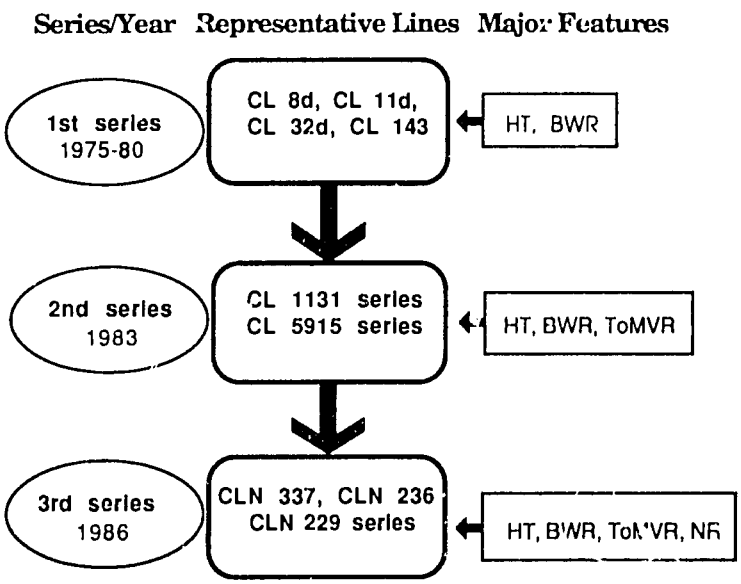
In recent years, further improvements of the tropical tomato have been obtained by sequentially incorporating additional resistance to diseases and by enhancing fruit quality. The new traits that have been added are: resistance to tomato mosaic virus (mainly gene *Tm-2*^{2}); resistance to rootknot nematode; resistance to fruit cracking; and improved fruit firmness and size (AVRDC. 1987a; AVRDC. 1989). The stepwise improvement of tropical tomato, especially for disease resistance is depicted in Figure 8.

As more desirable genes are added to the tropical tomato through further genetic manipulations, the valuable traits that they already possess may decrease in intensity. Complex characters like BW resistance and heat tolerance are especially vulnerable. Thus, increasing use of the backcross (BC) method to recover adequate levels of the previous breeding gains, while at the same time adding new traits, has been practiced in recent years at AVRDC. This method is finally combined with either the bulk, pedigree or single-seed descent schemes to handle the selfed BC populations (Opeña et al. 1987a).

Selection for complex traits is also delayed now until selections have reached the family or line stage. Early generation selections are still made but they are limited to simple, highly heritable traits like monogenic disease resistances. In so doing, the hybrid progenies are screened for desirable horticultural types before they are selected for complex traits, such as heat tolerance and BW resistance.

Enhanced Germplasm for the Humid Tropics

Genetic manipulations to combine the requisite traits for tropical adaptation led to the development of many breeding lines that were widely tested in Taiwan and in many tropical



HT = heat tolerant; BW = bacterial wilt-resistant;
ToMVR = tomato mosaic virus-resistant;
NR = rootknot nematode-resistant.

Figure 8. Stepwise improvement of tropical tomato for heat tolerance and disease resistance

countries. A significant portion of the screening and utilization of AVRDC's improved breeding lines was made possible through informal scientist-to-scientist collaborations. AVRDC has also entered into officially bilateral agreements with several countries, notably the Philippines, Thailand, Indonesia, Malaysia, and the Republic of Korea, thus, providing a steady conduit for the transfer of AVRDC's enhanced technology.

National programs worldwide have officially released a number of AVRDC's improved vegetable germplasm in the past (Opeña et al. 1987a; Opeña et al. 1988; Tay. 1989 in these proceedings). For tomato, 65 distinct breeding lines and accessions have been released to vegetable farmers in 26 countries/territories.

The most advanced of the tropically adapted lines already possess the combined features such as heat tolerance, multiple resistances to bacterial wilt, tomato mosaic virus, and rootknot nematode (see Figure 8), and improved fruit attributes such as firmness, crack resistance, and attractive smooth shape. In addition, newer lines tested since 1984 tended to have better yield and improved fruit size over older tropical lines. Whereas older lines generally yielded from 5 to 15 t/ha, the more recent lines tended to yield above 20 t/ha and as high as 35 t/ha in one year (Figure 9).

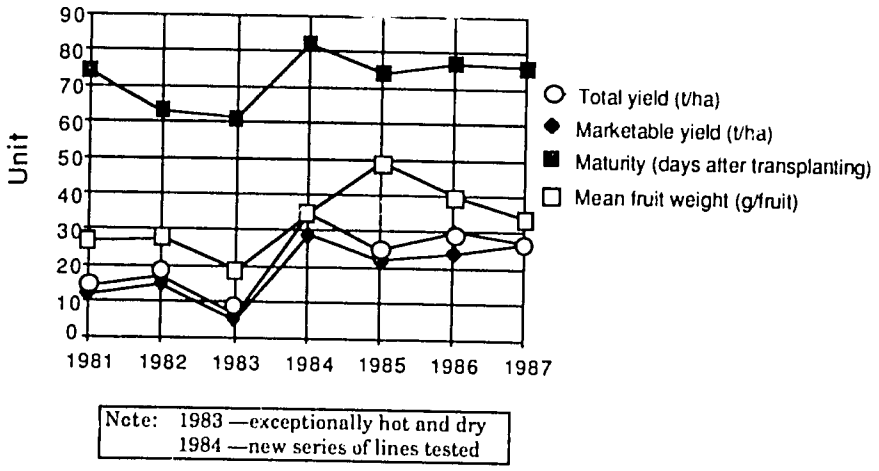


Figure 9. Comparative yearly means (1981-87) for various characters of tropical lines grown during the hot humid season.

Future Prospects for Improving Tropical Tomatoes

AVRDC research has successfully brought its horticultural crops to adapt reasonably well to the humid lowland tropics. Advanced breeding lines of AVRDC's principal vegetables resistant to one or more major diseases, are tolerant to hot wet conditions, and possess acceptable quality. Given these features, what may be expected of AVRDC's breeding lines in the future?

With an increasing pressure on environments brought about by the burgeoning population, global changes in climate, and marked reduction of farm inputs, the AVRDC future breeding lines will have to carry tolerances to more stresses than ever before.

In tomato, marked advances in the levels of disease resistance and in the range of diseases that the future breeding lines would be resistant to are expected. Progress in resistance breeding for potato virus Y, leafcurl virus, bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), and certain fungal diseases such as Cercospora leaf mold (*Cercospora fuligena*) is forthcoming. Even resistances to the unwieldy viruses, such as CMV, and equally important insects like fruitworm and aphids, may be unravelled as the potential of hitherto unexploited wild *Lycopersicon* and

Solanum germplasm is widely explored. The new tools of biotechnology may prove useful to better exploit this wild material.

Heat tolerance (specific for a hot dry condition), drought tolerance, tolerance of excess soil moisture or flooding, and even tolerance of poor soil fertility may have to be added into the physiological arsenal of the future tropical tomatoes.

There will also be a need to upgrade the quality of future tropical tomatoes, especially in the visible parameters of acceptability such as absence of cracks, reduced blotchy ripening, improved color, and increased longevity in transit and storage through better fruit firmness and/or inherently long shelf-life properties.

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Symposium Discussion

I.D. Erinle: Leaf diseases, in particular, early blight, leafmold and Septoria leafspot are important in the lowland tropics. Do you have a breeding program for resistance to any of these?

R.T. Opeña: There is no doubt that those diseases you mentioned are important in lowland tropics tomato production. We do not currently have any resistance breeding program for these, however, because there are far more pressing foliar disease problems like bacterial leafspot and black leafmold. In other words, our prioritization scheme puts early blight, leafmold and Septoria leafspot at a lower level than other diseases. In time, we will have a project on these, too.

J.C. Girard: What about late blight resistance? This disease may be damaging in the tropics during cool and wet periods or in altitude (cf: Island of Reunion).

R.T. Opeña: Late blight is a serious problem in the cool, moist highland production areas in the tropics. It has never been a limitation in the hot humid lowland areas. Since the emphasis of the AVRDC program is adaptation of tomato to hot, humid areas, we have not given any attention to late blight in so far as development of resistant lines is concerned. We have a small program for late blight resistance breeding in the processing type but this project has been of low priority.

E.S. Lim: What temperature range is used in the selection of heat tolerance in your lines. Is there any reference to high night temperature. (It would be of interest to you that some of your CL 5915 and CL 1131 material has yielded well under maximum day temperatures of above 40°C.)

R.T. Opeña: Our tropical breeding lines are selected regularly from plantings during the hot, wet summer season in Taiwan. During this period, day time temperature (maximum) could go as high as 34°C or so while night temperature would be no lower than 21°C.

86

10

Pepper Improvement for the Tropics: Problems and the AVRDC Approach

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Abstract

Results of literature and questionnaire surveys, and observations of AVRDC scientists indicate that viruses are the most important constraints in pepper production in the tropics. Chili veinal mottle (CVMV), cucumber mosaic (CMV), potato Y (PVY) and tobacco mosaic (TMV) viruses are the most prevalent viruses infecting peppers in tropical Asia. Bacterial spot and Phytophthora rot are other important diseases in both hot and sweet peppers, while anthracnose is more serious in hot pepper. Flooding stress and insect damage were also perceived as highly important for both hot and sweet peppers among the questionnaire respondents. Sunscald of sweet pepper and genetic impurity of the presently grown hot pepper cultivars are also problems which need attention. An increased level of pungency is desired for most of the commonly grown local varieties of hot pepper. The main strategy for sweet pepper varietal improvement at AVRDC will be concurrent backcross programs for the critical traits, followed by a pyramiding process. The effect of heat and other environmental stresses on plant growth, fruit development and yield also will be researched. For hot pepper, AVRDC's major activity will be to identify and distribute breeding materials, both in raw and enhanced forms. In order to best utilize the long-adapted landraces, an AVRDC-coordinated international hot pepper trial network (INTHOPENET) is proposed.

Introduction

Peppers (*Capsicum* species) are the world's second most important solanaceous vegetable after tomatoes. The worldwide planted area is estimated at 1.9 million ha. Hot peppers are frequently used in the diets of people living in the tropics and contribute to the income of tropical farmers. Growers in the tropics have serious production constraints with peppers. For example, sweet pepper is not yet genetically adapted to the tropical lowland and its production is confined to highland areas. Research on production constraints of peppers has been poorly organized and has not received full international attention like other important crop commodities. For this reason, since 1986, the Asian Vegetable Research and Development Center (AVRDC) has selected peppers as an additional principal crop for intensive research and development.

The present paper examines the major constraints to the production of both hot and sweet peppers in the tropics, with particular focus on Asia, and discusses the strategy and approach of AVRDC towards solving those constraints through varietal improvement. Background information for this paper was gathered from the literature, from a questionnaire survey, and from AVRDC's observations.

Methodology for Identification of Constraints

To assess the production constraints and other factors affecting peppers, questionnaires were sent to 264 cooperators in 55 countries from September to December, 1986. Target respondents

were identified from four major sources: (1) contributors to and subscribers of the Capsicum Newsletters, (2) participants of previous EUCARPIA (European Association for Research on Plant Breeding) pepper working group meetings, (3) Persons working on peppers according to the 1986 International Society of Horticultural Science (ISHS) Directory, and (4) AVRDC's mailing list. Questionnaires were also sent to major institutes and companies dealing with peppers.

By July 1987, 58 completed questionnaires (22.0%) were received from 29 countries, including eight tropical Asian, two temperate Asian, seven American, three African, seven European and two Oceanian countries. The response rate was somewhat lower than what could be expected in usual surveys, possibly because of the exhaustive nature of the questions included in the form. Interpretation of the results is, therefore, rather cautiously handled throughout this paper. The majority of respondents were plant breeders (48%) and horticulturists (31%). Out of the questions covering various aspects of pepper research and industry, only responses to those questions which are directly relevant to production constraints and varietal improvement are presented here.

AVRDC conducted a series of preliminary trials from 198[illegible] to 1985 to evaluate the performance in the hot and humid seasons of commercially available hot and sweet pepper cultivars collected from 12 different countries. Research projects initiated by various disciplines at AVRDC, since the elevation of peppers to principal crop status in 1986, have also helped confirm existing constraints and identify new ones.

The crop situation of peppers and the areas which need research were previously summarized by the IBPGR Secretariat (1983), and by Martin et al. (1979). There are also other sources of general information (Choudhury 1967; Grubben 1977; Knott and Deanon, 1967; Muthukrishnan et al. 1986; Tindall 1983, Yamaguchi, 1983). All these were used as references in identifying the problems (Tables 1 and 2).

Major Production Constraints

Diseases were considered the most serious production constraints of both hot and sweet peppers (Figures 1, 2). Insects, flooding and lack of suitable varieties were indicated as the next most important for both types of pepper. In the Asian tropics, flooding was considered more important than the insect problem, whereas in the rest of the world, insects and drought were regarded as more important than flooding. The lack of suitable varieties was shown to

Table 1. Importance[z] of pepper diseases based on different information sources.

Disease	Field observation in Taiwan		Literature	Questionnaire Survey[x]	
	1983-85[y]	1986-87		Tropical Asia	Other Regions
Virus complex	VH	VH	VH	99	90
Phytophthora rot	-	VH	VH	49	52
Anthracnose	-	H(?)	VH	38	19
Bacterial wilt	VH	H(?)	VH	34	20
Damping off	-	H	H	29	34
Bacterial leafspot	-	H	H	22	42
Nematode	-	?	M	11	17
Southern blight	VH	?	L-M	5	13
Cercospora leafspot	-	L	VH	4	5
Powdery mildew	-	H	L-H	2	10
Fusarium wilt	-	L	H	10	2
Others[w]	-	L	L	< 10	< 10

[z] EH = extremely high, VH = very high, H = high, M = medium, L = low [y] Based on AVRDC Progress Reports for 1983-1985 [x] Scores based on frequency and importance (100 = all respondents rated as the most important disease, 0 = no respondents listed the particular disease) [w] Black leafmold, mycoplasma, soft rot, Verticillium wilt, Choanephora blossom blight, etc

Table 2. Prevalence/importance[z] of viruses based on different information sources.

	Field observation in Taiwan		Literature	Questionnaire	
	1983-85	1986-87		Tropical Asia	Other regions
TEV	L	L	H	L	H
TMV	H	VH	VH	EH	EH
CMV	H	VH	VH	EH	VH
PVY	H	VH	VH	H	VH
PVMV	–	–	M	L	M
PMMV	–	–	L	L	M
TRSV	–	–	L	L	L
TSWV	–	y)	L	L	M
TLCV	–	–	M	M	M
PeMV	–	–	L	L	L
CVMV	–	VH	–	–	–

[z]EH = extremely high, VH = very high, H = high, M = medium, L = low y) = Elisa was not confirmed by virus isolation

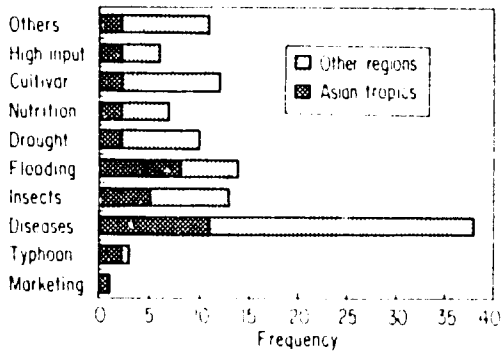

Figure 1 Relative importance of hot pepper production constraints (questionnaire survey)

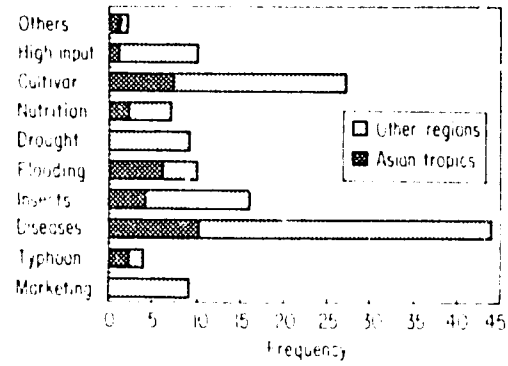

Figure 2. Relative importance of sweet pepper production constraints (questionnaire survey).

be more important for sweet peppers, especially in tropical Asia, than for hot pepper . This reflects the fact that sweet pepper is yet to be adapted to tropical environments. In the case of hot peppers, marketing problems appeared to be almost negligible. This may be mainly due to the fact that hot pepper is largely a home garden crop, and that the fruit can be stored for a long time in dried form until the market situation improves

Diseases

Among numerous diseases, the virus complex was rated as the paramount problem by the survey respondents regardless of region (Table 1). In the AVRDC fields, viruses were also observed to be far more serious than any other disease. Symptoms include mottle, mosaic, leaf deformation, leaf blistering, vein banding, stunting, wilting, systemic necrosis, and are dependent on the kind of virus, host genotype and environment. Virus infection results not only in yield loss but also in quality deterioration (Gracia et al. 1968; Kang et al. 1973; Villalon, 1975). In some areas, viruses have rendered pepper cultivation uneconomic, causing whole fields to be abandoned. Viruses inhibit the growing of the crop without frequent insecticide use, which in turn makes it difficult to monitor the insect population (AVRDC, 1989).

Viruses are also frequently cited in the literature as production constraints on pepper (Table 1). About 35 different viruses have been reported to infect peppers (Green and Kim, 1988; Martelli

and Quacquarelli, 1983). The most frequently mentioned virus by the survey respondents was tobacco mosaic virus (TMV), followed by cucumber mosaic virus (CMV) and potato virus Y (PVY). The importance of these viruses is also well recognized in the literature (Table 2). In a survey of 1,037 diseased leaf samples collected in Taiwan and Thailand and examined for the presence of 12 different viruses, only four viruses were detected by enzyme-linked immunosorbent assay (ELISA): the above-mentioned three and chili vemal mottle virus (CVMV) (AVRDC, 1989). In another series of ELISA tests of leaf samples collected from eight consecutive monthly plantings at AVRDC, CVMV and CMV appeared earlier and were more prevalent than PVY and TMV. For TMV and PVY the strain concept has been well established (Boukema, 1980; Gebre Selassie et al. 1982). So far, only tomato mosaic virus (ToMV) has been found in Taiwan. Preliminary strain typing of PVY isolates from peppers indicated that PVY-0 is most prevalent in Taiwan (AVRDC, 1989).

Phytophthora rot (*Phytophthora capsici*) was rated the second most important disease in the survey. It was followed by anthracnose (*Colletotrichum* spp.), bacterial wilt (*Pseudomonas solanacearum*), damping off and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), in order of importance, among the respondents from the Asian tropics. Interestingly the latter four diseases were rated in the reverse order among respondents from other regions (Table 1). In Taiwan, Phytophthora rot, bacterial spot, anthracnose and powdery mildew (*Leveillula taurica*) were found to be prevalent and often serious. Anthracnose normally appears at the red-ripening stage of fruit and was rated more of a problem in the tropics because growing hot pepper for red fruit predominates (Table 3). In Korea, strain G of *C. gloeosporioides* was found to infect both green and red fruit, whereas other strains and species caused damage mainly to red ripe fruit (Kim et al. 1986, 1988). Recently, green fruit infection also was found to be quite common in a pepper growing area in central Taiwan. Depending upon the growing environment, bacterial wilt may be a devastating disease. Resistance, however, appears to be common among tropical pepper genotypes (both wild and cultivated) which is not the case with tomatoes where resistance is rarely found (C. M. Messiaen, personal communication). It was also observed that many tropical landraces of hot pepper remain unaffected in AVRDC's tomato bacterial wilt nursery. In the course of varietal improvement it will be important, especially for sweet peppers, to ensure that new material will remain resistant to bacterial wilt. Incidence of powdery mildew, a warm dry-weather disease (Dixon, 1978), was lower during the humid, hot months than in other months in Taiwan (Table 3). Since powdery mildew can be controlled by appropriate chemical sprays (Gobbar and Peshney, 1981; Mathur et al. 1972), it will not receive priority in the AVRDC breeding program.

The frequency and importance of diseases in the literature surveyed generally agree with our field observations and with questionnaire survey results. However, significant discrepancies

Table 3. The incidence severity of pepper diseases at AVRDC, Taiwan (1987).

Disease	Disease occurrence[1]								
	March	April	May	June	July	Aug	Sept	Oct	Nov.
Virus complex	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +	+ + +
Bacterial leafspot			+	+ + +	+ + +	+ + +	+ + +	+ + +	+
Powdery mildew	+	+ +	+ + +	+ + +	+ +	+	+ +	+ + +	+ + +
Phytophthora blight	+	+ + +	+ + +	+ + +	+ + +	+ +	+ +	+	
Anthracnose			+	+	+ +	+ +	+ + +	+ + +	+ +
Southern blight						+ +	+		
Softrot		+	+	+	+	+	+		
Cercospora leafspot		+	+	+	+	+	+		
Sunscald	+	+ + +	+ + +	+ + +	+ + +	+ + +	+		
Blossom end rot			+	+ +					

[1] + = Incidence not common, severity low; + + = Common incidence with low severity or sporad : occurrence with high severity; and + + + = Common incidence with high severity

were found in southern blight (*Sclerotium rolfsii*), Fusarium wilt (*Fusarium* spp.) and Cercospora leafspot (*Cercospora capsici*). Fusarium wilt and Cercospora leafspot are frequently mentioned in the literature, but they were not found to be important either in the field or in the questionnaire survey. High incidence and severity of southern blight (*Sclerotium rolfsii*) during the summer months had previously been observed in Taiwan (AVRDC. 1987a). However, in an extensive field survey in 1987 it was found only in August and September and its severity was not great. Because of their obvious sporadic occurrence, these diseases will not be given high priority in the AVRDC varietal improvement program. Other fungal, bacterial, and nematode diseases which have not generally been problematic will not have high priority in the AVRDC breeding program.

Insects and Mites

Almost three hundred different insect and mite species attacking pepper plants and fruits at pre and postharvest stages have been reported from different parts of the world (AVRDC. 1989). At AVRDC, the incidence of thrips and mites was highest in the fields which received regular chemical sprays, while in fields without chemical sprays thrips and aphids were most prevalent. Aphids, whiteflies and thrips are also known to be important virus vectors, although the occurrence of whiteflies does not seem to be very common on this crop in Taiwan. In the survey, cutworms and fruitworms were also rated important. Some insect-tolerant genotypes have been reported (Muthukrishnan et al. 1986) but extensive screening needs to be conducted to identify reliable genetic resistance sources before these can be incorporated into the breeding program. In the future, therefore, insect control may have to rely on integrated control measures.

Abiotic Stresses

Pepper has a deep or moderately deep-root system (Lorenz and Maynard. 1980; Weaver and Brauner. 1927), however, water stress problems occur. Flooding is an important production constraint (Figures 1 and 2). Drought stress retards plant and fruit growth, triggers blossom end rot and abortion of fruit and flower, and thereby reduces yield and quality (Greenleaf. 1986; Cochran. 1936). Although irrigation is commonly practiced in major production areas (Table 4), studies should be conducted to better understand how the root system responds to adverse soil moisture conditions, and to identify tolerant genotypes. Genotypes with lodging-tolerant root and shoot architecture would be of great value in developing nonstaking varieties.

Table 4. Irrigation practices in major production areas of hot and sweet pepper.

	Region	Yes	Little	No	Total
Hot pepper	Tropical Asia	22[z]	1	7	30
	Other regions	28	–	5	33
	Sub total	50	1	12	63
Sweet pepper	Tropical Asia	32	0		32
	Other regions	60	0	1	61
	Sub total	92	0	1	93

Source: questionnaire survey. [z]No. of production areas.

High temperature has an adverse effect on fruit-set (Cochran. 1936; Dorland and Went. 1947; Rylski and Spigelman. 1982). Poor fruit-set was believed to be one of the major barriers to the tropical adaptation of sweet pepper. Usually only 5% to 15% of the total flowers which bloom develop to mature fruits, even in hot pepper grown under favorable temperatures. The rate for sweet peppers grown under high or optimum temperature lies in a similar range (Kuo. 1988. personal communication; Lee and Yoon. 1975). Flowering shows cyclic increase and

decrease, and the cycle is largely determined in relation to the number of fruits loaded at a particular time (Kato and Tanata, 1971). In successive monthly plantings at AVRDC, regardless of the transplanting date, flowers on the lower branches were usually observed to develop into fruits. As the plant ages, fruit-set tends to decrease more rapidly during the hot seasons. One clearly observed phenomenon was reduced fruit size in the hot season compared to that in the cool season (Table 5). Sunscald, which is caused by the exposure of fruits to strong sunlight, often becomes a serious problem in sweet pepper production (Greenleaf, 1986; Rabinowitch et al. 1986). Sweet pepper is generally believed to be the most vulnerable among solanaceous vegetables to various kinds of management and environmental shock. As a prerequisite to sweet pepper production in the tropics, the effects of heat and other adverse environmental factors on plant growth and fruit development need to be better understood.

In the tropics, hot pepper seeds are commonly saved from farmers' own fields for the next crop, whereas sweet pepper seeds are almost exclusively purchased from seed shops (Figure 3). Since pepper exhibits a varying degree of cross-pollination, in extreme cases as high as 60% (Csillery et al. 1986), genetic impurity of the seeding materials has to be addressed in breeding and seed production programs. The cleistogamous line discovered by Subramanya and Ozaki (1984) may be a key to secure total self-pollination, if this trait can be successfully incorporated into the cultivated varieties.

Preference Traits

In the questionnaire survey, color, shape in fresh state and size were considered as important fruit quality characters in both hot and sweet peppers regardless of geographical region

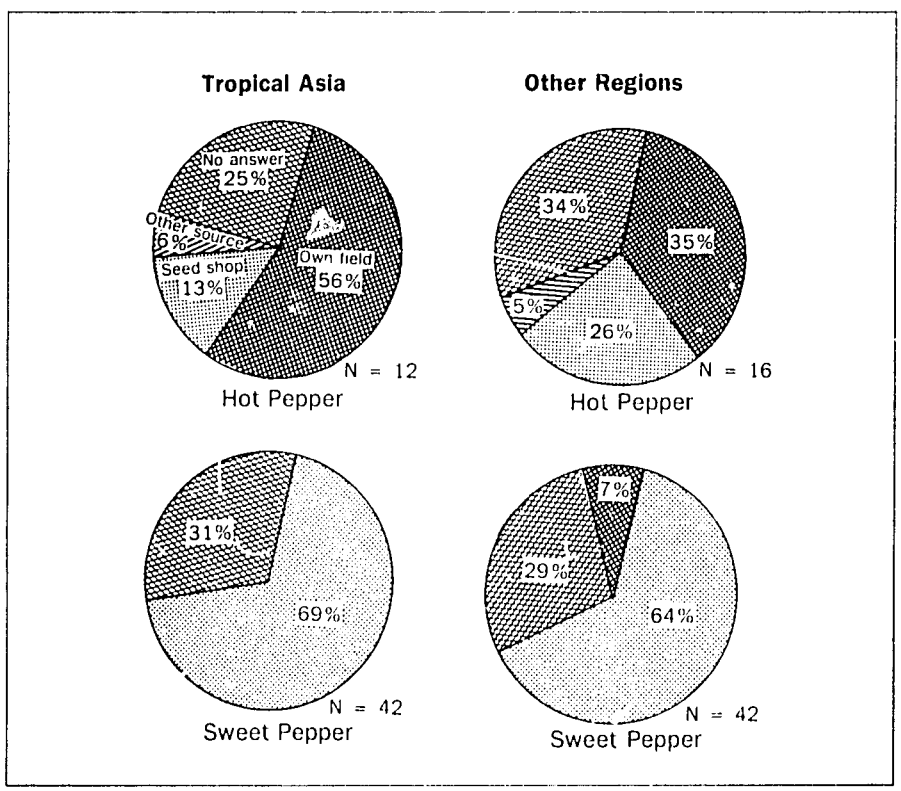

Figure 3. Farmers' seed source (questionnaire survey).

Table 5. Comparison of performance of sweet and hot pepper cultivars[z] in the cool and hot fruiting seasons.[y]

	Hot pepper			Sweet pepper		
	Cool season (C)	Hot season (H)	H/C (%)	Cool season (C)	Hot season (H)	H/C (%)
Total yield (t/ha)	30.6	17.4	57	61.7	19.8	32
Early yield (t/ha)[x]	7.2	12.2	–	18.3	14.3	–
TEY/TY (%)	18.6	73.2	–	30.0	74.0	–
Mean fruit wt. (g)	18.4	10.6	58	92.0	52.7	57

[z]Means of five hot and six sweet pepper cultivars included in both plantings. [y]Transplanting date for cool and hot season was 28 November, 1986 and 28 April, 1987, respectively. [x]Yield within two and three months from first flowering in sweet and hot peppers, respectively.

(Figures 4 and 5). For hot pepper, pungency level and dry fruit shape are also important, while fruit wall thickness is an additional important trait for sweet pepper. The majority of respondents from the Asian tropics and some from other regions favored an increased pungency level of the present hot pepper varieties (Figure 6). The recovery rate after grinding or drying is also an important concern depending upon the usage of hot pepper (Om and Pyo, 1981; Saharan Haji Anang, personal communication). Flavor has been an important preference trait for canned peppers and certain unique aromas are considered essential to peppers for fresh use in certain areas. A high sugar content is much preferred in Korea (Om and Pyo, 1981). In sweet pepper, the bell type fruit of about 100 g weight with dark green skin was favored by the majority of the respondents. Although the elongated fruit, weighing around 20 g and with shiny, strong red color and smooth skin, was widely preferred in hot pepper, its highly diversified utilization pattern makes it difficult or even useless to attempt to determine a single ideal fruit type that is acceptable in many different regions.

Approaches and Progress

Horticulturally, sweet and hot peppers are two different crops. However, they have a great deal in common in terms of nature and problems, mainly because of their close and often overlapping botanical relationship. The hot pepper has been adapted to diverse tropical farming environments for several centuries and has evolved into different plant and fruit types to adapt

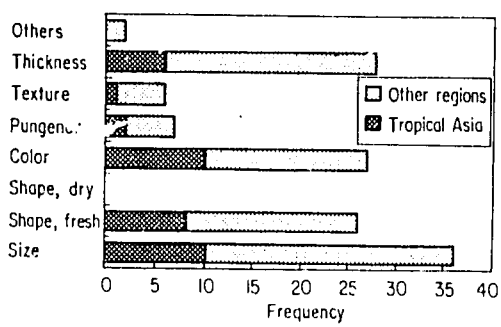

Figure 4. Relative importance of fruit characters of sweet pepper (questionnaire survey).

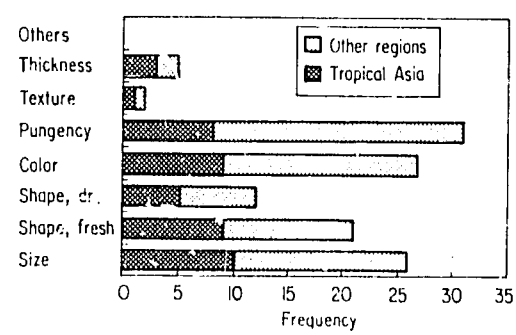

Figure 5. Relative importance of fruit characters of hot pepper (questionnaire survey).

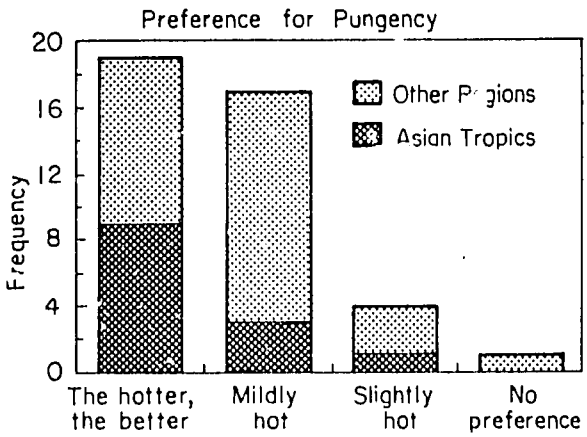

Figure 6.
Preferred pungency level of hot pepper (no. of respondents in questionnaire survey).

to area-specific cropping systems and utilization patterns. Consequently, some important problems are also area-specific. Since hot pepper is an important crop in the tropics in general, many national programs in Asia include this crop as a priority research commodity, although the coverage and capability of these programs may vary from one country to another. It does not seem justifiable for AVRDC to develop finished varieties for different countries. On the other hand, sweet pepper is not an established crop anywhere in the tropical lowlands and it needs to go through a whole process of tropicalization.

As a first step of the crop improvement program, mass screening methods have to be developed in order to identify the desired genotypes for the above important traits among germplasm as well as among segregants. Multiple-resistance screening methods also will be needed to incorporate the multiple resistance into a genotype.

Heterotic effect for important traits is well known in both hot and sweet peppers (Gill et al. 1973; Lippert. 1975; Om and Pyo. 1981). Sweet pepper F_1 hybrids, which are now widely used in temperate countries, also have a higher uniformity than open-pollinated varieties. Hot pepper F_1 hybrids are also being produced in Korea and Taiwan. Some of these have been developed by employing cytoplasmic or genic male sterility (Yoo. 1985). The AVRDC breeding program, however, will focus on the development of open-pollinated varieties, to allow farmers to save their own seeds for subsequent cultivation. Breeding of F_1 hybrids may be considered in the future as the socioeconomic environment in the tropics changes. Meanwhile, AVRDC should prepare to respond to the requests from national programs for male-sterile stocks.

Specific AVRDC strategies for the hot and sweet pepper are described below, followed by the progress made so far.

Approach for Hot Pepper

Hot pepper has a long history of cultivation in many different ecological environments, but has not attracted much attention for germplasm exchange and breeding. With such a crop, there is a good chance of identifying high-performing genotypes by simple trials with landraces collected elsewhere. To facilitate the exchange of material and multilocational trials, an international hot pepper trial network (INTHOPENET) is proposed with AVRDC as the coordinating body (Figure 7). Seeds of the most popular landraces would be provided by the national programs. AVRDC would multiply, purify at least partially, group into different plant and fruit types, and distribute those landraces among participants. Genotypes which out perform the local varieties or possess the desired traits can then be selected. Trial results will be compiled

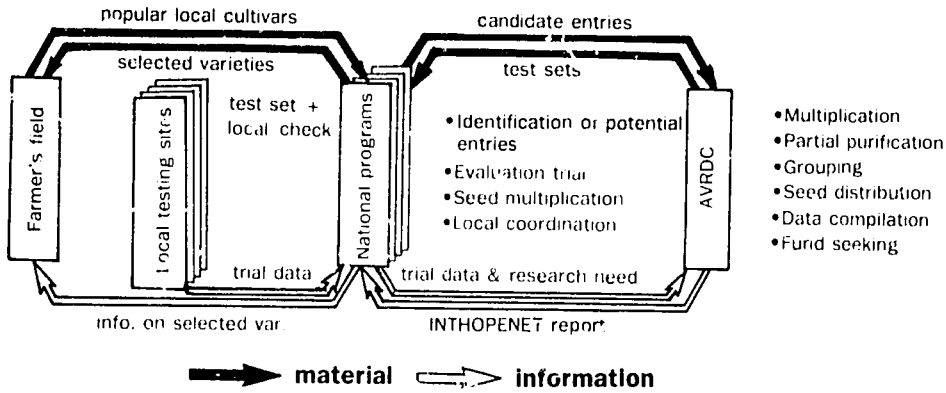

Figure 7. Flow of genetic materials and information in the proposed international hot pepper trial network (INTHOPENET).

by AVRDC and distributed to interested parties. Information generated from the proposed network will also serve to help define AVRDC's role and to establish the most effective scheme of interaction with the national programs. As the breeding programs of AVRDC and national institutes advance, the products of these programs will also become new entries in the network test set.

The major goal of AVRDC's varietal improvement program will be the identification and genetic enhancement of breeding stocks for high yield, high pungency and resistance to important diseases. Viruses, Phytophthora rot, anthracnose and bacterial leafspot are given the highest priorities among diseases. The genetic materials at various stages of enhancement will be provided to the national programs to help tackle their specific problems. Since high pungency and total self-pollination is widely needed in the tropics, AVRDC plans to develop backcross programs to incorporate these traits from less domesticated accessions into horticulturally acceptable plant and fruit types.

Approach for Sweet Pepper

In order to become acclimated to the lowland humid tropics, sweet pepper will have to gain tolerance to heat and other environmental stresses typical of the tropics as well as resistance to major viruses (CVMV, TMV, CMV and PVY), Phytophthora rot, bacterial spot and bacterial wilt. Early maturity and high yield also will be taken into consideration. As discussed above, the effects of heat, moisture, and other environmental stresses on plant growth and fruit development are yet to be studied and defined. Since sweet peppers have been selected and developed mainly for the temperate countries, it is not likely that sweet pepper accessions will be found possessing high stress tolerance or resistance which is critical for adaptation to the tropics.

Based on the above considerations, several concurrent backcrosses for single traits, or whenever possible, for a few important traits, will be the initial thrust. These will be followed by a pyramiding process (Figure 8). Resistances to viruses, bacterial spot, Phytophthora rot and bacterial wilt will be emphasized in the early years. Although not yet fully defined, heat tolerance should be the highest priority. Bell type cultivars selected for high yield and quality under summer conditions will be used as backcross recipients. Since most of the donor parents are expected to be the small-fruited pungent type, removal of pungency and recovery of the size and shape will have to be achieved in the course of the backcrosses.

Progress Made

In 1987, a new field screening method of bacterial wilt (*Psoudomonas solanacearum*) was developed for tomato which later was found applicable also for peppers. A susceptible variety

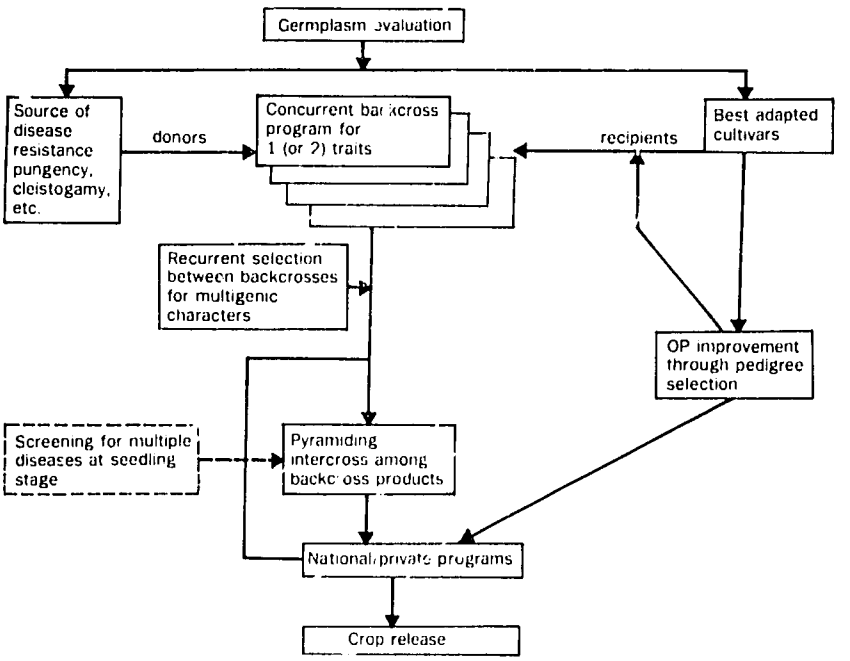

Figure 8. Scheme of sweet pepper varietal improvement.

is sown, mulched with rice hull, and irrigated overhead twice a day until the seeds emerge. At the 5-6 leaf stage, top leaves are cut with a sharp knife and a bacterial suspension of 1×10^8 CFU/ml is sprayed on the plants with a high pressure sprayer (> 25 kg/cm^2). When the seedlings wilt, usually 3-4 days after inoculation, all the plants are ploughed into the soil and the beds are reformed exactly where they were before plowing. Lines to be screened are planted in both outer rows on the three-row beds, while resistant and susceptible checks are planted alternately in the middle row of every bed. Plant mortality rating is carried out once a week for a two-month period starting at the third week from transplanting.

Mass screening for *Phytophthora capsici* is done by drenching pepper plants at the early flowering stage with 100 ml of inoculum with a suspension of 10^3 sporangia/ml. The test plants are grown in clay pots (17.5 cm diameter) together with resistant and susceptible checks.

In Taiwan, *C. gloeosporioides* was found to occur much more frequently than *C. capsici* (AVRDC. 1989). Species or strain distribution in the tropics and the varietal reactions with respect to these two species need to be studied. The method of Park et al. (1986) was found effective to differentiate anthracnose-resistant fruits from susceptible ones. In this method, fruits are washed with sterile distilled water and a central area of skin (5 mm in diameter) is punctured with short fine needles. A suspension of $2.2\text{-}3.1 \times 10^6$ conidia/ml is sprayed or carefully dropped on the punctured area. The fruits are then arranged on a prop in a sealed moisture box containing a small amount of water to provide enough humidity for spore germination and fungal development. The box is kept at room temperature (22°-28°C) for several days to two weeks before the lesion diameter is measured. Fruits at uniform maturing stage have to be used to improve reliability of the data obtained by this method. The method also has been used to test a range of temperatures and the effect of fruit maturity on disease development. Studies now are being conducted to investigate the disease reaction on attached and detached fruit.

Pungency of pepper is caused by a group of chemical compounds called capsaicinoids of which the two most important components are capsaicin and dihydrocapsaicin. In order to develop simple massive assessment methods of these principles, the near infrared reflectance (NIR)

technique (Iwamoto et al. 1984) was tested at AVRDC on two different batches of samples each consisting of 30 genotypes, whose capsaicin content ranged from 0.95 to 10.14 mg/100 g dry powder. A colorimetric method (Om and Pyo. 1981) was adopted to calibrate the NIR (Technican 400). The results show that a correlation coefficient of R = .955 can be obtained for calibration (AVRDC. 1989). The standard error of prediction was estimated as 0.67 and the regression of actual observation on the prediction was 1.02 (Williams. 1975). Although such results strongly indicate that NIR, in which sample preparation needs only drying and grinding, can be an ideal tool for mass screening, more studies are needed to reduce the number of filters used, and to understand the factors affecting pungency data.

Many reported sources for disease resistance have been collected, including those for resistance to nematodes and different strains of TMV and PVY (AVRDC. 1989). They are now in the process of confirmation. Table 6 lists the accessions or varieties which were confirmed at AVRDC as possessing genes for resistance to major diseases or for other important traits. Almost all those listed are hot peppers with various fruit and plant types. Since the AVRDC pepper germplasm collection already includes about 4500 accessions, more sources are expected to be identified or confirmed as studies progress.

Commercial varieties with superior general performance under Taiwan summer conditions had been identified in previous trials (AVRDC. 1987a). Hot pepper cultivars like Farmers Newcomer, Passion, and Hong Shan Ho, and a mild pepper, 672 Hungarian Wax, belong to this group. Sweet pepper cultivars such as Gypsy, Dalbon, Green Boy and Blue Star were found superior in general performance to many others tested (AVRDC. 1987a; 1987b; 1989). The cultivar, All Big was reported to be heat tolerant (IBPGR Secretariat. 1983), but its performance is yet to be confirmed under various tropical lowland conditions. Evaluations are ongoing to search for genotypes with desirable horticultural traits such as high yield and early maturity. Germplasm selected in this category will serve as recurrent parents in the backcross programs mentioned above.

Table 6. Accessions, cultivars or lines confirmed as possessing genes for resistance to major diseases and for other important traits.

Traits	Line or cultivar	Source
Resistance to		
PVMV	HDA 832	INRA, France
Phytophthora rot	C 113, C 2227, C 2230, C 2284, C 2289, C 1176A, TC 3191	USDA
Anthracnose	HDA 295	INRA, France
	Szechuan (OP), New Mexico (OP), Big Jim (OP)	
	Hong Shan Ho (F1), New Comer (F1), Hot Long (F1)	
Bacterial wilt	MC 4, MC 5, Hong Shan Ho[z]	MARDI, Malaysia; F1
High pungency	Habanero (*C. chinense*)	Peto Seed Co., USA
Cleistogamy	PBC 80	Subramanya, USA

[z]Found to be resistant in a field observation under natural infection in Malaysia in 1986.

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Symposium Discussion

L. Black: You stated that anthracnose was a greater problem in hot pepper than in sweet pepper. Is that due to the stage of fruit maturity at harvest or do sweet peppers possess genetic resistance not found in the hot pepper?

J.Y. Yoon: Maturity appears to be related. With a given genotype, the more mature the fruits are, the more susceptible they generally become to anthracnose. Since sweet peppers are more commonly harvested while they are green, selection for resistance to this particular disease may be less advanced than for hot peppers which are mostly harvested at a later maturity stage. The thicker fruit wall of sweet peppers may also contribute to the susceptibility.

J.F. Hadden: What method does AVRDC use to screen for anthracnose or riperot resistance in pepper?

T.C. Wang: The method we have used to screen for resistance is inoculating detached fruit under laboratory conditions. This method may have limitations, because disease reaction of detached fruit may not be the same as disease reaction in the field. We need to investigate this relationship further.

C.M. Messiaen: I suggest that attention be directed also to the leaf-distorting mite (*Polyphago tarsonemus latus*), which attacks peppers in many tropical countries. The symptoms may be mistaken for those caused by viruses. Resistance is available.

J.Y. Yoon: Thank you for this suggestion. We also have found that mites and the virus-like symptoms they cause are an important problem, especially in the fields regularly sprayed with insecticide. If the genetic resistance is confirmed, we shall try to incorporate it into the cultivated varieties.

Breeding for Combined Resistance to Bacterial Wilt and Rootknot Nematodes in Tomato

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Abstract

Tomato cultivation in the tropics and subtropics is severely limited by two important soilborne pathogens, *Pseudomonas solanacearum*, the causal agent of bacterial wilt (BW), and the rootknot nematode *Meloidogyne incognita*. BWR-1, a pure line BW-resistant selection from AVRDC accession L 33 (VC 8-1-2-1), and nematode-resistant varieties Patriot, Pelican, VFN 8 and 864-1-SB, were used as parents in a breeding program to develop fresh-market tomatoes with combined resistance to BW and nematode (N).

All the F_1s between BW- and nematode-resistant crosses were observed to be resistant to both diseases in pot and field tests. The hybrids VFN 8 × BWR-1, IIHR 864-1-SB × BWR-1 and Patriot × BWR-1 exhibited heterotic yields (20-30%) over BWR-1 in wilt-infested fields, indicating that scope exists for exploiting heterosis.

The segregating populations and their respective parents were sown in nematode-infested seed pans. On the 30th day after sowing, the seedlings were evaluated for galling. Only the nematode-resistant progenies were planted in the BW nursery. Segregation ratios in the F_2 of Patriot × BWR-1 for BW and N revealed the absence of independent assortment. Pedigree selection, under challenge inoculation of BW and N, resulted into high-yielding, large-fruited F_7 selections (above 1.5 kg/plant and 80 g average fruit weight) resistant to both diseases.

Introduction

Tropical and subtropical tomato cultivation is severely limited by two important soilborne pathogens: *Pseudomonas solanacearum*, the causal agent of bacterial wilt; and the rootknot nematode, *Meloidogyne incognita*. Both pathogens are also important in India, especially in the state of Karnataka, which is a major tomato growing area in the country. Varieties/lines bred for resistance to rootknot nematode (N) have proven resistant in our tests (Rao and Tikoo. 1975; Reddy et al. 1987). However, this has not been the case with the introductions resistant to bacterial wilt (BW) (Rao et al. 1975). This necessitated a breeding program to develop varieties resistant to the local BW isolates. A pure line selection with a dominant gene for BW resistance (Tikoo et al. 1983) was developed from the AVRDC accession L 33 (VC 8-1-2-1) (Tikoo et al. 1986). There are several reports of BW and N interactions affecting BW resistance in tomato (Temiz. 1968; Jenkins. 1972; Wishnuwardhana. 1979; Napiere. 1980; Goth et al. 1983). Hence, combined resistance to BW and N is important for longer stability and success of a cultivar. The present study details our efforts in this direction.

Materials and Methods

The experimental material consisted of the bacterial wilt-resistant line BWR-1, four nematode-resistant (NR) lines Patriot (PAT), Pelican (PEL), VFN-8 and 864-5B (Table 1). BWR-1 was

Table 1. Characteristics of the parental lines used in this study.

IHR no.	Name	Source	Remarks
663-12-3	BWR-1	IIHR	Pure line developed from AVRDC Acc. L 33 (VC 8-1-2-1); determinate; bacterial wilt-resistant.
915	Patriot	E.V. Wann, South Carolina, USA	Green shoulder; semideterminate; medium large; round, deep red, firm fruits; nematode-resistant.
550	Pelican	USAID, New Delhi, India	Green shoulder; indeterminate; very large, round fruits; big blossom-end scar and radial cracks; nematode-resistant.
864-SB	FAR 82 R F_2	M.A. Stevens, UC Davis, USA	F_8 derivative from the original line; nematode-resistant.
593	VFN-8	C.M. Rick, UC Davis, USA	Determinate; large fruits; medium firm; variable fruit shape; nematode-resistant.
911	T-3615-36-81-Mass	E.V. Wann, South Carolina, USA	Determinate; oblong, firm small fruits; early blight tolerant.

crossed with the four NR lines and the F_1s were tested in BW- and N-infested soils. Pedigree selection was followed in the segregating generations from F_2 to F_7 to select for high yield, average fruit size of above 50 g, and combined resistance to BW and N.

A double cross (BWR-1 × PAT) × (BWR-1 × IHR-911) was obtained in 1985 and advanced to the F_3, and evaluated during the rainy season when early blight (*Alternaria solani*) is most prevalent, in a soil known to carry BW and N. Early blight tolerance in IHR-911 was defined as its ability to retain its foliage beyond 100 days after transplanting with only a few leafspots on its top leaves. By comparison, the susceptible parents suffer severe defoliation with over 75% of leaves being infested.

The above experiments were carried out in a BW nursery. At the beginning of these studies a susceptible variety, Pusa Ruby, was grown in this plot. Twenty-day-old seedlings were inoculated with a tomato isolate of *P. solanacearum* biovar III, suspended in sterile water (10^8 Cfu/ml) after culturing for 48 hours growth on TTC agar medium (Kelman, 1954), using the stem puncture method. When over 95% of the plants had wilted, the plants were plowed under. Subsequently, all breeding materials were planted in this nursery, keeping every sixth row planted with the susceptible check. In order to assure that no escapes were selected, stem puncture inoculation of all plants was carried out in every selection cycle at the 20th day after transplanting. Plants surviving beyond 100 days were selected as BW-resistant. Our earlier studies had indicated this to be the best stage for selection for true BW resistance (Tikoo et al. 1986). F_2 and F_3 progenies were first sown in seed pans where a nematode population of one larva per gram of soil was maintained. On the 30th day after sowing, the seedlings were screened for galling, scoring all galled seedlings as susceptible and only the gall-free ones as resistant. The resistant seedlings were then planted in the BW nursery. During the F_4 stage, 100 g of nematode infested soil (10 larvae/g of soil) was applied per plant in the BW nursery to ensure a uniform spread of nematodes in the soil. This helped in the selection for both BW and N in this plot at the end of the cropping season. This method was used in all the following evaluations.

The F_1s and the parents were grown in a randomized block design with three replications and 10 plants per entry per replication to obtain comparative yield data. The fertilizer applied

throughout the field evaluation was 60 kg N, 35.2 kg P, 14.5 kg K as basal and 60 kg N as a top-dressing 30 days after planting. The spacing was 90 cm between rows and 30 cm between plants. Plant populations used in the segregating progenies from F_3 onwards numbered 40 per progeny.

Results and Discussion

Heterotic F_1s Resistant to BW and N

All four F_1s using BWR-1 crosses with nematode-resistant lines were resistant to both rootknot nematode and bacterial wilt (Table 2). These results confirm the dominance of resistance to bacterial wilt in BWR-1 (Tikoo et al. 1987; Anand et al. 1987). Over 80% of the plants of the nematode-resistant parents did not survive beyond 80 days after planting in the disease nursery plot. No mortality was observed in the case of BWR-1 and the four F_1s even up to 120 days. Peaking of survival rates in the wilt nursery by the 80th day has been repeatedly observed in previous experiments on several wilt resistant lines (Tikoo et al. 1986) as well as on F_1s and parents in an 8 × 8 diallel involving wilt-resistant lines with varying levels of resistance (Anand et al. 1987). Consequently, selection for true resistance to bacterial wilt in a segregating population has been carried out only when the plants selected for yield and other attributes did not show wilting symptoms or oozing until the end of the crop. Resistance to nematodes has been reported to be monogenic dominant (Gilbert and McGuire. 1955; Singh et al. 1974), incomplete dominant (Winstead and Barham. 1957; Fatunla and Salu. 1977) or monogenic recessive (Sidhu and Webster 1973), depending upon the genotypes used. The nematode-resistant sources used in this study have shown monogenic dominant resistance (Table 3).

Differences in yield per plant and average fruit size amongst the entries were significant (Table 2). BWR-1 × VFN8, BWR-1 × 864SB and BWR-1 × PAT exhibited heterotic yields of 57, 36 and 34%, respectively over BWR-1. Fruit weight for the three hybrids was significantly higher than that of BWR-1 (Table 2). These results indicate that it is possible to develop heterotic F_1 hybrids resistant to both nematodes and bacterial wilt. Judicious choice of nematode-resistant parents for better fruit quality and yield, and transfer of the resistance of BWR-1 into better quality cultivars, could substantially improve the quality of F_1 hybrids that were obtained in the current study. Transfer of the bacterial wilt and nematode resistance into diverse genotypic backgrounds would also ensure higher levels of heterosis for commercial exploitation.

Table 2. Yield and other observations on BW and N-resistant parents and their F_1's.

Entry	Yield/plant (kg)	Average fruit wt. (g)	% Survival against BW (100th day)	Galling index[z]		Estimated yield (t/ha)
				Pot	Field	
BWR-1	1.10	63.1	100.0	4.2	4.6	34.9
BWR-1 × PAT	1.43	89.4	100.0	1.0	1.0	46.9
BWR-1 × PEL	1.25	86.5	100.0	1.0	1.0	39.7
BWR-1 × VFN-8	1.73	119.9	100.0	1.0	1.0	54.9
BWR-1 × 864-SB	1.50	55.0	100.0	1.0	1.0	47.6
PAT[y]	0.20	80.5	0.0	1.0	–	–
PEL[y]	0.10	120.5	0.0	1.0	–	–
VFN-8[y]	0.18	110.6	0.0	1.0	–	–
864-SB[y]	0.10	50.0	0.0	1.0	–	–
F value	22.7**	5.64**	–	–	–	–
CD 5%	0.31	19.4	–	–	–	–

[z] 1 = no galling, 5 = severe galling. [y] Nematode resistant lines did not survive beyond 60 days after planting, hence, no estimated yield data is available.

Table 3. Response of F_2 populations to nematodes in pot tests and the resultant resistant progenies to bacterial wilt in wilt-infested soils.

Entry	No. of plants	Fequency[z]		Chi square	P
		R	S		
Reaction to nematodes					
BWR-1 × PAT	150	114	36	0.08	0.7-0.8
BWR-1 × PEL	161	124	37	0.20	0.5-0.7
BWR-1 × VFN-8	147	112	35	0.15	0.5-0.7
BWR-1 × 864-SB	160	123	37	0.36	0.5-0.7
Pooled data	618	473	145	0.77	0.6-0.7
Reaction to BW					
BWR-1 × PAT	94	64	30	2.3	0.1-0.2
BWR-1 × PEL	71	55	16	0.32	0.5-0.7
BWR-1 × VFN-8	90	62	31	4.09	0.05-0.1
BWR-1 × 864-SB	94	63	31	4.09	0.05-0.1
Pooled data	349	244	105	4.8	0.05-0.1

[z]R = No. of plants resistant to BW; S = No. of plants susceptible to BW.

Segregation for Nematode and Bacterial Wilt Resistance

The response of the parental, F_1 and F_2 populations to nematode on the 30th day after sowing is described below:

The NR lines and the four F_1s had a galling index of 1 indicating their resistance (Table 2). BWR-1 had a galling index of 4.2, indicating its high susceptibility. For nematodes, the pooled data of F_2 populations showed a segregation ratio of 473 resistant: 145 susceptible plants (Table 3). The individual F_2 populations as well as the pooled data had a good fit into a 3R : 1S ratio, confirming the well known inheritance pattern for monogenic dominant genetic control of nematode resistance in tomato.

The resultant nematode-resistant seedlings, when planted in the bacterial wilt-infested soil, segregated into 64 resistant (R): 30 susceptible (S) in the case of BWR-1 × PAT; 55 R : 16 S in BWR-1 × PEL; 62 R : 28 S in BWR-1 × VFN-8; and 63 R : 31 S in BWR-1 × 864-SB (Table 3). Except in the case of BWR-1 × PEL, none of these ratios fit the 3 R : 1 S ratio for bacterial wilt resistance. BWR-1 is known to possess a single dominant gene for bacterial wilt resistance (Tikoo et al. 1983) in the absence of nematodes. The deviation from the expected ratio was a consequence of an excess of susceptible plants. Since the F_2s were grown in nematode-infested seed pans before planting in the field, nematodes could possibly have predisposed to BW some of the plants which, otherwise, should have been resistant.

In a sequential inoculation study of this interaction in these crosses, Nirmala Devi (1987) observed that the digenic ratio for resistance to bacterial wilt and nematodes fit into a 9:3:4 ratio. This was attributed to parasitic epistasis similar to that reported by Sidhu (1984) in the case of Fusarium wilt and nematode resistance in tomato.

Development of Lines Resistant to Both BW and N

F_2 populations of BWR 1 × PAT and BWR-1 × PEL were evaluated for yield, fruit size, color, firmness and general vigor. None of the plants in BWR-1 × PEL merited further advancing because of poor fruit quality, evidenced by severe radial cracks, soft fruits, and poor color. From the F_2 of BWR-1 × PAT, five individual plant selections were made (Table 4). Two of these plants exceeded the parents for average fruit weight, indicating transgressive segregation. The reaction of F_3 progenies from these plants to rootknot nematodes, and that of the resultant resistant seedlings to bacterial wilt, is presented in Table 5. This indicates that while plants 4

Table 4. Yield and other observations on F_2 selections in the cross BWR-1 × PAT having BW and N resistance.

F_1 plant no.	Yield/plant (kg)	Fruits/ plant	Average fruit wt. (g)	Remarks
4	1.21	11	110.0	Green shoulder, semideterminate, good color
5	2.30	23	100.0	Determinate, excellent external and internal color, fewer leafspots, medium firm, large fruits
6	1.80	30	60.0	Green shoulder, good color, medium firm, semideterminate
40	1.95	30	65.0	Green shoulder, medium firm, semideterminate
51	1.68	21	80.0	Green shoulder, medium firm, large fruits
55	0.81	18	45.0	Excellent color, large
Parents				
BWR-1	1.10	17	63.1	When grown in BW and N-infested plot
PAT	0.95	12	80.0	When grown in nematode-infested plot

Table 5. Reaction to rootknot nematodes and bacterial wilt in F_3 of BWR-1 × PAT.

Code no.	Pedigree	Reaction to Nematodes R : S	Reaction to BW[z] (total/healthy)
84 BWR 59	BWR-1 × PAT F_1 BK-4	35 : 15	30/30
84 BWR 60	BWR-1 × PAT F_1 BK-5	28 : 12	28/26
84 BWR 61	BWR-1 × PAT F_1 BK-6	34 : 0	30/20
84 BWR 62	BWR-1 × PAT F_1 BK-40	26 : 0	26/26
84 BWR 64	BWR-1 × PAT F_1 BK-55	40 : 0	21/18

[z]At 120 days after transplanting

and 5 were heterozygous for nematode resistance, the rest were homozygous. The resultant progenies, except plant 6, showed very high levels of resistance to bacterial wilt. Pedigree selection in these populations was continued up to F_7 laying emphasis on yield, fruit size and other physical attributes besides the combined BW and N resistance. The best progenies were developed from the F_2 plants 4 and 5 (Table 6). Fruit size increase over the larger-fruited parent Patriot was from 21 to 111%. These results prove that transgression for fruit size can be stabilized.

Three plants were selected from the F_2 population of the double cross (BWR-1 × PAT) × (BWR-1 × IHR 911) for BW + N resistance, a high level of tolerance to early blight, and high yield. From the progeny of these plants, six plants with resistance to bacterial wilt and nematodes and tolerance to early blight were selected, data on which are presented in Table 7. Once again transgression for both yield and fruit size is evident. Most of these plants were observed to be very vigorous. Some of these were very firm, with uniformly deep red and oblong fruit like the early blight tolerant parent IHR-911. Their progenies could also be used for the development of cultivars suitable for processing.

Conclusion

The present study has thus led to the following observations:

1. Heterotic F_1 hybrids resistant to both bacterial wilt and rootknot nematodes were developed. By transferring the wilt resistance of BWR-1 to better genotypes/cultivars, fruit quality could be improved.

Table 6. Yield and other attributes of a few promising bacterial wilt and nematode-resistant F_7 families and individual plant selections from the cross BWR-1 × PAT during 1987 as compared to BWR-1.

Line no.	Original F_2 plants (no.)	Plants planted (no.)	Fruits/ plant (no.)	Yield/plant	Average fruit size	Characters
Progeny averages						
84 BWR 59-8-5-1-BK	4	40	13.8	0.94	76.4	Round, semideterminate, medium firm, good color very much less rotting
84 BWR 59-8-SB-SB-SB	4	40	18.8	1.96	104.3	Round, semideterminate, medium firm, good color, very much less rotting
84 BWR 59-13-11-12-SB	4	40	16.0	1.99	121.0	Round, medium firm, deep red, no green shoulder
84 BWR 59-13-11-1-SB	4	40	13.8	0.94	76.4	Late, no green shoulder, semi-determinate, Sq. Rd.
84 BWR 60-4-7-BK-BK	5	40	4.9	0.68	143.6	Round, no green shoulder, semideterminate, deep red, few cat face fruits
Individual plant selections from above						
84 BWR 59-8-5-1-3	4	–	7.0	1.0	142.9	No green shoulder, Sq Rd., deep red, medium firm
84 BWR 59-8-SB-5B-16	4	–	24.0	2.9	120.8	No green shoulder, round, medium firm, deep red
84 BWR 60-4-7-BK-14	5	–	17.0	2.5	144.1	Round, no green shoulder, semideterminate
84 BWR 60-8-8-2-11	5	–	8.0	1.2	180.0	Round, determinate, no green shoulder, soft

Table 7. Yield and other attributes in BW- and N-resistant F_3 selections from the double cross (BW-1 × PAT) × BWR-1 × IHR-911.

Line/parents	Fruit/plant (no.)	Yield/plant (kg)	Av. fruit wt. (g)	EBT[z]	Characters
Selected F_3 plants					
BWR 57-BK-1-5	36.0	3.20	88.9	Good	No green shoulder, semideterminate, deep red, firm
BWR 57-BK-1-11	23.0	2.30	100.0	Good	No green shoulder, semideterminate, firm, deep red, vigorous branches
BWR 57-BK-2-4	37.0	2.08	56.2	Good	Green shoulder, determinate, no rot, early, dark green leaves
BWR 57-BK-2-8	21.0	1.90	90.4	Good	Green shoulder, determinate, vigorous branches, firm
BWR 57-BK-2-12	30.0	2.20	73.3	Good	Green shoulder, semideterminate, vigorous branches, deep red, firm
BWR 57-BK-2-15	23.0	1.98	85.9	Good	Green shoulder, semideterminate, vigorous branches, deep red, firm
Parents					
BWR-1	14.4	1.10	76.3	Poor	Round, determinate, soft fruits
Patriot	12.0	1.02	85.0	Poor	Round, green shoulder, semideterminate, firm
IHR 911	25.0	0.88[y]	35.0	Good	Oblong, no green shoulder, firm, determinate, deep red, BW susceptible

[z]Early blight tolerance. [y]Yield recorded in wilt-free field.

2. Preselection for nematode resistance in nematode-infested seedling beds proved effective. This helps in handling a larger number of crosses and reduces the area required per cross for field evaluation.
3. Pedigree selection was effective in selection for resistance to both diseases.
4. With the development of advanced lines which are resistant to both bacterial wilt and nematodes, it should become possible to develop tomato hybrids in India with multiple disease resistance. For example, resistance to Fusarium wilt and Septoria leaf spot, which is dominantly controlled in both cases, could be added to the F_1 hybrids.

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12

Breeding of Processing Tomatoes with Genetic Resistance to Rootknot Nematodes (*Meloidogyne incognita*)

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Abstract

Three new cultivars — Uco 2 INTA, Uco 3 INTA, and Uco 4 INTA with genetic resistance to rootknot nematodes (*Meloidogyne incognita* Kofoid et Chitwood) have been obtained at La Consulta Experiment Station after eight years of selection by pedigree method. The material used in the breeding program originated from the two-way cross between Rossol and UC 82 B. Uco 2 INTA has pear-shaped fruits which are suitable for canning as whole peeled tomatoes. Uco 3 INTA yields elongated and pointed fruits which may be canned as whole peeled tomatoes after size screening. Uco 4 INTA has square-round fruits which are also suitable for canning as whole peeled tomatoes after size screening, provided the plants are grown at a high density. Although the firmness and the resistance to over-ripening of the fruits of the new varieties are lower than for those of UC 82 B, they are better than those of Rossol, a fact that has been noted since the early stages of selection. Moreover, when cropped in nematode-infected areas the new cultivars have shown that they are better choices for growers than those derived from either susceptible, firm-fruited cultivars or resistant, soft-fruited cultivars. These new materials are currently being distributed among farmers in the various tomato production areas in the country.

Introduction

Resistance to rootknot nematodes was first observed in 1941 in *Lycopersicon peruvianum* (Bailey, 1941). The barrier that prevented the introduction of resistance into the cultivated *L. esculentum* was overcome when Smith (1944) obtained the interspecific hybrid through embryo culture. A single dominant gene was later named *Mi* (Gilbert and McGuire, 1955, 1956); however, it has been demonstrated that the dominance is incomplete (Barham and Winstead, 1957). By using the backcross method of breeding, the rootknot nematode-resistant cultivars VFN 8 and Anahu were developed (Medina Filho and Stevens, 1980). Almost all current resistant cultivars originate from either one of these two sources.

Argentina produces about 350,000 t of processing tomatoes annually. The leading producing areas are the provinces of Mendoza, Río Negro and Santiago del Estero. Mendoza has about 10,000 ha of the crop and the following climatic and agronomic conditions: 270 mm of rain annually, particularly concentrated in the growing season, and temperature extremes of 36.7°C and -11.1°C. The frost-free period lasts five to six months, from October to April. The crop is established almost completely by transplanting. The harvest begins early in February. The dominant pest is rootknot nematode. As a consequence, Ronita and Rossol (Pecaut and Laterrot, 1969, 1970) were the most popular cultivars for many years. More recently, Uco 1 INTA (Crnko and Gallardo, 1978, unpublished) were planted. During the last few years, varieties with firm fruit and thick pericarp (which are, however, not resistant to rootknot nematodes), have become

increasingly popular with the processing industry. As a consequence, several crops established in infested soils were lost and the growers suffered not only from the loss of the crop but also from the high cost of the chemicals used to control the pest (Gallardo et al. 1982). The climatic conditions of Río Negro province are similar to those of Mendoza. Spotted wilt is the major disease in this area. The crop is established by direct seeding. The most popular variety is UC 82. Santiago del Estero is a warmer province which has the following climatic conditions: 552 mm of rain per year, concentrated during the last period of the crop (November and December), and temperature extremes of 45.1°C and -7.2°C. The frost-free period is about nine months, from September to May. Direct seeding is the predominant technique for establishing the crop. Rootnot nematode is the major pest in this area.

Average yields of tomatoes are similar in all the producing areas of the country at about 18 t per hectare. Nevertheless, some good growers are able to produce more than 50 t per hectare.

Materials and Methods

The material used in the breeding program originated from the two-way cross between Rossol and UC 82 B (Figure 1). The hybrid population was subsequently handled by the pedigree method. Rossol was chosen as a parent because it carries the *Mi* gene for resistance and because of its suitability for the management conditions in Argentina. Moreover, Rossol is well adapted to the requirements of the processing industry in the country, particularly because it is harvested sequentially. The other parent, UC 82B, was chosen because of its outstanding yield in nematode-free areas, its firm and well colored fruits, and its good plant coverage. The main selection objective was to obtain rootknot nematode-resistant plants with fruits firmer than those of Rossol. The selection was oriented towards a plant with good cover, pear-shaped or square-round fruits, with thick pericarp, good internal and external color, and with good vine retention at maturity. Characteristics such as earliness, vigor, health, yield, and processing properties were also considered.

For nematode resistance screening, an adaptation of the method described by Laterrot (1968) was used. Lines selected for their good horticultural attributes were sown in plastic flats, seven rows each and twelve seeds per line. The soil was steam-sterilized before sowing. One nematode gall, including eggs, was placed at 1 cm depth beside each emerging seedling. Plants were kept in a chamber where temperatures were between 16 and 27°C. Four to five weeks after the inoculation, the seedlings were pulled out. After rinsing the roots, the root damage caused by nematodes was evaluated in each plant according to the following classification: 0 = no galls; 1 = rare and minute galls; 2 = several galls and 3 = galls in clusters. Plants classified as resistant (nematode damage 0 and eventually 1) were then transplanted to the field in summer or to the greenhouse in winter.

Results and Discussion

Three nematode resistant cultivars, Uco 2 INTA (Figure 2), Uco 3 INTA (Figure 3) and Uco 4 INTA (Figure 4) were obtained after eight years of breeding. The main characteristics of these cultivars are shown in Table 1. Their processing characters are shown in Table 2. A final confirmatory nematode test was performed on the plants coming from foundation seeds of each of the three cultivars (Table 3).

Although the firmness and resistance to over-ripening of the fruits of the new varieties are less than those of UC 82 B, they are better than those of Rossol, a fact that was observed since the early stages of selection. Moreover, when grown in nematode-infested areas, the new cultivars have shown that they are better alternatives for growers than nonresistant, firm-fruited cultivars, or resistant, soft-fruited ones.

Fig. 1. Root systems of an early resistant line and its parents (left: UC 82B; middle: Rossol; right: resistant line).

Fig 2. Uco 2 INTA.

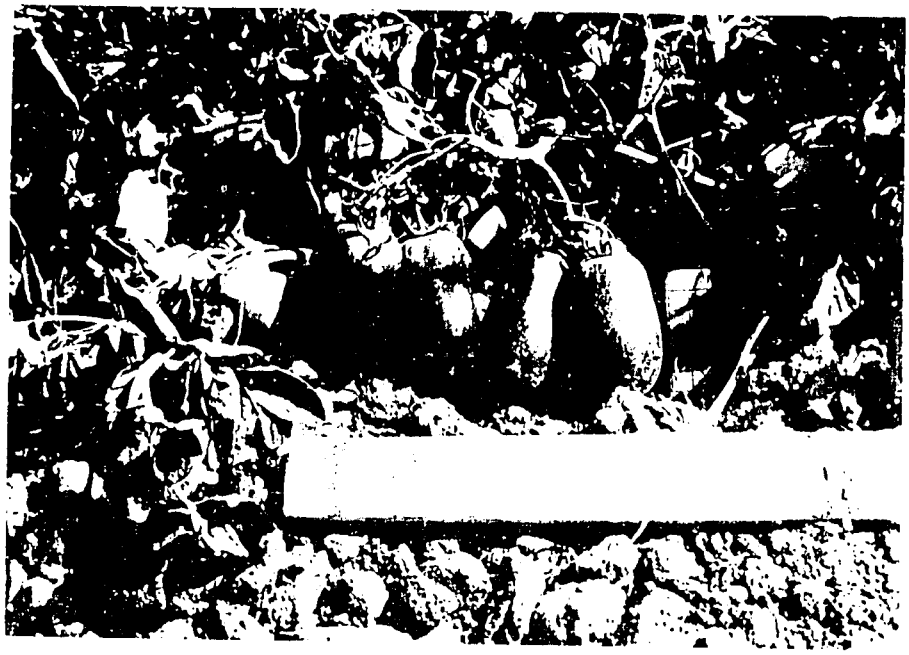

Fig. 3. Uco 3 INTA.

Fig. 4. Uco 4 INTA.

Table 1. Main characteristics of the fruits and plants of the new cultivars and their parents.

Characteristics	Uco 2 INTA	Uco 3 INTA	Uco 4 INTA	Rossol	UC 82 B
Parents	UC 82 B × Rossol	Rossol × UC 82 B	Rossol × UC 82 B		
Plant					
Habit	sp[z]	sp	sp	sp	sp
Size	medium	medium	medium	large	small
Growth	erect	erect	prostrate	erect	prostrate
Vine cover	moderate	moderate	good	moderate	very good
Stem					
Branching	moderate	moderate	moderate to profuse	moderate	profuse
Fruit					
Fruits per truss	5 or more	5 or more	5 or more	4 or more	5 or more
Length/width	1.40	1.70	1.23	1.48	1.0
Number/kg	16	15	14	17	14
Shape	oblate-pear	elongated, pointed	square-round	oblate-pear	square-round
Color (Agtron E-5)	34	31	30	31	30
Shoulder color	uniform	uniform	uniform	uniform	uniform
Pericarp	thick	thick	medium	medium	thick
Firmness[y]	3	4	3	2	5
Pedicel					
Joint	yes	yes	yes	yes	yes
Length (mm)	15	12	12	8	13
Stem retention (%)	25	23	23	50	17
Other					
Disease resistance[x]	V, F1, N	V, F1, N	V, F1, N	V, F1, N	V, F1, F2
Processing use	whole peeling or puree	whole peeling or puree	whole peeling or puree	whole peeling or puree	whole peeling or puree
Ripening	extended	extended	concentrated	extended	concentrated
Average yield (t/ha)	40	45	40	40	50[w]

[z]Determinate. [y]Subjective assessment of fruit resistance to pressure exerted by fingers, scale from 1 (least consistent) to 5 (most consistent). [x]Verticillium wilt; F1 = Fusarium wilt, race 1; F2 = Fusarium wilt, race 2; N = nematode. [w]In nematode-free soils.

Table 2. Processing characters of the new cultivars and their parents.

	New cultivars			Parents	
	Uco 2 INTA	Uco 3 INTA	Uco 4 INTA	UC 82 B	Rossol
Juice yield (%)	88	86	89	77	88
pH	4.45	4.03	4.10	4.05	4.30
Acidity (%) (citric acid)	0.36	0.48	0.48	0.37	0.45
°Brix	5.1	5.0	5.1	4.8	5.0
Total solids (TS)	5.8	5.7	6.0	5.1	5.5
Soluble solids	5.1	5.1	5.3	4.7	5.0
Water insoluble solids (WIS)	0.74	0.58	0.64	0.49	0.53
(WIS/TS) × 100	12.7	10.2	10.7	9.5	9.7
Agtron value (E-5)					
Peeled fruit	25	26	25	24	22
Juice	27	33	28	21	26

Table 3. Rootknot nematode resistance of the new cultivars and their parents.

Cultivar	Disease rating[z]			
	0	1	2	3
	Number of plants[y]			
Uco 2 INTA	9.75	0.5	0	0
Uco 3 INTA	9.5	0	0	0
Uco 4 INTA	8	0	0	0
UC 82 B	0	0	0.25	8.5
Rossol	10.5	0	0	0

[z]0 = no galls; 1 = rare and minute galls; 2 = several galls, and 3 = galls in clusters. [y]Mean of 4 replications.

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Symposium Discussion

J.C. Girard: Are your varieties also resistant to bacterial wilt?

G.S. Gallardo: No.

13

Breeding for Resistance to *Scrobipalpula absoluta* (Meyrick) among *Lycopersicon* Accessions in Brazil

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Abstract

Scrobipalpula absoluta (Meyrick) (Lepidoptera: Gelechiidae) is the main pest endangering the tomato industry in Brazil and is posing a serious threat because very few insecticides are efficient in its control. Investigations were conducted leading to the identification of resistance to *S. absoluta* among *Lycopersicon* accessions in our breeding program. Free-choice tests in greenhouse and field using commercial cultivars, *Lycopersicon esculentum* accessions and wild species demonstrated that *L. hirsutum* f. *typicum* (PI 126445, PI 127826, PI 127827), *L. hirsutum* f. *glabratum* (PI 126449, PI 134417, PI 134418) and *L. pennellii* (LA 716) were highly resistant independent of the insect population pressure. Commercial cultivars Angela Gigante, Rio Fuego, Floradade, Olho Roxo, Europeel, Calypso, Petomech, Rossol and the *L. esculentum* accessions (PI 124036, PI 140412), *L. esculentum* var. *cerasiforme* (PI 129154) and *L. pimpinellifolium* (PI 126436, PI 126925, PI 126931) were completely destroyed even when exposed to moderate populations of *S. absoluta*. Selected wild *Lycopersicon* accessions crossed and back-crossed to commercial varieties produced progenies that had a degree of damage that differed from both parents, indicating genetic progress in the levels of resistance in relation to the susceptible *L. esculentum*. Physical barrier due to the presence of trichomes, changes in normal larval behavior, adult avoidance to oviposition, larval intoxication and high pupal mortality appeared to be associated with the resistant wild accessions identified here.

Introduction

Scrobipalpula absoluta (Meyrick) is the major pest in Brazilian tomato production (Souza et al. 1983). Few insecticides are efficient in its control and even under regular spraying damage may vary from 14% to 68%. Losses and complaints are frequent among tomato growers (Barbosa et al. 1985; Haji et al. 1986). *S. absoluta* feeds in the foliar parenchyma, stems and fruits and may reach three to five generations during the growing season (Coelho and Franca. 1987). It is a very recent tomato pest in Brazil. It was first recorded in October 1980 near Jaboticabal, SP (Moreira et al. 1981), and in the next year it was found destroying processing and fresh-market tomatoes in the semiarid region 2,000 km away (Moraes et al. 1982). In autumn 1982 it was reported as the most serious threat to the tomato industry in all major production areas in the country. Such a fast spread was mostly possible due to the characteristics of tomato commercialization in Brazil, in which the produce is transported by trucks over long distances.

Glandular trichomes and alkaloids present in many wild *Lycopersicon* accessions and cultivated tomatoes are known to defend plants against spider mites (Stoner et al. 1968; Snyder and Carter. 1984), aphids and their relatives (Gentile et al. 1968; Williams et al. 1980), coleopterans (Kennedy and Dimock. 1983), and lepidopterous larvae (Williams et al. 1980;

Dimock and Kennedy. 1983). Resistance in the genus *Lycopersicon* has been associated with increased pest mortality (Juvik and Stevens. 1982c; Kennedy and Dimock. 1983), longer developmental time (Juvik and Stevens. 1982c), decreased food acceptance (Kennedy and Dimock. 1983), host evasion (Gentile et al. 1968; Stoner et al. 1968; Aina et al. 1972; Snyder and Carter. 1984), change in behavior (Stoner et al. 1968), reduction in oviposition (Aina et al. 1972; Gentile et al. 1969) due mainly to entrapment (Stoner et al. 1968; Gentile et al. 1969), ingestion of toxic compounds (Duffey and Isman. 1981; Kennedy and Yamamoto. 1979), fumigant action (Dimock and Kennedy. 1983) or simple presence of a physical barrier. *Lycopersicon pennellii* and *L. peruvianum* have been identified as promising sources of resistance to *S. absoluta* (Castelo Branco et al. 1987; Lourencao et al. 1984) and *L. pennellii* and *L. hirsutum* have been found to be resistant to other very closely related gelechiids (Schuster. 1977; Schuster et al. 1979; Juvik et al. 1982a).

We report here the results of experiments designed to identify sources of resistance to *S. absoluta* among *Lycopersicon* accessions, some of the factors which might be involved in the resistance, and evidence that genetic progress in the levels of resistance in relation to the commonly cultivated tomato in Brazil can be attained.

Materials and Methods

General Procedures

Twenty-two sources of germplasm were used in the preliminary screening and other studies. They are the commercial varieties: Angela Gigante, Rio Fuego, Floradade, Olho Roxo, Europeel, Calypso, Petomech and Rossol; *Lycopersicon esculentum* accessions: PI 124036 and PI 140412; *L. esculentum* var. *cerasiforme*; PI 129154; *L. pimpinellifolium*: PI 124436, PI 126925, and PI 126931; *L. hirsutum* f. *typicum*: PI 126445, PI 127826 and PI 127827; *L. hirsutum* f. *glabratum*: PI 126449, PI 143417 and PI 134418; *L. pennellii*: LA 716; and a hybrid *L. esculentum* (Calypso) × *L. pennellii*. Two BC_1S_2 *L. esculentum* × *L. pennellii* selections (264-6-A and 264-11-A) and 10 hybrids (F_1, F_2BC_1, F_3) of *L. esculentum* × *L. pimpinellifolium* (PI 732293-V), *L. esculentum* × *L. hirsutum* f. *typicum* (PI 127826) and *L. peruvianum* (PI 128650) from the breeding program for virus resistance at the Centro Nacional de Pesquisa de Hortalicas (CNPH) were field evaluated for resistance to *S. absoluta*. The accessions with PI code were obtained from Richard L. Wilson, USDA-Plant Introduction Station, Ames, Iowa. *Lycopersicon pennellii*, LA 716 seeds were provided by Dr. Charles M. Rick, University of California, Davis. These plant materials were solicited based on their relative success as source of resistance to many arthropods under greenhouse or field evaluations conducted mostly in the United States. Commercial cultivars used here were purchased from Brazilian seed dealers.

Seedlings were obtained from seeds sown in seedbeds established in peat-sand soil mixture supplemented with NPK 4-14-8 formula and grown under field conditions. Diurnal temperature in greenhouse and field fluctuated from 18-22°C to 22-26°C, and 50 to 80% relative humidity with 11 to 13 hours photophase during winter and summer months, respectively. Few *L. hirsutum* accessions needed a pregerminative stage prior to sowing. In this case, seeds were left overnight on paper filter saturated with water in petri dishes. Plants were transplanted either to pots (4 kg peat-sand soil 2 mix) or field fertilized with NPK formula (4-14-8 + 0.05% Zn; 2 t/ha) 22 to 25 days after sowing (d.a.s.) when they were 15-18 cm tall with four to six leaves. Wild *Lycopersicon* accessions generally were sowed one week to 10 days in advance to commercial cultivars in order to have compatible development. Potted plants in the greenhouse were stalked and pruned to one main stem when needed for ease of handling. Field plants were not stalked and were furrow irrigated. There was no need for fungicide treatment and no insecticides or acaricides were used during these investigations.

Eggs, larvae, pupae and adults were obtained from natural populations collected mainly as larvae and pupae from commercial production areas in Brasilia, DF. They were maintained

on tomato plants cultivated all year round in the field or greenhouse. Insects for each experiment were assured through use of spreader plants heavily infested with *S. absoluta*. Plants were either cut or kept alive and disposed between rows or plants in the greenhouse or field three to five days after transplanting. Field infestation was assured also by planting susceptible tomato nearby the experiment area.

Screening Tests in Greenhouse

1. Twenty-one accessions and cultivars were evaluated and only LA 716 from those listed above was not used here. Each genotype was replicated nine times and each plant was measured and the number of leaves determined. Larvae and mines per plant were counted 35, 55 and 70 d.a.s. Eggs were counted in the top three leaves in plants 70 d.a.s.

2. Only the cultivar Rossol was not tested in this screening when seven replications were used. The evaluations made anteriorly were repeated with 55 d.a.s. plants. In addition, each plant was graded visually, by rating leaf and plant damage using a scale from one (no damage) to five (complete destruction). Four people graded 35 d.a.s. plants (moderate insect population) and three people graded 55 d.a.s. plants (high insect population) independently.

Assessment of Host Resistance

Preference test. Twelve randomized plants each of Angela Gigante, Calypso, Floradade and Olho Roxo, *L. esculentum* var. *cerasiforme* (PI 129154), *L. pimpinellifolium* (PI 126436), L. *hirsutum* f. *typicum* (PI 127826, PI 127827), *L. hirsutum* f. *glabratum* (PI 134417, PI 134418), *L. pennellii* (LA 716) and the hybrid Calypso x LA 716 were exposed to very high insect population over four days. Plants were at the same age and they had no prior contact with the insect before being placed in the greenhouse. Eggs were counted on several leaves of similar maturity and from equivalent plant position. These leaves were removed and measured on LI-3000 leaf meter. The number of eggs was recorded for 100 cm^2.

Antibiosis test. Plants were maintained under heavy insect infestation for 15 days. After that period, all pupae found on leaves in each plant were collected, measured, weighed and placed in petri dishes with moist filter paper. Percent adult emergence was recorded.

Breeding and Further Screening

Greenhouse. *Lycopersicon esculentum* Calypso × *L. hirsutum* f. *typicum* (PI 127826) hybrids were back-crossed to Calypso. Four hundred plants F_2BC_1 [(Calypso × PI 127826) × Calypso)] were obtained and evaluated for resistance to *S. absoluta* 85 d.a.s. Three hundred heavily infested Rio Fuego plants placed among test plants 35 days prior to evaluation insured enough insect pressure. Fourteen plants were selected visually and had the number of mines and larvae recorded. For comparative purposes a sample of 10 plants from each Rio Fuego and F_2BC_1 population were also evaluated using the same criteria. Nine of those selected plants failed to produce fruits and/or seeds. Five produced seeds and plants were obtained as described earlier. These progenies, named MMX 196-4-B, MMX 196-6-B, MMX 196-9-B, MMX 196-11-B and MMX 196-14-B, were then compared to their parents, Calypso and PI 127826. The criterion for evaluation was based on a rating scale of scores varying from one to five, for leaves and plants separately. Each plant was scored individually by three people.

Field. Ten plants of each commercial cultivar and an advanced hybrid selected previously as virus tolerant were planted 0.5 m spaced within rows each 1.0 m apart. Seven replications were used. The number of mines in the first fully expanded leaf at the top was recorded in each plant.

Statistical Analysis

First screening data was processed by analysis of variance and by decomposing the degrees of freedom of the dependent variables number of mines, larvae and eggs, corrected by the variables plant length and number of leaves. All the remaining data were analyzed by analysis of variance, Duncan's multiple range test, or the LSD test (P = 0.05) after transformation, as necessary, to $\sqrt{x + 0.5}$.

Results and Discussion

Screening Tests in Greenhouse

i. The number of mines, larvae and eggs was a useful parameter to discriminate between susceptible and resistant germplasm (Table 1). There were measurable differences among wild *Lycopersicon* species (group 1 × group 2). Any of these accessions included in group 2 (Table 1) would be useful sources of resistance to *S. absoluta* and could be used as parents in a breeding program. However, we found that countings alone could be misleading in some circumstances. Number of mines/leaf/plant depend on cultivar, plant age, insect population and size of lesion caused by larvae. Resistant accessions in some cases presented a very high number of small lesions, whereas lesions in susceptible cultivars generally coalesced, making it difficult to record the exact number of mines. Extensive damage may also imply early pupation by *S. absoluta* larvae and in addition may make the plant less attractive to adults for oviposition. Crude countings of live specimens or damage to them do not represent the differences that experienced eyes can distinguish quite easily (Table 2). Although the quantitative approach to measure the differences among accessions was useful in this case, there was a real need for another way to evaluate plants, to facilitate and improve accuracy in future screenings, when probably differences among plants in more advanced generations might not be easily perceived.

Table 1. Partial sum of squares and F values from analysis of variance of the number of mines, larvae and eggs of *S. absoluta* on plants of *Lycopersicon* accessions, Brasilia, DF, 1983.

Source of variation		Dependent variables					
		Mines[z]		Larvae[z]		Eggs[z]	
	df	SS[y]	F value[x]	SS[y]	F value[x]	SS[y]	F value[x]
1. Cultivars vs accessions	1	12151.1	ns	937.9	5.2*	240350.1	21.9**
2. Between cultivars	7	82164.1	2.7**	3540.5	2.8**	204094.4	2.6*
3. Between wild accessions	12	413932.5	8.1**	15652.4	7.3**	594524.1	4.5*
4. Group 1 vs group 2	1	413932.5	ns	937.9	5.2*	240350.1	21.9**
5. Within group 1	5	12151.1	8.0**	8932.2	10.0**	157861.7	2.8*
6. Within group 2	6	169524.7	ns	640.2	ns	386536.1	5.8**
7. *L. hirsutum* vs hyb. *L. pennellii*	1	24218.7	ns	19.3	ns	207865.4	18.9**
8. Between *L. hirsutum*	5	7736.1	ns	640.1	ns	198914.5	3.6**
9. *L.h. typicum* vs *L.h. glabratum*	1	19715.9	ns	492.7	ns	143409.8	13.0**
10. Between *L.h. typicum*	2	12253.7	ns	43.7	ns	61952.3	ns
11. Between *L.h. glabratum*	2	15400.5	ns	56.2	ns	3267.8	ns

[z]Mean no. of mines, larvae and eggs recorded on plants 70 d.a.s. [y]Partial sum of squares. [x]ns, *, **Non significant (ns) or significant at 5% (*) or 1% (**) levels. [w]Group 1: *L. pimpinellifolium* (PI 126925, PI 126436, PI 126931); *L. esculentum* (PI 124036, PI 140412); *L. e.* var. *cerasiforme* (PI 124036). Group 2: *L. hirsutum* f. *typicum* (PI 126445 PI 127826, PI 127827); *L. hirsutum* f. *glabratum* (PI 126449, PI 134417, 134418); *L. pennellii* (LA 716).

Table 2. Number of larvae, mines and degree of damage caused by *S. absoluta* on *Lycopersicon* accessions, processing and fresh-market tomato cultivars, Brasilia, DF, 1983.

Accessions and cultivars	Degree of damage[z] 35 d.a.s.		Degree of damage[z] 55 d.a.s.		No. of mines[x]	No. of larvae[x]
	Leaf	Plant	Leaf	Plant	55 d.a.s. Plant	
L. pennellii LA 716	1.1 a[y]	1.0 a	2.1 b	2.1 b	1.9 a	1.1 abcd
L. hirsutum f. *glabratum*						
PI 126449	1.4 ab	1.0 a	1.9 ab	1.9 ab	3.1 ab	0.7 a
PI 134417	1.8 abcd	1.6 abcd	1.4 a	1.4 a	4.0 abcd	1.5 abcdefg
PI 134418	1.8 abcd	1.5 abc	1.8 ab	1.8 ab	4.1 abcd	1.1 abcde
L. hirsutum f. *typicum*						
PI 126445	1.7 abc	1.3 ab	1.4 a	1.4 a	3.3 abc	0.9 ab
PI 127826	2.2 bcde	1.7 abcd	1.7 ab	1.7 ab	5.1 bcde	1.4 abcdef
PI 127827	1.8 abcd	1.3 ab	1.3 a	1.3 a	4.1 abcd	1.1 abcd
Calypso × LA 716	3.0 e	2.6 def	3.3 c	3.3 c	6.3 de	1.0 abc
L. esculentum						
PI 124036	2.3 cde	2.0 bcde	4.4 d	4.4 d	5.7 bcde	1.4 abcdefg
PI 140412	2.4 cde	2.4 bcdef	4.8 d	4.8 d	5.7 bcde	1.6 abcdefg
var. *cerasiforme*						
PI 124436	3.1 e	2.9 ef	4.9 d	4.9 d	5.8 bcde	1.2 abcdef
L. pimpinellifolium						
PI 129154	2.3 cde	2.0 bcde	4.9 d	4.9 d	4.7 abcde	1.9 cdefg
PI 126925	2.4 cde	2.0 bcde	4.8 d	4.8 d	4.8 bcde	1.8 cdefg
PI 126931	2.6 de	2.5 cdef	4.9 d	4.9 d	5.3 bcde	1.1 abcde
Europeel	2.3 cde	2.1 bcde	4.8 d	4.8 d	5.5 bcde	1.4 abcdefg
Floradade	2.6 de	2.5 def	4.9 d	4.9 d	6.9 de	2.0 defg
Petomech	2.7 e	2.8 ef	4.9 d	4.9 d	6.0 cde	1.7 bcdefg
Olho Roxo	2.7 e	2.6 ef	4.9 d	4.9 d	6.1 cde	2.3 g
Angela Gigante	2.8 e	2.7 ef	4.9 d	4.9 d	7.3 e	2.1 fg
Rio Fuego	2.9 e	2.5 cdef	4.8 d	4.8 d	5.7 bcde	2.1 efg
Calypso	3.0 e	3.1 f	4.9 d	4.9 d	6.3 de	2.1 efg

[z]Grades ranged from 1 (no damage) to 5 (heavy damage) on leaves and plants. [y]Means within columns followed by the same letter are not significantly different at P = 0.05 by Duncan's multiple range test. [x]Data transformed to $\sqrt{x + 0.5}$ for statistical analysis.

2. The adoption of a grading scale to evaluate the germplasm improved the discrimination among susceptibles and resistants independent of plant age or insect infestation (Table 2). *L. pennellii*, *L. hirsutum* f. *typicum* and *L. hirsutum* f. *glabratum* were distinctively more resistant than all other varieties or accessions examined. The hybrid Calypso × LA 716 was placed intermediarily between its parents, and well separated from all susceptibles. All *L. hirsutum* accessions and *L. pennellii* maintained resistance even with increasingly higher insect populations (Table 2). *Lycopersicon pimpinellifolium* accessions did not differ from commercial varieties even under moderate *S. absoluta* population levels and all of them were practically destroyed 25 days after initial exposure to the pest. Cultivar Angela Gigante lasted longer to show damage when exposed to the insects, recovering faster than other susceptibles in the absence of the pest. Examining the low number of mines found on LA 716 versus the rating it received suggests that the plant is avoided by *S. absoluta* for oviposition, whereas the few larvae hatched did not reject the plant as food. A similar relationship was observed in the hybrid Calypso × LA 716. *Lycopersicon hirsutum* f. *typicum* and *L. hirsutum* f. *glabratum* had low number of mines and larvae, and the damage on leaves and plants was among the lowest, independent of accession and insect exposure levels (Table 2).

Assessment of Host Resistance

Preference test. The number of eggs laid on *L. pimpinellifolium*, Olho Roxo and Floradade was two- to fivefold higher than on *L. pennellii*. Oviposition was also low on *L. hirsutum* f. *glabratum* and *L. hirsutum* f. *typicum* (Table 3). Calypso had almost 300% more eggs than *L. pennellii*. Oviposition on Calypso × LA 716 was intermediate to that found for its parents. Low oviposition in both *L. hirsutum* forms agree with results reported earlier for lepidopterous pests (Kennedy and Dimock, 1983) in which fumes of toxic compounds in the air surrounding the plants caused larvae to die.

Antibiosis test. The number of pupae collected on leaves of commercial varieties was 5 to 18 times higher than the number of pupae collected on leaves of wild *Lycopersicon* species (Table 4). *Lycopersicon hirsutum* f. *glabratum* PI 134417 apparently had a strong effect on larval development and mortality. No pupae were collected from those plants. Pupal mortality as measured by adult emergence was very high on *L. hirsutum* f. *typicum* PI 127826 and PI 127827, suggesting that a toxic factor to the larvae was involved. A toxic compound, 2-tridecanone, found in trichome exudate of *L. hirsutum* f. *glabratum*, has reportedly increased larval mortality of several insects, especially lepidoptera (Williams et al. 1980; Dimock and Kennedy, 1983; Kennedy and Dimock, 1983). We observed that second and third instars of *S. absoluta* were restless on both *L. hirsutum* varieties and tended to leave the feeding spot. In the case of *L. hirsutum* f. *typicum*, most of the larvae became unable to walk over the heavy leaf and stem pilosity a few minutes after leaving the leaf tissue. Dead larvae were frequently found on the trichomes of PI 127826 and PI 127827.

Breeding and Further Screening

Greenhouse. Regarding the damage to leaves or plants, 80% to 100% of the selected plants among 400 plants of the F_2BC_1 [(Calypso × PI 127826) × Calypso] population were graded less than two, whereas 90% to 100% of the other plants were rated three or above (Figure 1). Progenies of F_2BC_1 presented levels of resistance intermediate between both parents (Table 5) and it should be noted that Calypso plants had to be replenished because they died before

Table 3. *S. absoluta* preference for oviposition on wild *Lycopersicon* accessions and commercial varieties of tomato, Brasilia, DF, 1984.

Accessions and cultivars	Mean no. eggs[z]
L. pennellii	6.0 a[y]
L. hirsutum f. *glabratum*	
PI 134417	9.6 ab
PI 134418	11.7 ab
L. hirsutum f. *typicum*	
PI 128827	11.8 ab
PI 127826	13.2 abc
Calypso × LA 716	16.1 abc
Angela Gigante	16.4 abc
Calypso	22.9 c
L. esculentum var. *cerasiforme*	
PI 124036	25.6 c
Floradade	29.6 c
Olho Roxo	29.8 c
L. pimpinellifolium	
PI 129154	33.8 cd

[z]Mean no. eggs on 100 cm^2 foliar area. [y]Means followed by the same letter are not significantly different at P = 0.05 by Duncan's multiple range test.

Table 4. Mean number of pupae and percent adult emergence of *S. absoluta* reared on wild and domesticated *Lycopersicon* species, Brasilia, DF, 1984.

Accessions and cultivars	Number of pupae[z]	% adult emergence	Length (mm)	Pupae	
				Diameter (mm)	Weight (mg)
L. pennellii LA 716	1.0 ab[y]	100.0 a	4.30 ± 0.84[x]	1.15 ± 0.07	3.48 ± 1.14
L. hirsutum f. *glabratum*					
PI 126449	2.6 abc	50.0 bcd	4.00 ± 0.30	1.17 ± 0.07	2.09 ± 0.69
PI 134417	0.0 a	–	–	–	–
PI 134418	1.3 ab	66.6 abc	4.00 ± 0.04	1.13 ± 0.05	2.29 ± 1.01
L. hirsutum f. *typicum*					
PI 126445	2.3 abc	100.0 a	4.53 ± 0.31	1.25 ± 0.05	3.51 ± 0.56
PI 127826	2.0 abc	12.5 d	4.06 ± 0.31	1.18 ± 0.09	1.75 ± 0.82
PI 127827	1.6 abc	33.3 cd	4.31 ± 0.35	1.23 ± 0.05	2.35 ± 0.22
Calypso × LA 716	6.7 bcdef	74.7 abc	4.33 ± 0.24	1.20 ± 0.06	2.74 ± 0.78
L. esculentum PI 124036	5.2 abcde	62.0 abc	4.26 ± 0.12	1.20 ± 0.06	2.82 ± 0.55
L. esculentum PI 140412 var. *cerasiforme*	7.8 cdef	88.8 ab	4.41 ± 0.39	1.25 ± 0.08	2.99 ± 0.57
PI 126436	4.4 abcd	42.8 bcd	4.19 ± 0.27	1.18 ± 0.08	2.38 ± 0.71
L. pimpinellifolium					
PI 126154	6.7 bcdef	60.2 abc	4.27 ± 0.12	1.24 ± 0.10	2.65 ± 0.90
PI 126925	5.5 abcde	87.7 ab	4.33 ± 0.18	1.23 ± 0.06	2.78 ± 0.50
PI 126931	7.6 bcdef	80.0 ab	4.10 ± 0.30	1.15 ± 0.11	2.55 ± 0.43
Europeel	5.3 abcde	6.6 d	4.27 ± 0.55	1.23 ± 0.07	2.72 ± 1.10
Petomech	11.1 cdef	81.1 ab	4.51 ± 0.22	1.33 ± 0.12	3.39 ± 0.81
Olho Roxo	15.3 def	76.2 abc	4.37 ± 0.16	1.21 ± 0.06	3.02 ± 0.38
Floradade	16.0 ef	83.5 ab	4.32 ± 0.13	1.22 ± 0.04	3.03 ± 0.39
Rio Fuego	17.0 ef	87.8 ab	4.18 ± 0.22	1.18 ± 0.12	2.61 ± 0.31
Angela Gigante	17.5 ef	82.5 ab	4.37 ± 0.17	1.25 ± 0.03	2.96 ± 0.40
Calypso	18.3 f	87.3 ab	4.31 ± 0.12	1.23 ± 0.02	2.82 ± 0.40

[z]Mean no. pupae/plant. [y]Means within columns followed by the same letter are not significantly different at P = 0.05 by Duncan's multiple range test. [x]Mean ± SD.

Table 5. Degree of damage recorded on F_2BC_1 progenies and susceptible and resistant parents, Brasilia, DF, 1985.

Germplasm	Degree of damage[z]	
	Leaf	Plant
L. hirsutum f. *typicum*		
PI 127827	1.0 a[y]	1.0 a
MMX 196-4-B	2.8 b	2.8 b
MMX 196-4-B	3.2 c	3.5 c
MMX 196-11-B	3.5 d	3.7 cd
Calypso	3.8 e	3.8 d

[z]Grades ranged from 1 (no damage) to 5 (heavy damage) on leaves and plants. [y]Means within columns followed by the same letter are not significantly different at P = 0.05 by Duncan's multiple range test.

plants of MMX 196-4-B, MMX 196-6-B and MMX 196-11-B had shown symptoms of insect damage.

Field. *Lycopersicon hirsutum* f. *typicum*, *L. hirsutum* f. *glabratum* and *L. pennellii* confirmed in the field the high resistance identified in previous experiments. Three of the hybrids screened for virus tolerance-CNPH 364 [Angela Gigante × *L. pimpinellifolium* (PI 732293-2-V)], CNPH 362 [Angela Gigante × *L. pimpinellifolium* (IVT)] and VC 329 [Calypso × *L. hirsutum* f. *typicum*

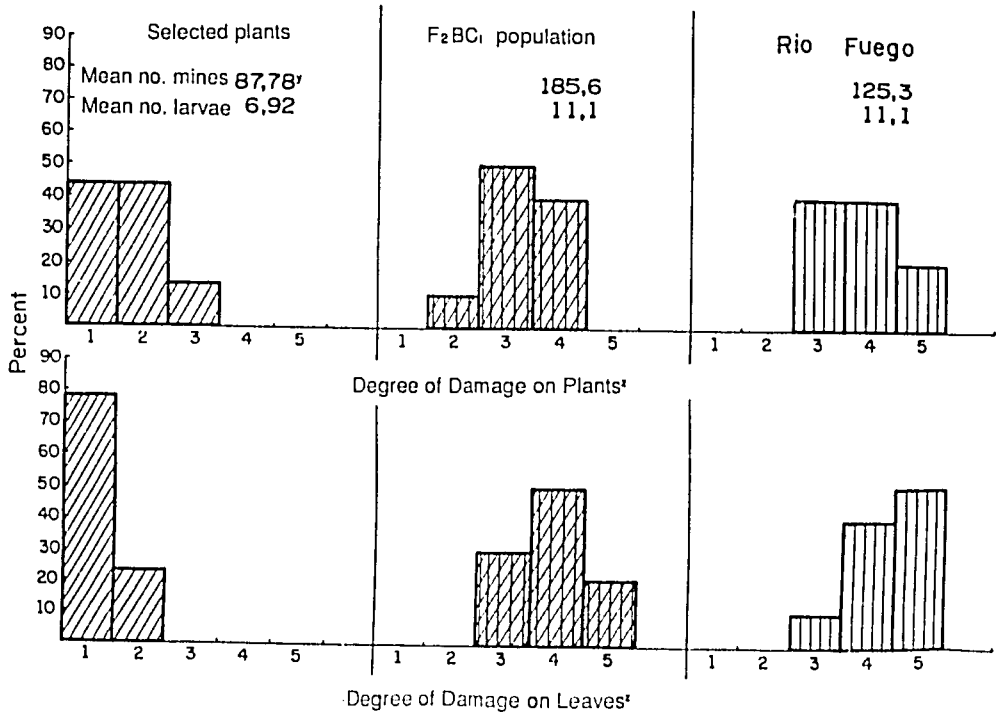

Figure 1. Degree of damage and percent distribution of selected plants from $F_2BC_1\{[(Calypso \times PI\ 127826)]\} \times$ Calypso compared to the susceptible cultivar Rio Fuego, Brasilia, DF, 1985. [z]Grades ranged from 1 (no damage) to 5 (heavy damage) on leaves and plants. [y]Mean number of mines and larvae/plant.

Table 6. Field resistance of *Lycopersicon* genotypes to *Scrobipalpulo absoluta*, Brasilia, DF, 1986.

Genotypes	Mean no. of mines/10 leaves	Std.error
L. hirsutum f. *typicum*		
PI 127827	7.2	0.1
L. pennellii LA 716	8.1	0.5
L. hirsutum f. *glabratum*		
PI 134418	8.6	0.3
CNPH 364	10.3	0.7
CNPH 264-6-A	10.4	0.6
VC 329	10.6	1.2
CNPH 362	11.3	0.7
CNPH 365	12.5	0.7
CNPH 264-11-A	12.6	1.3
VC 363	13.1	1.7
Rey 310	13.9	1.1
CNPH 356	14.8	1.2
Rio Grande	15.1	1.6
Rey 310	16.2	1.5
Angela Gigante	16.5	1.5
Floradade	18.3	1.6
Rio Fuego	18.7	2.6
Calypso	19.5	2.2
CNPH 367	20.1	2.3
Tropic	20.5	2.1
CNPH 368	20.7	2.8
LSD (P = 0.05) 4.3		

(PI 127826)] — and CNPH 264-6-A, the BC_1S_2 *L. esculentum* × *L. pennellii* selected according to the methodology developed by Castelo Branco et al. (1987), presented levels of resistance comparable to those of the wild *Lycopersicon* accessions mentioned above (Table 6). All commercial cultivars had the highest levels of mines among the genotypes tested. CNPH 367 and CNPH 368, both hybridized to *L. peruvianum* (PI 128650), were among the most susceptible genotypes.

In summary, the results reported here present evidence that breeding tomato for resistance to *S. absoluta* is viable. Sources of resistance were identified and *L. hirsutum* f. *typicum* (PI 127826 and PI 127827), *L. hirsutum* f. *glabratum* (PI 134417 and PI 134418) and *L. pennellii* (LA 716) are particularly recommended. Fortunately these species intercross quite well with improved *L. esculentum* varieties. Alkaloid content (Juvik and Stevens. 1982a) and glandular trichomes, both responsible for resistance to insects in *L. hirsutum* and *L. pennellii*, are readily transferred and usually segregate in the F_2 generation (Snyder and Carter. 1985; Lemke and Mutschler. 1984) and hybrids can be efficiently selected by visual and/or tactile means (Castelo Branco et al. 1987). However, we sometimes found problems in fruit set and in producing viable seeds mainly on plants derived from these accessions which appeared to be highly resistant to *S. absoluta*. In other instances, we found in advanced generations known resistant plants segregating to very poor agronomical characters such as plant architecture, fruit size, fruit color and fruit shape. There is a pressing need for direct studies to determine the mechanistic basis of resistance found in these accessions, which is well advanced in relation to other arthropods (Kennedy and Dimmock. 1983 and references therein). Apparently several factors might be involved here. Physical barriers due to the presence of trichomes, changes in normal larval behavior, adult avoidance and larval intoxication appeared to be associated with *L. hirsutum* f. *typicum*, *L. hirsutum* f. *glabratum* and *L. pennellii*.

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-123-

14

Use of Tomato Fruit Ripening Mutants to Enhance Fruit Storage Life

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Abstract

Four single gene mutants (Never ripe (*Nr*), Green ripe (*Gr*), ripening inhibitor (*rin*) and nonripening (*nor*) which dramatically alter tomato fruit ripening have been identified and described. These ripening mutants are distinguished from the carotene mutants by their multiple effects on the changes normally associated with tomato fruit ripening. The recessive mutants *rin* and *nor* have been extensively examined for their effects as heterozygotes on ripening and fruit shelf life. The *nor* mutant has proven of particular interest for practical breeding purposes because of its dramatic effect as an heterozygote on ripening rate and subsequent shelf life. Furthermore, there appear to be more than two alleles at this locus (*nor* and nor^A) which differ in degree of ripening inhibition. The extent to which ripening is affected by these alleles is also dependent upon genetic background such that a wide array of distinct ripening types are possible using this unique germplasm. We have developed several adapted *nor* F_1 hybrids and nor^A inbreds for commercial scale shelf life, taste panel and consumer acceptance studies to explore the feasibility of utilizing this novel germplasm for fresh market tomato hybrids and/or inbred cultivars. This presentation will summarize the genetic, breeding, postharvest, taste panel and consumer acceptance studies with variants of *nor* and will speculate on the market place situations where this novel germplasm may prove useful.

Introduction

Several genes with major effects on tomato fruit ripening have been identified, described and characterized (Hobson, 1967; Ng et al. 1977; Palmieri et al. 1975; Robinson et al. 1968; Tigchelaar et al. 1973; 1978). These ripening mutants are distinct from the many carotene mutants of tomato by virtue of their multiple effects on the ripening process. Fruit softening, carotenoid biosynthesis, respiratory behavior and ethylene production are all substantially altered and fruit shelf life may be dramatically extended.

Varietal differences in ripening behavior and subsequent shelf life have been reported for many perishable horticultural commodities. Melon, apple and pear varieties with widely differing ripening and shelf life characteristics are accepted commodities in the US marketplace. This report will review recent research to characterize genetic variants affecting tomato ripening and to assess the potential for use of this variation in applied breeding programs to enhance fresh tomato quality and shelf life.

Materials and Methods

Genetic and Breeding Studies

In recent years, several tomato fruit ripening variants have been reported and described (Table 1). Tests of allelism of these new variants were performed by intercrossing each new

variant with known standard stocks of the ripening inhibitor (*rin*) and nonripening (*nor*) mutants. Allelism was confirmed by the absence of normal ripening segregates in F_1 and F_2.

These tests of allelism and evaluation of F_2 populations revealed a wide range of variation in the inhibition of ripening in lines allelic with *nor*. As a result, our ripening breeding program was expanded to explore this wide variation and develop adapted inbred *nor* lines with improved fruit quality, shelf life and acceptable horticultural characteristics. The best inbred lines and F_1 hybrids with normal ripening inbreds were subsequently selected for shelf life, raw product quality and taste panel acceptance evaluations following various times in transit or storage.

Table 1. Tomato fruit ripening variants used in tests of allelism.

	Variety name	Origin Reference
Alcobaca	Portugal	(Leal and Mizubuti. 1971)
Long Keeper	Burpee Seed Co.	–
Garden Peach	Puerto Rico	–
Spanish Winter	Burpee Seed Co.	–
Italian Winter (nor)	Italy (Canada)	(Tigchelaar et al. 1973)
nor^2	Italy	(Soressi. 1975)
nor^3	Italy	(Soressi. 1975)
rin	US (spontaneous mutant)	(Robinson and Tomes. 1968)

Harvest Maturity, Taste Panel and Raw Product Quality Studies

Two experiments were conducted to assess the shipping and shelf life advantages and taste panel acceptability of three contrasting genotypes with distinctive ripening characteristics. The normal ripening hybrid Sunny, a heterozygous *nor* F_1 hybrid, (VFN8 × *nor Fldde*) and a nor^A inbred (LK 7432), developed in a joint project between Purdue and CIFAP, were grown in Culiacan, Mexico, and fruit was shipped as part of a commercial consignment to Lafayette, Indiana. Attempts were made to simulate as closely as possible the commercial handling and shipping practices used for fresh tomato exports from Mexico. Shipments of Sunny were limited to mature green (USDA color stage 1)* and breaker (stage 2) fruit whereas other genotypes were shipped at breaker (stage 2) and more advanced maturities (stages 3 and 4) (USDA. 1973). Following arrival in Lafayette, fruits were stored at 20 ± 1°C and evaluated at three to four day intervals for percent usability and external color and subjected to taste panel and raw product quality evaluations (color, percent soluble solids and titratable acidity).

This study was repeated during the summer of 1987 using locally produced fruit. Because there was no need for long-distance shipping, more advanced maturity stages were used in shelf life and taste panel studies. Sunny, harvested mature green (stage 1), at breaker (stage 2-3) and approximately fully ripe (stage 4-6) tomatoes were compared with a *nor* F_1 hybrid (XPH 5597) and a nor^A inbred (LK 7432) harvested at three maturity stages (USDA color stages 2, 3 and 4-5). Use of mature green fruit of the latter two genotypes was omitted because they do not ripen acceptably in storage. Shelf life, color development and taste panel scores were followed at four to five day intervals for up to 43 days at storage temperatures of 12 ± 1°C and 20 ± 1°C. On each taste panel date, locally available fruit were purchased for use as the standard

*USDA color stages:
1) Mature green (stage 1): Tomato surface is completely green.
2) Breaker (stage 2): Break in color from green to yellow pink or red on not more than 10% of the fruit surface (generally at the stylar end).
3) Turning (stage 3): More than 10% but not more than 30% of fruit surface shows color change from green to red.
4) Pink (stage 4): More than 30% but less than 60% of fruit surface show color change to pink or red color.
5) Light red (stage 5): More than 60% but not more than 90% of the fruit surface is pink or red.
6) Red (stage 6): More than 90% of the fruit surface is red.

to compare with stored samples. In this paper, we will only report results of advanced harvest maturity (stages 4-6) fruit storage studies.

Results

Tests of Allelism and Inbred Line Development

The ripening behavior of F_1 hybrids of *rin* and *nor* crossed with other reported ripening variants is given in Table 2. All these new variants behave as alleles at the *nor* locus based upon the mutant fruit phenotype in F_1 and failure to recover normal ripening recombinants in F_2. Crosses with *rin*, by contrast, all displayed a normal F_1 phenotype with respect to fruit ripening and the expected two-gene segregation ratios were observed in the F_2. Based on these observations, we conclude that the landrace varieties Spanish Winter and Alcobaca and the recently released variety Long Keeper carry an allele similar to the *nor* allele originally identified in the landrace variety Italian Winter. The variety Garden Peach appears to be identical to the cultivar Long Keeper.

Kopeliovitch et al. (1979a; b; 1980) have studied and characterized the variety Alcobaca and report that while it behaves similarly to *nor*, it is nonallelic and affects ripening in a quantitative rather than qualitative way. Mutschler (1984a) has also suggested nonallelism and has proposed the gene symbol *alc* to explain the ripening aberrancy in the variety Alcobaca. Lobo et al. (1981; 1982) in contrast report that Alcobaca carries a third allele (nor^A) at the *nor* locus based on extensive genetic studies. Our results support the conclusions of Lobo et al. and further indicate that several abnormal ripening varieties carry an allele similar to the *nor* allele initially identified in the variety Italian Winter.

During tests of allelism and breeding studies with *nor* we have observed substantial variation in the degree of inhibition of ripening in varieties, F_2 segregates, and inbred lines developed using various sources of the *nor* allele. These observations suggest more than two alleles at the *nor* locus and/or the existence of modifier genes which quantitatively alter the expression of *nor*.

We have developed a series of inbred lines from diverse sources of *nor* which vary strikingly in the degree to which ripening is inhibited. These range from inbreds in which ripening is virtually completely inhibited (*nor Fldde*) to inbreds in which almost normal ripening (as measured by internal color development) occurs (LK 7432). These latter inbred types appear to be of particular interest from a plant improvement standpoint because we can combine acceptable ripening and color development with the dramatic shelf life enhancement characteristics of *nor*.

A unique and distinguishing feature of all *nor* F_1 hybrids we have observed is the failure of detached mature green fruit to develop acceptable color and/or to ripen substantially. It appears that some stimulus from vegetative tissues is needed to stimulate acceptable ripening and color development. A similar effect of stage on maturity at harvest has been observed in many *nor* inbreds and *nor* × normal F_1 hybrids (Kopeliovitch et al. 1979a; 1980; McGlasson et al. 1983;

Table 2. Tests of allelism of tomato fruit ripening variants.[z]

	1	2	3	4	5	6	7
1. *rin*	–	+	+	+	+	+	+
2. *nor*		–	–	–	–	–	–
3. nor^2			–	–	–	–	–
4. nor^3				–	–	–	–
5. Alcobaca (nor^A)					–	–	–
6. Long Keeper						–	–
7. Spanish Winter							–

[z] – = allelic; + = non-allelic.

Mutschler, 1984b; Tigchelaar et al. 1978). As a result, harvesting and post harvest handling practices have been examined to develop a better understanding of the handling requirements and consumer acceptance of this unique germplasm.

Harvest Maturity and Taste Panel Studies

Results of studies of harvest maturity effects on shelf life, color development, flavor rating and raw product quality following semicommercial shipments of three genotypes from Culiacan, Mexico to Lafayette Indiana are given in Figures 1-6.

Tomato fruit shelf life. The shelf life is expressed as percent usable fruit as a function of genotype, stage of maturity at harvest and time in storage at 20 ± 1°C following commercial shipment from Culiacan, Mexico to Lafayette, Indiana is given in Figure 1. Both the *nor* hybrid (VFN8 × *nor* Flde) and the *nor*^{A} inbred (LK 7432) showed substantially improved shelf life when compared with the normal cultivar Sunny harvested at mature green (stage 1) or at breaker (stage 2). Stage 4 fruit of the *nor* hybrid showed unacceptably high losses in transit, however stage 2 and 3 harvested fruit had substantially better shelf life than Sunny harvested at mature

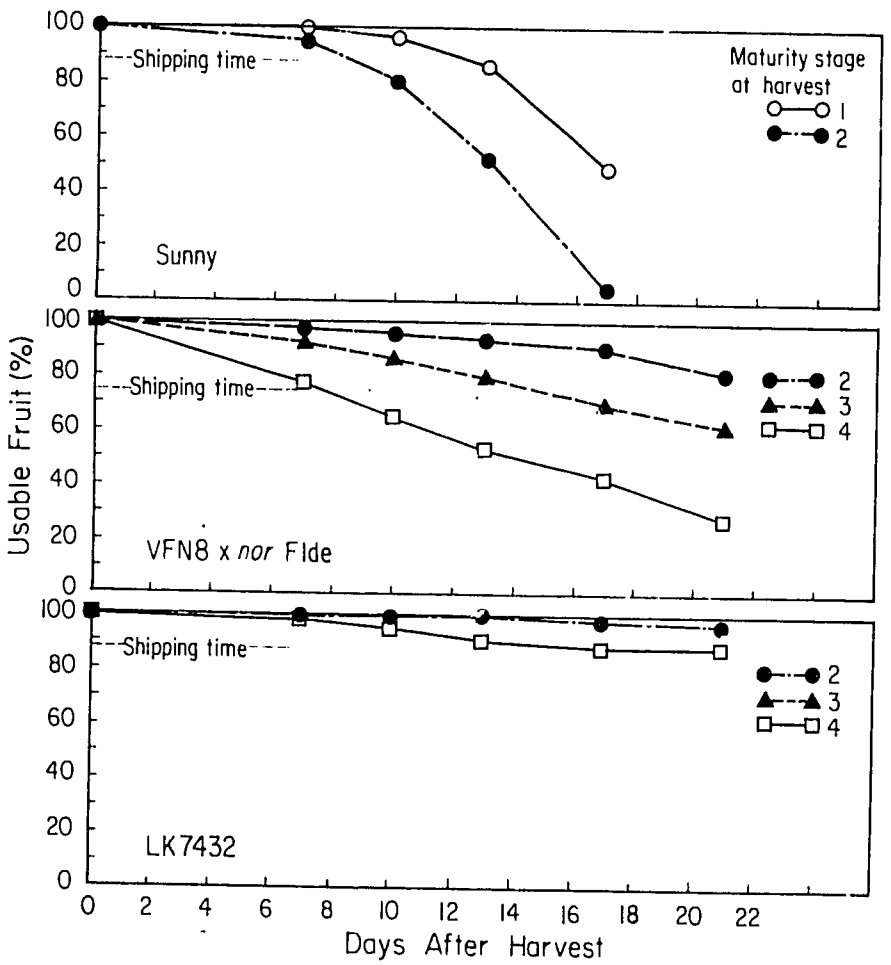

Figure 1. Percent usable fruit following transit and during storage at 20°C as a function of variety and maturity stage at harvest.

green or at breaker stage. The most dramatic extension of shelf life was observed with the inbred LK 7432 in which postharvest losses remained at less than 10% for two weeks after arrival, regardless of stage of maturity at harvest.

Color development in transit and storage. Color development as a function of variety, maturity stage at harvest and time in storage at 20 ± 1°C is given in Figure 2. Harvesting fruit of the normal variety Sunny at breaker resulted in a uniformly colored product on arrival at Lafayette, whereas mature green fruit resulted in a heterogeneous product (checkered) in which complete ripening did not take place until after several days in storage. All harvest maturity stages (2, 3 and 4) of the *nor* hybrid arrived uniformly colored, however they all displayed an orange-red external color (classified as stage 5) which was distinctive from the normal deep red external color of the cultivar Sunny. External color development in LK 7432 occurred very slowly during transit and storage and only fruit harvested at stage 4 reached traditionally acceptable color scores (stage 5) during subsequent storage.

Taste panel flavor ratings. Flavor ratings of diced fresh tomato samples as a function of genotype and maturity stage at harvest as a function of time in transit and storage is given in Figure 3. No significant differences in flavor ratings among genotypes were evident on arrival

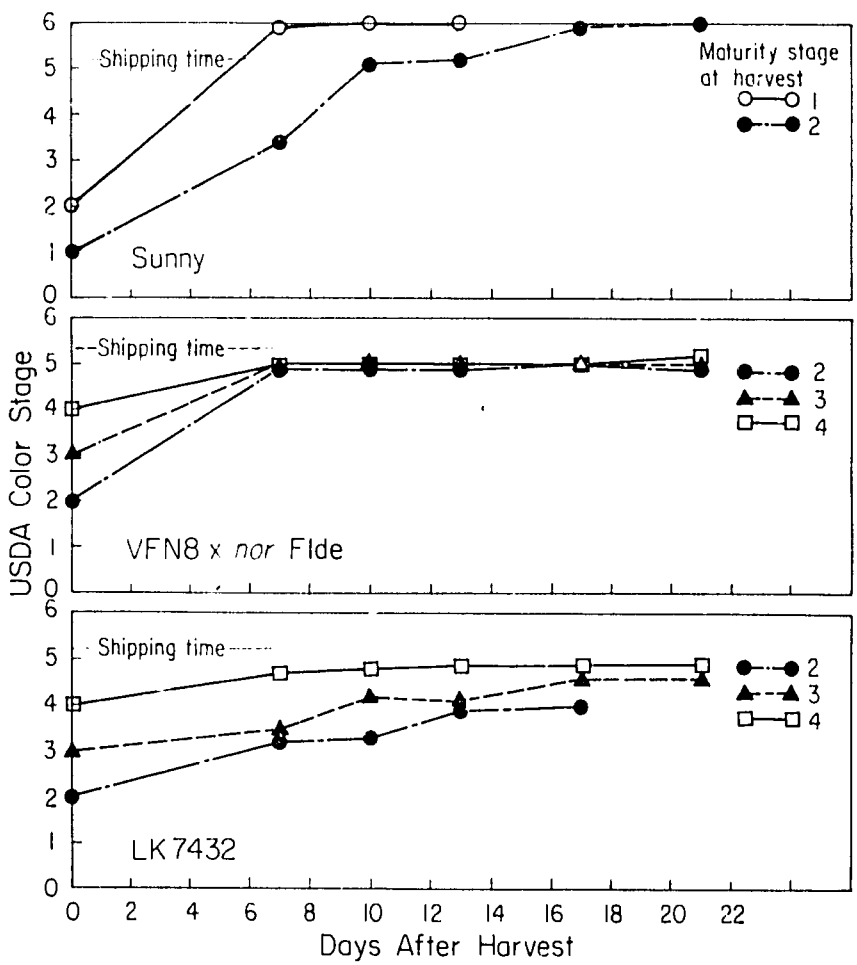

Figure 2. USDA fruit color score following transit and during storage at 20°C as a function of variety and maturity stage at harvest.

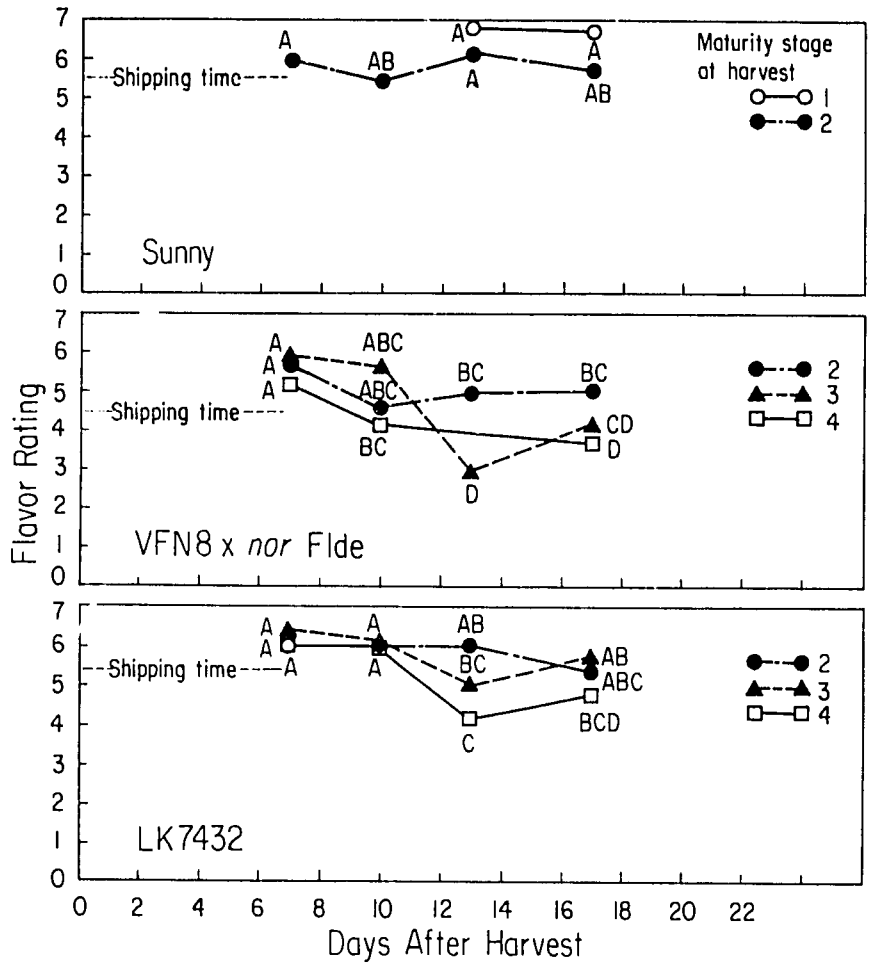

Figure 3. Hedonic flavor ratings as a function of genotype, maturity stage at harvest, and time in transit and storage at 20°C. [1]Points on a given date with the same letter are not significantly different.

(day 7 after harvest), however significant genotype and maturity stage differences developed with time in storage. By day 13 after harvest (one week after transit), fruits harvested at advanced maturity (stages 3 and 4) were judged significantly inferior in flavor when compared with the normal variety Sunny harvested mature green or at breaker. This demonstrates that flavor deterioration may occur in storage in long shelf life hybrids before significant declines in shelf life precludes use of the fresh commodity.

Raw Product Quality Studies

Changes in total color (measured as a/b ratio of a juice extract) titratable acidity (expressed as % citric acid) and soluble solids (measured as °Brix) as a function of genotype, maturity stage at harvest and time in storage are given in Figures 4-6.

Average fruit color. The fruit color improved for each harvest maturity class with increasing time in storage is provided in Figure 4. Genotype and maturity stage differences in color were

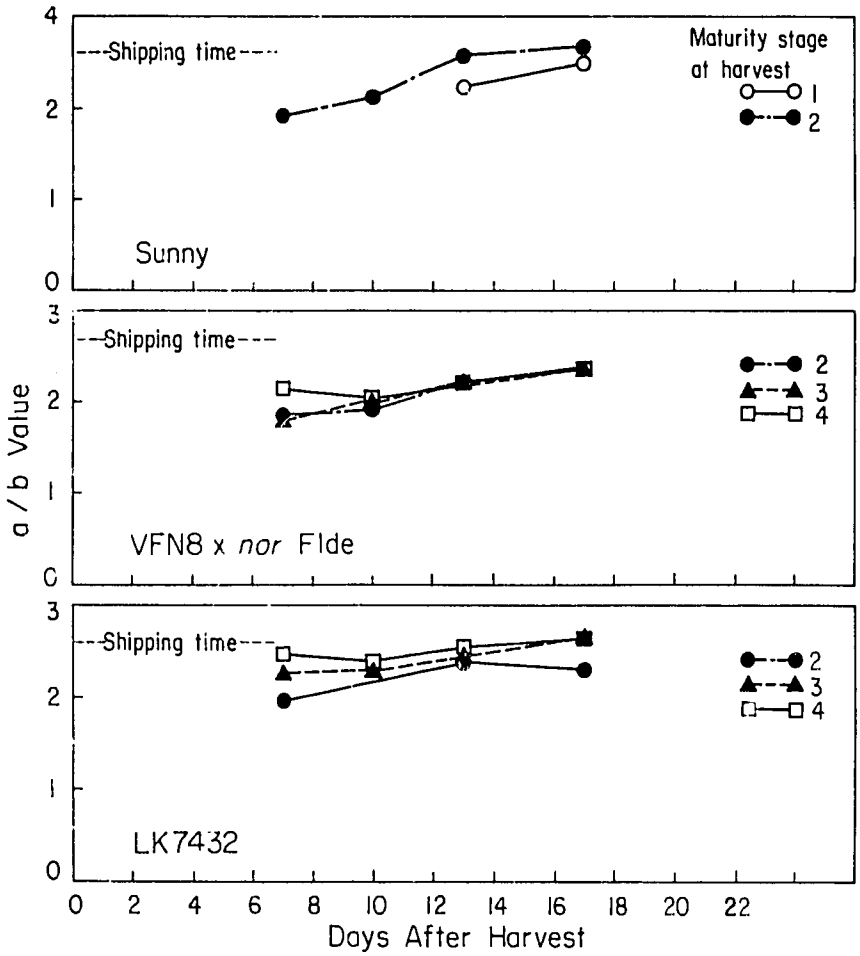

Figure 4. Average fruit color (measured as a/b value) as a function of genotype, maturity stage at harvest and time in transit and storage at 20 C.

substantially less than for external color estimates (Figure 2) substantiating visual observations that external color deficiencies in fruit of the *nor* F_1 and LK 7432 were largely limited to the fruit pericarp; both genotypes give internal fruit color visually comparable to the normal variety Sunny.

Total acidity. Total acidity was consistently lower in fruit harvested at more advanced maturities and declined further with time in storage. Differences in titratable acidity due to stage of maturity at harvest and time in storage were substantially larger than differences attributable to genotype.

Soluble solids. Changes in soluble solids resulting from harvest maturity or time in storage were relatively minor when compared with genotype effects. The VFN8 × *nor* F_1 hybrid consistently gave the lowest soluble solids estimates whereas Sunny and LK 7432 were consistently above 5. More extensive studies are needed to document the nature of changes in soluble solids during prolonged storage of ripe tomato fruit.

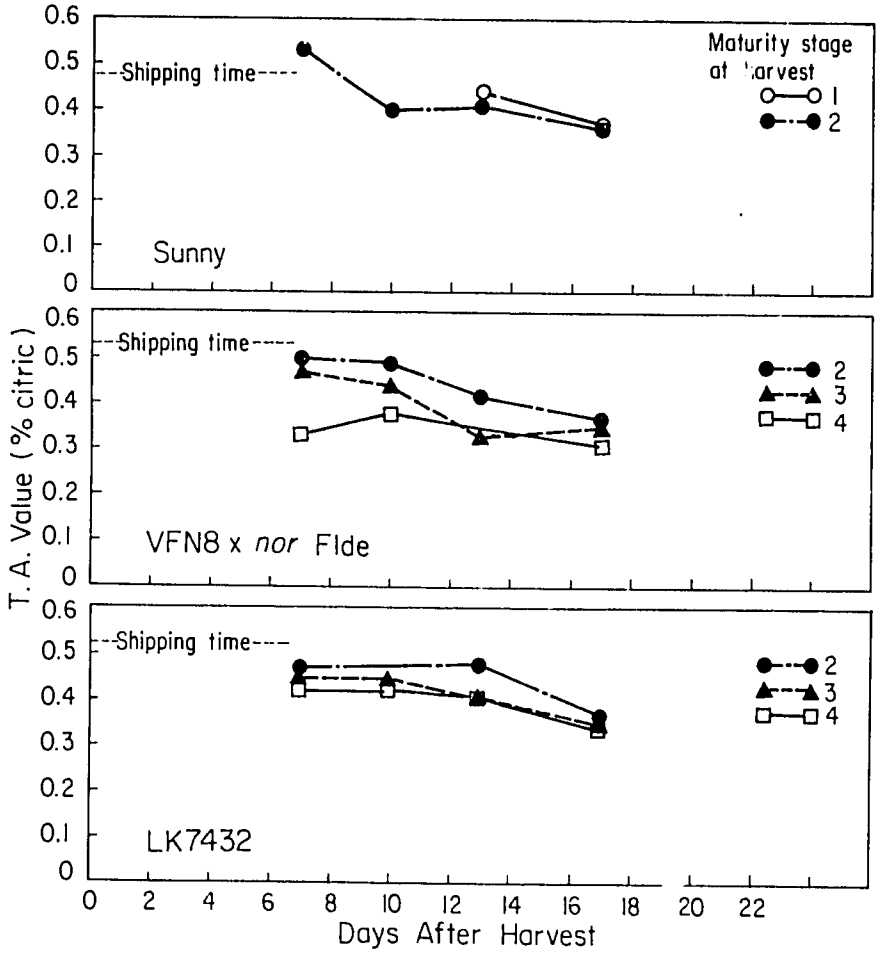

Figure 5. Titratable acidity (% citric acid) as a function of genotype, maturity stage at harvest and time in transit and storage at 20°C.

Shelf Life Taste Panel and Quality Evaluations of Fruit Harvested at Advanced Maturities

Eliminating the need for long-distance fruit shipment may permit the harvest and handling of fresh tomatoes for local markets at more advanced fruit maturities. In studies carried out at Lafayette, we focused our efforts on postharvest studies of fruit of each genotype harvested at relatively advanced maturities (USDA stage 4-6) and compared experimental samples stored at two temperatures (12 + 1°C and 20 + 1°C) with fresh fruit purchased at a local supermarket on each evaluation date. Results of these studies are given in Figures 7-9.

Shelf life. The differences between the normal variety Sunny, a heterozygous *nor* F_1 hybrid (XPH 5597) and the nor^A inbred (LK 7432) as a function of genotype, storage temperature and time in storage are shown in Figure 7. Very rapid losses in shelf life were observed for the normal variety Sunny; minor improvements were noted for the *nor* F_1, and very dramatic improvements in shelf life occurred for LK 7432 with more than 80% of fruit usable after more

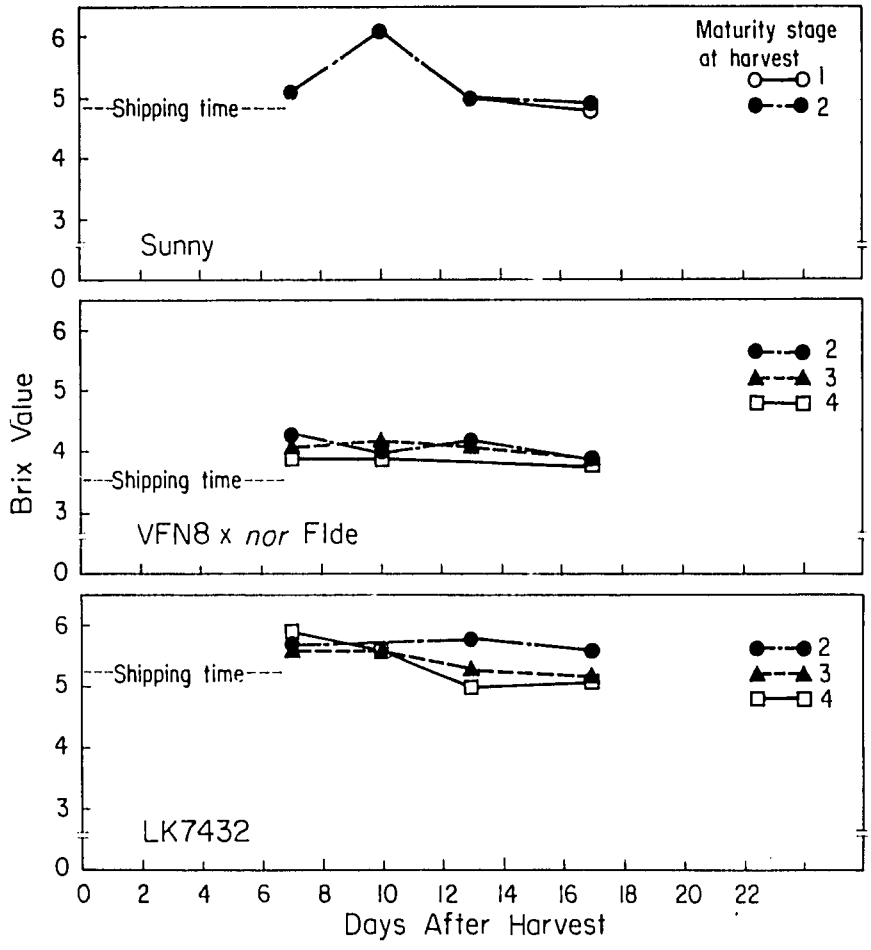

Figure 6. Percent soluble solids (expressed as °Brix) as a function of genotype, maturity stage at harvest and time in transit and storage at 20°C.

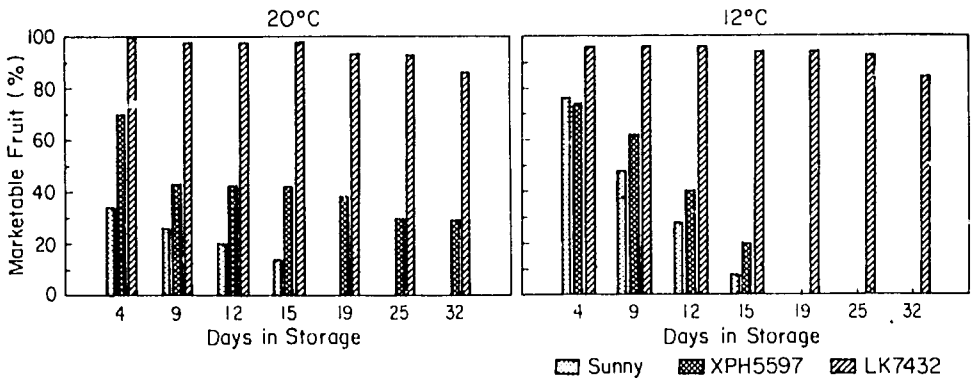

Figure 7. Storage life (expressed as percent marketable fruit) as a function of genotype and time in storage at 20 + 1°C and 12 + 1°C for fruit harvested at USDA color stage 4-6.

than one month in storage at both 12° and 20°C. Genotype differences in shelf life were substantially larger than differences due to temperature.

Color development. Color development, as estimated by the USDA external color score, was virtually complete for Sunny and XPH 5597 after four days of storage (Figure 8). Slight improvements in external color of LK 7432 occurred during storage and substantially better external color development was observed at the lower temperature. Fruit of this genotype exhibited an orange-red external color which is visually distinctive from fully ripened normal fruit.

Flavor scores. Flavor scores on a hedonic rating scale from 1 (dislike extremely) to 9 (like extremely) are given in Figure 9. These comparisons included the three genotypes being studied as well as an unstored sample purchased from a local supermarket on each taste panel date. No significant genotype differences in taste panel flavor scores were noted for the first three evaluation dates (4, 9 and 12 days in storage). During this storage period, however, average flavor ratings declined from approximately 6 (like slightly) to approximately 5 (neither like or dislike). Subsequent taste panel ratings included only LK 7432 compared with store-purchased

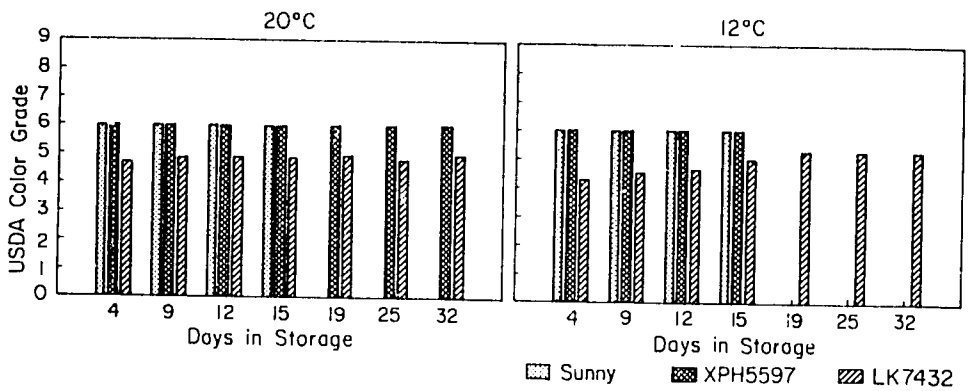

Figure 8. USDA color score as a function of genotype and time in storage at 20 + 1°C and 12 + 1°C for fruit harvested at USDA color stage 4-6.

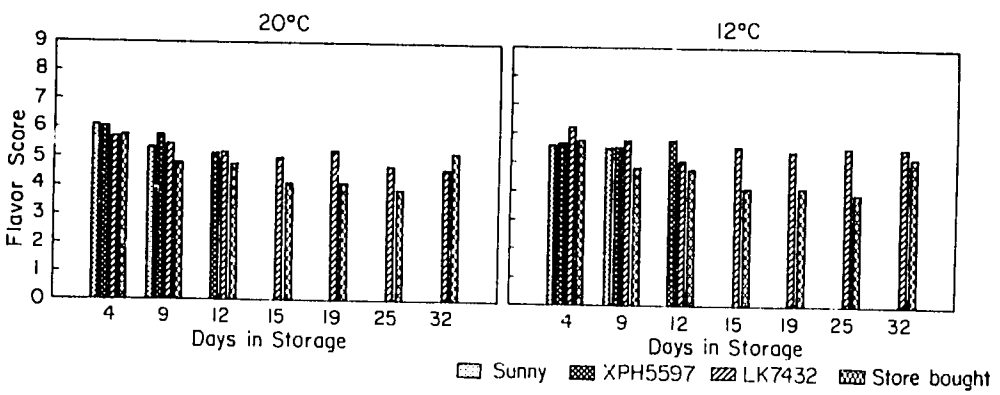

Figure 9. Hedonic flavor ratings as a function of genotype and time in storage at 20 + 1°C and 12 + 1°C for fruit harvested at USDA color stage 4-6. [1]Fresh locally purchased fruit were used on each taste panel date.

fruit. These comparisons were continued for as long as stored usable fruits of this genotype were available and considered cosmetically acceptable (42 days).

Contrary to our expectations, flavor ratings of stored samples of LK 7432 remained relatively constant during the test period and were numerically superior to store-purchased samples on five of seven taste panel dates for fruit stored at 20°C and on all nine evaluation dates when fruit were stored at 12°C. At this temperature, average taste panel scores dropped below 5 (a neutral score) only after approximately 40 days in storage.

Results and Discussion

The wide range of variation in the degree of ripening inhibition observed among breeding lines and landrace varieties homozygous for *nor* (or alleles of *nor*) makes this germplasm of particular interest to exploit the dramatically extended shelf life characteristics of *nor*. Part of this observed variation may result from more than two alleles (*nor* and nor^A) at the nor^+ locus as suggested by Lobo et al. (1982). However, the wide quantitative differences in ripening also strongly implies modifier genes which alter the expression of *nor*.

Based on observations of many inbred lines and F_1 hybrids developed using several distinct sources of *nor*, the following fruit characteristics distinguish inbreds homozygous for *nor* (or its alleles).

1) Mature external fruit color may vary from almost totally inhibited (USDA Color stage 1-2) to partially inhibited (Color stage 4-5). Internal fruit color may vary from almost total inhibition to visually normal.
2) Ripening and color development of detached fruit is substantially inhibited if fruits are harvested mature green or at early ripening stages (stages 2-3).
3) F_1 hybrids involving normal inbreds × very inhibited *nor* inbreds ripen later and more slowly than the normal parent and frequently show external color abnormalities (yellow top, blotchy ripening). Hybrid *nor* fruit harvested when immature or at early ripening stages do not ripen to full color.
4) Substantial variation among distinct inbreds and different hybrid combinations appears to exist for each of the above.
5) Substantially better external color development was observed during storage at 12°C than at 20°C.

The differences in ripening behavior and shelf life of normal ripening and *nor* tomato fruit is analogous, in many respects, to the ripening and shelf life differences between honeydew and cantaloupe melons. The latter two crops are distinctive and widely appreciated commodities in the US marketplace. By contrast, the wide variation in tomato shelf life, ripening behavior and resulting product quality has not been utilized to develop distinctive fresh market tomato commodities.

Our preliminary studies suggest that the substantial genetic variation affecting tomato ripening and shelf life can be used to develop distinctive cultivars with dramatically enhanced shelf life and acceptable flavor. Postharvest handling and marketplace consumer acceptance studies are currently in progress to assess the handling requirements and consumer acceptability of these novel types.

Acknowledgments

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Symposium Discussión

S.S. Cheng: In Latin America, hyperinflation is currently going on at 20% to 30% per month. Delayed maturity can mean losing money for business. Aren't there other genes for fruit maturation consistency without delaying maturity?

E.C. Tigchelaar: There are other genes for firmness which do not delay ripening. However, breeding for extreme firmness may contribute to the poor quality and consumer acceptance we have experienced in the American market. The ripening mutants do not delay earliness seriously (two to four days) and I suspect that part of the shelf life enhancement is due to a slower loss of firmness during ripening.

Y. Haile: Have you harvested the fruits at different stages and exposed them to different temperature ranges?

E.C. Tigchelaar: Yes, we have. However, I think additional work is needed, since ripening of detached fruit is quite different at different temperatures. We have found better color development and flavor retention of *nor* hybrids and nor^{λ} inbreds at lower temperatures (12°

versus 20°C) during storage. Some of this data is presented in the manuscript to be published and we expect to publish additional information elsewhere in the near future.

R.T. Opeña: Have you looked at the combination of ripening mutants, e.g. *nor*, with other mutants, specifically *dg* (dark green). I have seen a combination between Alcobaca and *dg* that I thought, at least from our perceived standard in developing countries, is acceptable already or even as good as the normal tomato in terms of color?
E.C. Tigchelaar: Yes. Unfortunately we have found *dg* even more difficult to work with than hp (for the same reasons) so while it can be used to improve color, it introduces a lot of problems in horticultural adaptation. Maybe we should try to educate the consumer to deemphasize cosmetic qualities like color and judge these products with their tastebuds'.

R.L. Villareal: What is the latest on the development of processing tomato inbreds/hybrids using the ripening mutants? What advantage would this have over the other genes (i.e. high pigment, crimson gene, etc.)?
E.C. Tigchelaar: There is some interest in nor^A types for consistency-based processed tomato products (e.g. catsup) if satisfactory color can be obtained. Our work has been based largely on the use of this germplasm for fresh market tomato improvement. While *hp* improves consistency, we feel undesirable pleiotropic effects associated with *hp* could be difficult, if not impossible, to overcome. The crimson 09^c gene affects only color and seems to effectively improve color of nor^A inbreds. LK 7432 used in these studies carries both the nor^A and 09^c genes; the latter gene greatly improves internal color of nor^A inbreds.

137

Stress Physiology

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.138

15

Relationship between Hormonal Levels in Pistils and Tomato Fruit-set in Hot and Cool Seasons

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Abstract

Pistils from two days before anthesis to six days after anthesis of seeded and parthenocarpic tomatoes (*Lycopersicon esculentum* Mill.) were analyzed for endogenous abscisic acid (ABA), dihydrozeatin riboside (diHZR), gibberellic acid (GA_3), indole-3-acetic acid (IAA), and zeatin riboside (ZR) in hot and cool seasons. The pistil of the respective stages from the cool season contained higher levels of IAA and GA_3 than those of the corresponding stages from the hot season. The IAA level decreased from preanthesis to anthesis and increased thereafter in both seasons. ABA level was high at pre and postanthesis stages in the hot season; however, it remained low in the cool season. Levels of ZR and diHZR in both hot and cool seasons maintained a similar pattern of changes; they increased from preanthesis to three days after anthesis before declining. The level of diHZR at postanthesis was lower in the cool season than in the hot season. Genetically parthenocarpic Severianin contained a high IAA level at preanthesis. Severianin and a progeny of its hybrid had lower levels of ABA, ZR and diHZR than seeded tomatoes after anthesis in the hot season. On the other hand, they also had higher fruit-set rates without exogenous GA_3 or 4-chlorophenoxyacetic acid (CPA) applications than the seeded tomatoes. The results indicate that both auxins and GA were interacting with ABA in controlling fruit-set. The balance of these plant hormones was liable to alternation by high temperatures, and subsequently determined the potential of fruit-setting. A high ratio of ABA : IAA and GA_3 at high temperature was unfavorable for fruit-set, but could be overcome by exogenous auxins and GA_3.

Introduction

Tomato production in the tropics is beset by many problems, and one of the major ones is poor fruit-set (Villareal, 1980). At high temperatures, the probability of floral abscission is usually low just before anthesis but high for a few days after anthesis (Iwahori, 1967). Maximum day and minimum night temperatures above 32°C and 21°C, respectively, are known to limit fruit-set due to an impaired complex of physiological processes in the pistil, resulting in floral or fruit abscission (El Ahmadi and Stevens, 1979; Kuo et al. 1979; Picken, 1984). Exogenous applications of synthetic auxin chlorophenoxyacetic acid (CPA) and synthetic cytokinin (N-6 benzyladenine), are able to overcome reduced fruit-set induced by 4 to 5 hour exposure to 40°C at anthesis (Iwahori, 1968), and endogenous hormones are implicated in the process of pollination, fertilization and abscission (Kuo et al. 1986; Mapelli et al. 1978; Sawhney, 1984; Sjut and Bangerth, 1981; 1983; 1984). The facultative parthenocarpy of certain tomato lines expressed at high temperatures is also associated with endogenous hormones (George et al. 1984). Attempts have been made to relate the hormonal changes to tomato fruit-set under short periods of stressful high temperature, where reduced indole-3-acetic acid (IAA) content in developing fruit (Iwahori, 1967), and reduced auxin and gibberellic acid (GA) content in floral buds and young fruits (Kuo and Tsai, 1984) were reported. There has been little investigation, however,

on the hormonal changes, especially hormones other than auxins and GA, in the process of fruit-setting under stressed growing conditions.

The purpose of this study was to analyze the changes of auxin (IAA), GA, cytokinins (dihydrozeatin riboside-diHZR and zeatin riboside-ZR), and a natural hormone inhibitor abscisic acid (ABA) in the tomato pistil during flowering and fruit-set to understand the hormonal regulation of fruit-setting processes under stressful and optimal growing temperature conditions. A possible relationship between hormones and fruit-set of seeded and parthenocarpic tomatoes when exposed to hot and cool seasons was explored.

Materials and Methods

Plant Material

Four tomato lines [TK-70, CL 1131, facultative parthenocarpic Severianin, and (S × P)-0-4 (a progeny of Severianin × Positional Sterile)] were grown in the field during the hot season, and three lines [CL 1131, TK-70 and PT 1013 (a progeny of Severianin × Heinz 1350)] during the cool season of 1984/85. A randomized complete block design with three replicates, each with 32 plants, was employed for both seasons. Floral buds at 2 days before anthesis (2 DBA), flowers at anthesis, and 3 and 6 days after anthesis (3 and 6 DAA) from each replicate were continuously sampled from July 18 (35 days after field planting) to 31 for the hot season, and December 1 (45 days after field planting) to 11 for the cool season. Means (and ranges) of maximum and minimum temperatures (C) from field planting to last sampling were 33.0° (28.0°-35.0°) and 24.7° (23.0°-26.0°), respectively, for the hot season; and 27.9° (22.0°-32.0°) and 18.1° (12.0°-22.0°), respectively, for the cool season.

Extraction and Purification of Hormones

Pistils were excised from floral buds and open flowers. They were grouped according to the field replication, and then counted and weighed. Each replicate was homogenized separately with cold 80% methanol. After filtering, the residue was re-extracted for 24 hours at 4°C. The combined extract was evaporated under vacuum (35°C) to an aqueous solution, then added with an equal volume of 0.5 M phosphate buffer (pH 8.0), and purified with polyvinylpyrrolidone (PVP). The PVP slurry was filtered and eluted with 50 ml of 0.5 M phosphate buffer (pH 8.0). The filtrate was adjusted to pH 2.5 with 6 N HCl, and then partitioned three times with equal volumes of ethylacetate. The ethylacetate phase was evaporated to dryness under vacuum (35°C), taken up in 0.5 ml methanol, and separated by means of thin-layer chromatography on 0.3 mm silica gels (Sigma) using chloroform:ethylacetate:acetic acid (12 : 8 : 1, v/v) as solvent. The chromatogram was divided into 10 equal fractions, and the fractions which corresponded to ABA, GA_3 and IAA were separately scraped off and eluted with ethylacetate and methanol (1 : 1, v/v). The eluted solution was evaporated to dryness and stored at -15°C until further analysis with high performance liquid chromatography (HPLC). For the extraction of cytokinins, the aqueous phase, after partitioning with ethylacetate at pH 2.5, was readjusted to pH 8.0 with 1 N NaOH, and partitioned three times with n-butanol. The n-butanol fraction was evaporated to dryness under vacuum (45°C) and stored at -15°C.

Quantification of Hormones

The hormonal content of extracts was quantified by the Water Associates HPLC system consisting of one solvent delivery system (model 6000A), universal injector (U6K), variable wavelength absorbance detector (model 440), a Merck Li-Chrosorb RP-18 (10 μm) column, Perkin Elmer recorder (model 56), and Hewlett Packard integrator (model 3390A). The sample was dissolved in 250μ methanol, and 10-15μ were injected. For elution, a solvent system of

methanol:water:acetic acid (45 : 55 : 1.2, v/v) at 1.2 ml/min was used for ABA, GA_3 and IAA. For ZR and diHZR acetonitrile : 10 mM ammonium acetate (15 : 85, v/v) at 1.0 ml/min was used. Hormones were detected at 254 nm, and quantified by standards of (+) cis-trans ABA, GA_3, IAA, ZR and diHZR. All measurements were repeated three times with three replicates for each treatment.

Application of CPA and GA_3

Plants of TK-70, CL 1131, Severianin, and (S × P)-0-4 (or PT 944 in the cool season) were grown in a randomized complete block design with three replicates, each with 32 plants, next to the field used for sampling the reproductive organs. Plants were maintained as double stems. The entire clusters, with their first flowers newly opened, of the second to sixth clusters were briefly dipped once in CPA (100 mg/l) or GA_3 (400 mg/l) in 0.02% Tween 20, or only in 0.02% Tween 20. Fruits were harvested 51 days after planting in the hot season, and 62 days in the cool season. Data on fruit yield/plant, number of fruits/plant, fruit size, and number of seeds/fruit were determined. The percent fruit-set of each cluster was also calculated.

Results

In the hot season the ovaries in all lines gradually increased in fresh weight from 2 DBA to anthesis. Thereafter, the ovary growth of CL 1131 and TK-70 arrested, but Severianin and S × P-0-4 continued a rapid growth between 3 and 6 DAA. In the cool season the ovary of CL 1131, PT 1013 and TK-70 increased steadily from 2 DBA to 6 DAA, except where there was a rapid growth of CL 1131 between 3 and 6 DAA (Figure 1).

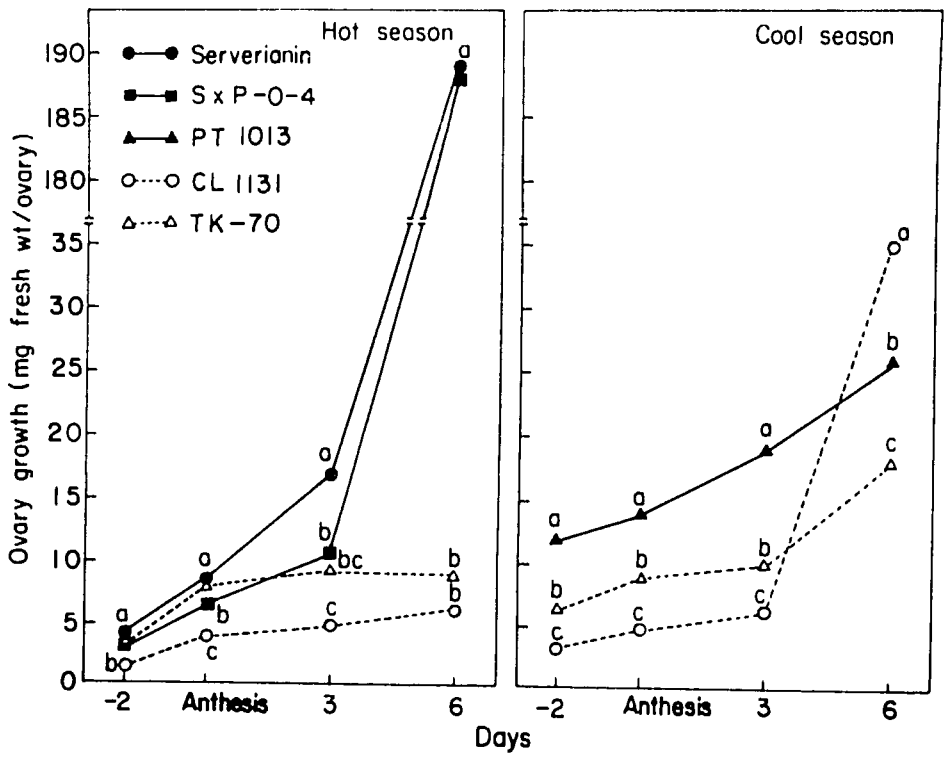

Figure 1. The growth patterns of tomato ovaries during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

The IAA level in the pistil decreased from 2 DBA to anthesis, which was the lowest among various developmental stages determined in Severianin, CL 1131, and TK-70, in the hot season (Figure 2). Severianin had the highest IAA level at 2 DBA. The IAA level increased after anthesis in Severianin, CL 1131, and TK-70 until 3 DAA and decreased thereafter. TK-70 had the highest IAA level at 3 DAA and (S × P)-0-4 maintained low IAA levels after anthesis. In the cool season the IAA level also decreased from 2 DBA to anthesis. The apparent increase in the IAA level did not occur until after 3 DAA in TK-70. In general, IAA levels of corresponding developmental stages were higher in the cool season than in the hot season, 2.6to 6.5-fold for CL 1131 and TK-70 at 2 DBA and anthesis, except with TK-70 at 3 DAA in the hot season.

The GA_3 level in the pistil was higher than the IAA level in both hot and cool seasons. In the hot season, it decreased from 2 DBA to anthesis in TK-70 and CL 1131 whereas no or little decline occurred in Severianin and S × P-0-4 (Figure 3). The GA_3 level peaked at 3 DAA for Severianin and TK-70 in the hot season and decreased after that. In the cool season the GA_3 level of TK-70 also descended from 2 DBA to anthesis. The GA_3 level of corresponding stages were higher in the cool season than in the hot season, 7to 61-fold for CL 1131 and TK-70 at 2 DBA and anthesis.

The ABA level in the pistil was substantially higher than the IAA and GA_3 levels in the hot season; it also decreased from 2 DBA to anthesis, and increased thereafter to maxima at 3 and 6 DAA for TK-70 and CL 1131, respectively (Figure 4). In the cool season, ABA levels apparently did not change before and after anthesis.

In contrast to IAA and GA 3 , ABA levels of corresponding stages were higher in the hot season than in the cool season, 1 to 4-fold for CL 1131 and TK-70 at 2 DBA and anthesis.

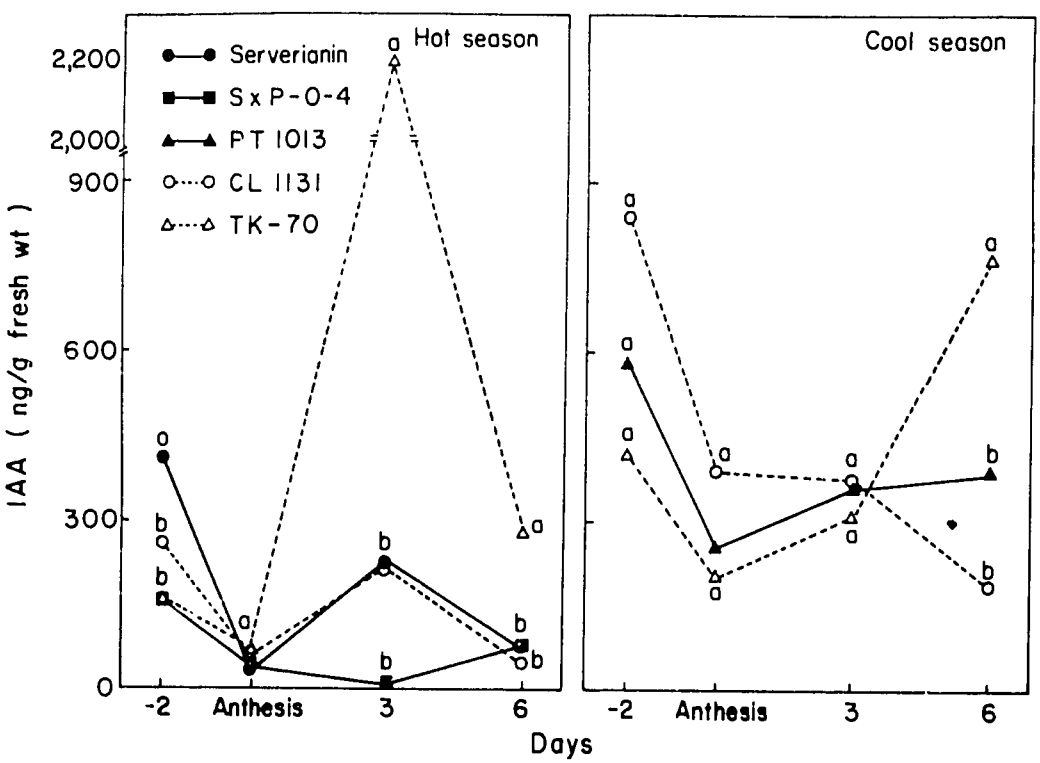

Figure 2. IAA content of pistils during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

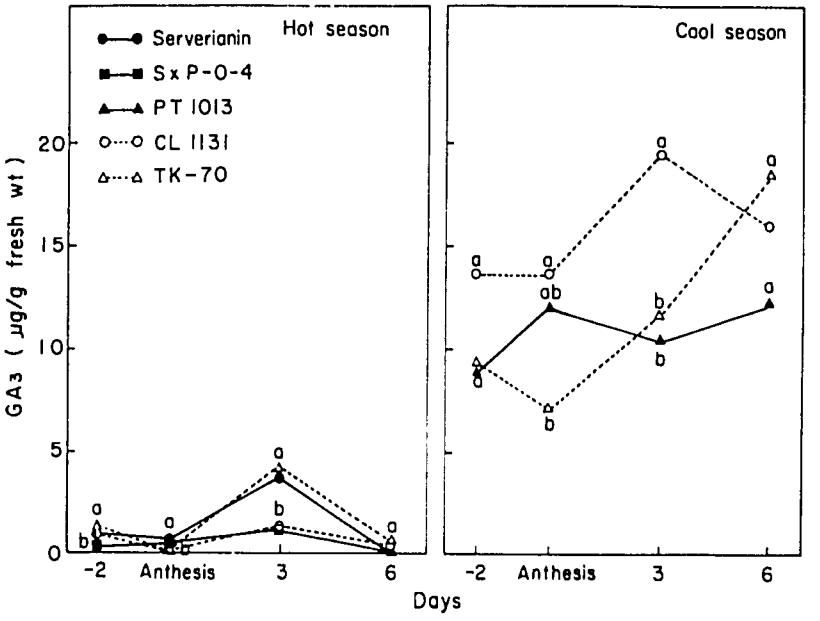

Figure 3. GA_3 content of pistils during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

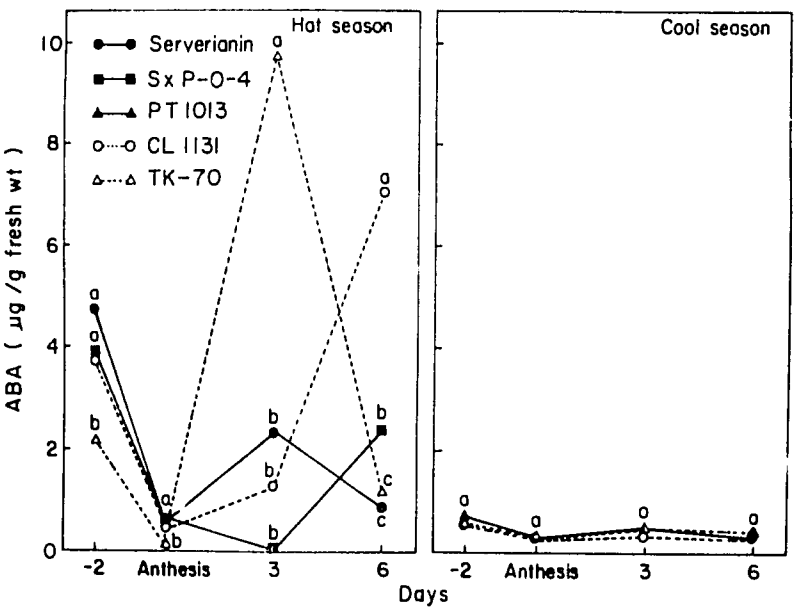

Figure 4. ABA content during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

In contrast to IAA, GA_3 and ABA levels in the pistil, the ZR level increased in both seasons from 2 DBA to 3 DAA before declining, except with TK-70 in the hot season (Figure 5). Severianin and S × P-0-4 had lowest ZR levels at 6 DAA in the hot season, whereas CL 1131 had the lowest level at 6 DAA in the cool season.

The diHZR level of CL 1131 and TK-70 increased from 2 DBA to 3 DAA in the hot season (Figure 6). In Severianin it decreased from preanthesis to anthesis then slightly increased, whereas in (S × P)-0-4 it peaked at anthesis. Both Severianin and (S × P)-0-4 had lowest diHZR levels at 6 DAA in the hot season. In the cool season, the diHZR level of PT 1013 and CL 1131 decreased from 2 DBA to anthesis then slightly increased to 3 DAA before declining again. In the hot season, parthenocarpic tomatoes generally maintained lower levels of ribosidic cytokinins after anthesis than seeded tomatoes.

In the hot season, neither CL 1131 nor TK-70 was able to set any fruit without exogenous CPA or GA_3 (Table 1), which substantially increased fruit-set in all entries. CL 1131 had the highest fruit-set with CPA or GA_3. GA_3 was more effective than CPA in evoking fruit-set in Severianin and (S × P)-0-4. There was a decreasing trend of fruit-set with increasing order of cluster. Both CPA and GA_3 increased fruit yields of CL 1131, Severianin and (S × P)-0-4, however, only CPA was effective in TK-70 (Table 2). GA_3 increased fruit number in CL 1131. However, CPA was more effective than GA_3 in increasing fruit size. GA_3 was found to decrease fruit size of Severianin and (S × P)-0-4. In all entries CPA or GA_3 application resulted in seedless fruits. In the cool season, the fruit-set was high without CPA or GA_3 (Table 3). With the exception of GA_3 on Severianin, neither CPA nor GA_3 improved the fruit-set. There was also a decreasing trend in fruit-set with increasing order of cluster, regardless of treatments. CPA increased fruit yield in PT 944, whereas GA_3 decreased fruit yield in TK-70 (Table 4).

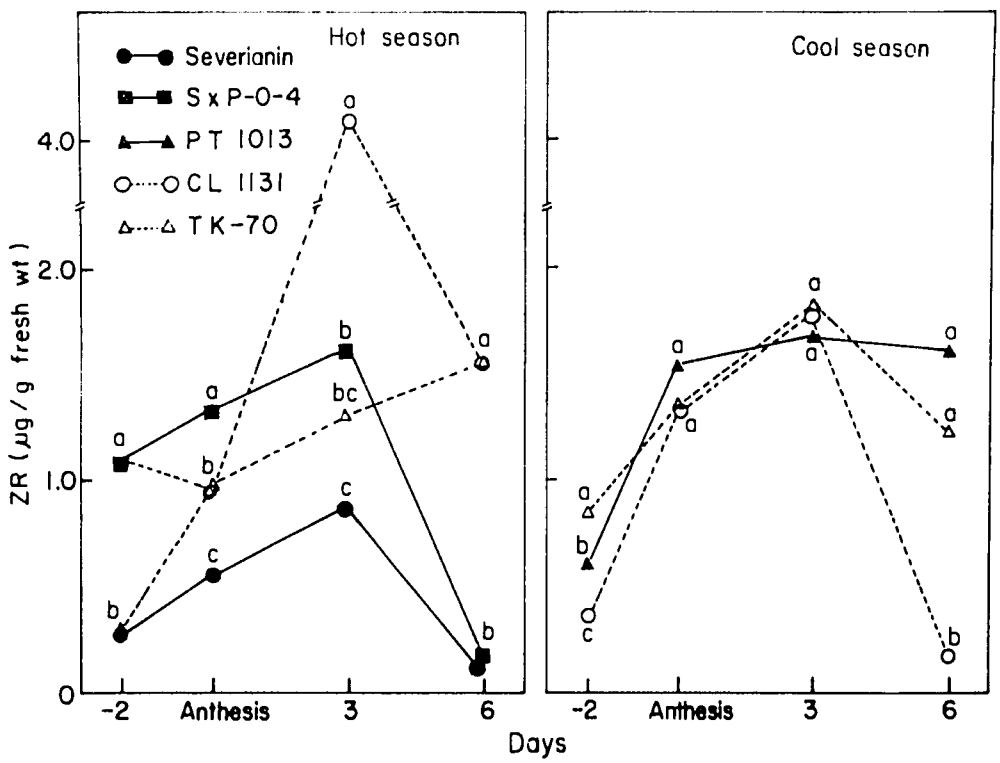

Figure 5. ZR content during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

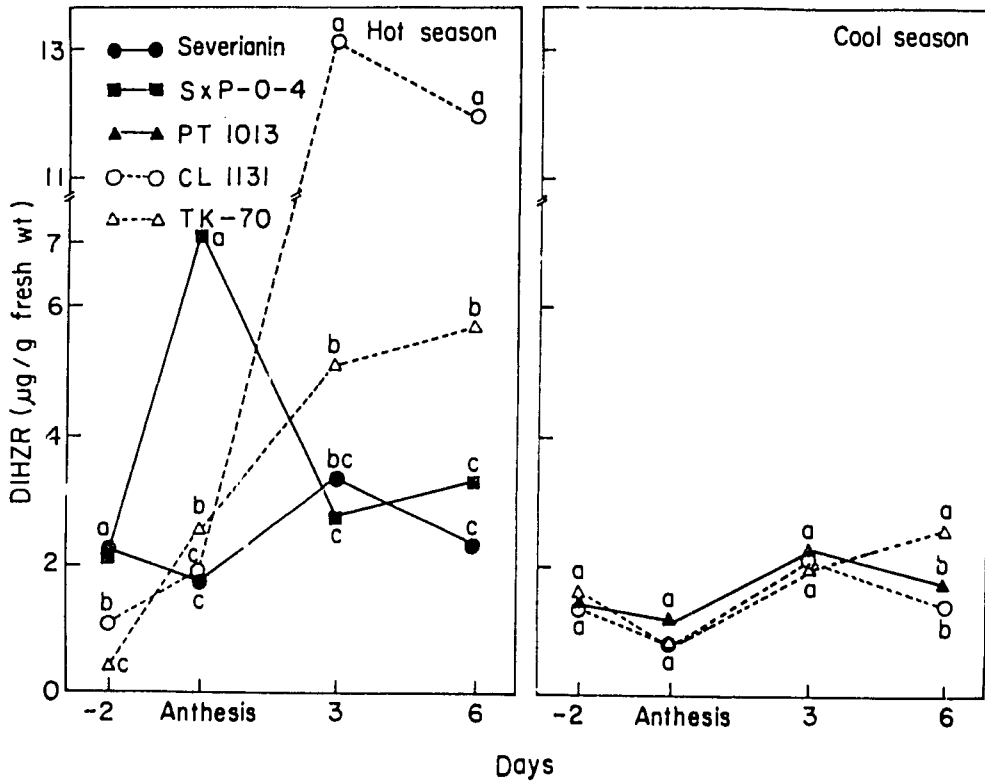

Figure 6. DiHZR content during the initiation of fruit-set. Mean separation by Duncan's multiple range test, 5% level. Within each sampling time, points followed by the same letter do not differ significantly.

Table 1. Effect of CPA (100 mg/l) and GA_3 (400 mg/l) on fruit-set (%) of tomatoes during the hot season.

Entry	Chemical	Fruit-set (%)					
		Cluster order					
		2nd	3rd	4th	5th	6th	Mean
CL 1131	CPA	83 a[z]	77 a	74 a	72 a	69 a	76 a
	GA_3	76 a	75 a	85 a	77 a	76 a	78 a
	CK	0 e	7 de	0 f	0 c	0 e	1 g
TK-70	CPA	46 cd	53 b	24 cd	16 c	13 c-e	30 de
	GA_3	42 cd	23 cd	21 de	38 b	26 bc	30 de
	CK	0 e	0 e	0 f	0 c	0 e	0 g
Severianin	CPA	46 cd	42 bc	37 bc	36 b	27 bc	38 cd
	GA_3	70 ab	54 b	49 b	51 b	24 b-d	50 b
	CK	30 d	17 de	8 ef	9 c	9 de	15 f
(S × P)-0-4	CPA	43 cd	23 cd	25 cd	4 c	22 b-d	23 ef
	GA_3	52 bc	41 bc	36 bc	38 b	36 b	41 bc
	CK	10 e	6 de	2 f	2 c	1 e	4 g
Mean		42	35	30	29	25	

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 2. Effect of CPA (100 mg/l) and GA 3 (400 mg/l) on fruit-set, fruit yield, fruit number and fruit size of cluster 2 to 6, and seed number during hot season.

Entry	Chemical	Yield (g/plant)	Average fruit no./plant	Average fruit size (g)	Seed no. /fruit
CL 1131	CPA	793 a[z]	27 b	29 e	0
	GA_3	367 c	34 a	11 f	0
	CK	0 d	0 g	–	–
TK-70	CPA	544 b	6 d-f	88 a	0
	GA_3	38 d	4 fg	10 f	0
	CK	0 d	0 g	–	–
Severianin	CPA	820 a	9 c-e	88 a	0
	GA_3	747 a	14 c	53 c	0
	CK	321 c	4 e-g	72 b	0
(S x P)-0-4	CPA	431 bc	5 d-f	81 ab	0
	GA_3	409 c	10 cd	41 d	0
CK		84 d	1 fg	89 a	0

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 3. Effect of CPA (100 mg/l) and GA 3 (400 mg/l) on fruit-set (%) of tomatoes during the cool season.

Entry	Chemical	Fruit-set (%)					
		Cluster order					
		2nd	3rd	4th	5th	6th	Mean
CL 1131	CPA	97 ab[z]	96 ab	100 a	98 a	98 a	98 a
	GA_3	100 a	97 ab	99 a	96 a	95 a	97 a
	CK	93 a-d	99 a	97 a	88 ab	88 ab	93 ab
TK-70	CPA	73 de	63 c	64 cd	56 c	51 d	62 d
	GA_3	73 de	77 bc	68 cd	63 c	69 b-d	70 cd
	CK	77 c-e	61 c	61 cd	68 bc	50 d	63 d
Severianin	CPA	97 b-e	75 c	72 cd	71 bc	66 b-d	73 cd
	GA_3	90 a-d	81 a-c	76 bc	80 a-c	81 a-c	81 bc
	CK	73 de	76 c	51 d	62 c	58 d	64 d
PT 944	CPA	77 c-e	77 bc	76 bc	74 a-c	52 d	71 cd
	GA_3	70 e	79 a-c	76 bc	75 a-c	72 b-d	74 cd
	CK	82 a-e	67 c	58 c	56 c	65 cd	66 d
Mean		84	79	75	74	65	

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 4. Effect of CPA (100 mg/l) and GA_3 (400 mg/l) on yield components, fruit-set and seed number of clusters 2 to 6 of tomatoes in the fall season.

Entry	Chemical	Yield (g/plant)	Average fruit no./plant	Average fruit size (g)	Average seed no./fruit
CL 1131	CPA	1469 ef[z]	33 ab	44 e	17 ef
	GA_3	1162 f	33 ab	35 e	52 d
	CK	1248 f	37 a	33 e	88 b
TK-70	CPA	2588 a	21 ef	126 ab	14 e-g
	GA_3	1724 de	23 d-f	74 cd	71 c
	CK	2547 ab	28 b-d	90 c	115 a
Severianin	CPA	2539 ab	21 ef	120 b	1 h
	GA_3	2217 a-c	30 bc	72 d	3 gh
	CK	2161 a-d	24 de	90 c	24 e
PT 944	CPA	2595 a	18 f	142 a	5 f-h
	GA_3	2090 b-d	26 c-e	81 cd	21 e
	CK	1966 cd	23 d-f	86 cd	78 bc

[z]Mean separation within columns by Duncan's multiple range test, 5% level.

CPA decreased fruit number and fruit size of TK-70, and increased fruit size of Severianin and PT 944. GA_3 increased fruit number but decreased fruit size of Severianin. Both CPA and GA_3 decreased seed number, with greater reduction by CPA than GA_3.

Discussion

ABA, auxin, GA, and cytokinins are shown to be present in the flowers of tomato (Iwahori, 1967; Kuo and Tsai, 1984; Leonard and Kinet, 1982; Sawhney, 1984; Sjut and Bangerth, 1981; 1983; 1984). The present study demonstrated that these hormones were also present in the pistil of tomato prior to anthesis (Figures 2, 3, 4, 5 and 6), which raise questions concerning their exact role in the pistil. GAs are required for ovule development (Sawhney, 1984), and floral fertility (Groot et al. 1987). High ABA levels inhibit pollen germination (McLeod, 1975). In contrast to ABA, both IAA and GA promoted in vitro pollen germination and pollen tube growth (Kuo et al. 1979). It is thus possible that the reduced amounts of IAA and GAs and the increased amount of ABA in the pistil prior to anthesis at high temperatures might reduce the normal pistil development and the chance of fertilization.

The fact that levels of IAA and GA_3 declined to the minimum at anthesis and then increased (Figures 2 and 3) was also observed by others (Kuo and Tsai, 1984; Mapelli et al. 1978; Sjut and Bangerth, 1981; 1984). This probably was responsible for the retarded ovary growth and the increased abscission at anthesis. The ovary would not resume growth (Bunger-Kibler and Bangerth, 1983; Mapelli et al. 1978; Sjut and Bangerth, 1983) until pollination or fertilization, which took place at 2 to 4 DAA (Iwahori, 1967). The concentration of GAs in the pollen (Tsao, 1980) could be an important, although not necessarily the only, factor in sustaining a higher GA_3 level than IAA level in the pistil (Figures 2 and 3).

High temperature is known to reduce IAAand GA-like substances in young fruits of tomato (Kuo and Tsai, 1984), and auxins in developing fruits between 5 to 10 DAA (Iwahori, 1967). The present study shows that the tomato pistil at postanthesis of hot season also had low IAA and GA_3 levels (Figures 2 and 3). On the other hand, exogenous CPA or GA_3 were able to overcome the poor or absence of fruit-set in the hot season (Tables 1 and 2).

These results suggest that the reduction of both IAA and GA_3, due to high temperature, was accountable for poor fruit-set in the hot season. Regarding the role of IAA and GA_3 in fruit-set, the high IAA level in the pistil could be an important factor in their resistance to abscission because IAA is known to inhibit tomato flower abscission (Roberts et al. 1984). On the other hand, GAs enhanced xylem differentiation (Bangerth and Sjut, 1978), therefore, they might increase auxin transport thus, preventing abscission.

The developing seed has been the source of ABA (Sjut and Bangerth, 1983). However, the low ABA level in the pistil in the cool season (Figure 4), along with reduced seed formation in hot season (Table 2) due to reduced pollination and fertilization (El Ahmadi and Stevens, 1979; Kuo et al. 1979; Picken, 1984), seem to refute the suggestion that the developing seed is the only source of ABA. High ABA contents in the leaves were associated with high temperatures (Daie and Campbell, 1981), with greater increases in the roots than the leaves under stress conditions (Cornish and Zeevaart, 1985). Thus, high temperature might increase ABA levels in the shoot or root, and later the ABA could be translocated to the pistil. Since both GA and ABA are products of the terpenoid pathway of biosynthesis (Sembder et al. 1980), it is also possible that the GA synthesis took precedence over the ABA synthesis in the cool season. As plants became stressed, synthesis of GA declined, permitting the synthesis of relatively greater amounts of ABA. Since ABA caused abscission of pedicels (Kuo et al. 1979; 1986), the high ABA concentration over IAA and GA in the pistil before and after anthesis in the hot season could be a major factor in the high probability of abscission.

Both zeatin and dihydrozeatin are naturally occurring cytokinins. Their ribosides were more mobile but less active than free cytokinins (Palmer et al. 1982; Sembder et al. 1980). The root system was a main site of zeatin and zeatin riboside synthesis (Koda and Okazawa, 1978), and

their balance was subjected to alternation by soil temperature (Menhenett and Wareing, 1975). High ZR levels during the period of anthesis to 3 DAA (Figure 5) indicate that this less active form of zeatin was translocated from the xylem sap (Van Staden and Menary, 1976) to the pistil, where it was converted to a more active form. During the period of preanthesis and early postanthesis stages, the ovary growth was mainly attributed to cell division, and at subsequent stages, to cell expansion (Bohner and Bangerth, 1988; Bunger-Kibler and Bangerth, 1983; Mapelli et al. 1978). High endogenous cytokinins were responsible for cell division in the ovary (Abdel-Rahman et al. 1975; Bohner and Bangerth, 1988; Mapelli, 1981). Since zeatin and its riboside are known to be converted into diHZR and its riboside, degradation metabolites of zeatin (Sembder et al. 1980), it is possible that high temperature caused rapid conversion of ZR to diHZR (Figures 5 and 6) before it could be freed as an active zeatin for cell division. This was supported by the fact that the high ZR and diHZR contents of CL 1131 and TK-70 after anthesis (Figures 5 and 6) were associated with the smallest ovary growth in the same interval (Figure 1).

The high level of IAA before anthesis (Figure 2) and low ribosidic cytokinins after anthesis (Figures 5 and 6), found in parthenocarpic Severianin and (S × P)-0-4, were in accordance with other parthenocarpic tomatoes (Mapelli, 1981; Mapelli et al. 1978). Parthenocarpic Severianin under high temperature conditions still produced adequate IAA (Figure 3), in spite of possible heat damage on parts of reproductive organs, to counteract the potential abscission caused by high a ABA level (Figure 4). On the other hand, IAA peaked at 3 DAA and corresponded to the approaching end of cell division and the beginning of cell expansion (Mapelli et al. 1978). Thus, it is possible that a high IAA level is related to the start of cell expansion processes, which take precedence over cell division caused by cytokinins.

Varietal difference in fruit-setting rates of tomatoes with an equal amount of CPA or GA_3 in the hot season (Table 1) could be attributed to variations of endogenous GA, IAA and ABA before and after anthesis, or varietal receptiveness towards different kinds of GAs. Both TK-70 and Severianin contained high GA_3 levels at 3 DAA. TK-70 also had a high IAA level at the same stage. It is possible they did not require excess CPA and GA_3 for fruit-set; however, the highest ABA level of TK-70 at 3 DAA could counteract exogenous CPA or GA_3 on fruit-set at high temperature. Thus, TK-70 was less responsive to exogenous CPA or GA_3. The fact that CL 1131 was most responsive in fruit-set to exogenous CPA or GA_3 could be attributed to low IAA and GA_3 in the pistil (Figures 2 and 3). The decreasing trend of fruit-set with increasing cluster order (Tables 1 and 3) could be a result of first-induced fruits having a dominant effect on the growth of later induced ones.

With respect to fruit size, GA_3-induced fruits were smaller than the nontreated control or CPA-induced fruits in the hot season (Table 2). This may be due to the limiting effect of GA_3 on cell division (Sjut and Bangerth, 1983). The high ratio of GA_3: auxin was detrimental for the growth of tomato fruits (Bangerth and Sjut, 1978). Similarly, the high GA_3 level or GA/auxin ratio at 3 and 6 DAA of CL 1131 in the cool season (Figure 3) could account for its small fruit size under favorable, cool temperature conditions (Table 4). On the other hand, ABA concentration in distal, small fruits was shown to be higher than that in proximal, large fruits (Ho et al. 1983). Therefore, it is possible that the high ABA level in the pistil (Figure 4) could also contribute to the small fruit size, in general, in the hot season (Table 2).

The developing seeds are recognized as the source of auxins and GAs needed for fruit development (Varga and Bruinsma, 1976). High temperatures prevented normal pollen and ovule development and enhanced style elongation (El Ahmadi and Stevens, 1979), hence the failure of fertilization for seed formation. This may be responsible for parthenocarpic fruits induced by CPA or GA_3, or spontaneous fruit-set in genetically parthenocarpic Severianin induced by high temperature (Table 2). On the other hand, although the cool season was ideal for the normal process of fruit-setting, the rapid ovary enlargement caused by CPA or GA_3 might still prevent fertilization, resulting in reduced seed formation (Table 4).

Conclusions

From the foregoing information and the known physiological properties of the hormones, there is little doubt that auxin, GAs, cytokinins and ABA in the pistil act alone or interact to influence fruit-set of tomato. Since information on the chemical nature and the metabolism of the hormones in the initiation of fruit-set is still far from complete, it remains a matter of conjecture as to how they may be interacting under high temperature conditions. Considering that increased ABA levels and reduced GA_3 and IAA levels (Figures 2, 3 and 4) have correlation with respect to poor fruit-set in hot season, and vice versa in cool season, therefore, it would be plausible that the ratio of ABA : IAA and/or GA_3, which is liable to alteration by high temperature, is responsible in controlling fruit-set.

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150

16

Abscission of Reproductive Structures in Pepper: Causes, Mechanisms and Control

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Abstract

The most frequent causes of abscission of pepper flowers, fruit and flower buds are environmental factors such as heat, drought or low light conditions, diseases or insect pests. When at least some of these stresses are present, abscission appears to be mediated by ethylene generated within the reproductive tissue. Although the synthetic auxin NAA is very effective in preventing abscission of disbudded pedicels, the same compound does not prevent abscission of shade-stressed buds. This indicates the involvement of other compounds in growth which help prevent abscission under stress. When stress is imposed on pepper plants during reproductive growth, the susceptibility of reproductive structures varies with age of tissue: from open flowers (most susceptible), buds, young fruit to old fruit (most resistant). The best approach to abscission control is the development of resistant cultivars. Screening methods that identify genotypes resistant to stress-induced abscission have been developed. Of these, the use of ethephon sprays to mimic the ethylene generated by stress has proven effective and easy to apply.

Introduction

Loss of flower buds, flowers and young fruits in pepper (*Capsicum annuum* L.) is one of the most important factors limiting the production of this crop in both temperate and tropical conditions (AVRDC, 1986; Greenleaf et al. 1978; McGraw and Greig, 1986; Minges and Warholic, 1973). While the disorder is most often associated with large-fruited sweet peppers such as the bell types (Cochran, 1936; Rylski and Spigelman, 1982; Sawahata et al. 1980), similar observations have also been made on three cultivars of chilli pepper (Dorland and Went, 1947) and on 'hot' pepper (Song et al. 1976). Within and among these types, however, considerable varietal differences appear to exist, which allow cultivar selection for better fruit-set under adverse environmental conditions (Greenleaf et al. 1978). The development of abscission resistance selection techniques requires an understanding of the causes and the mechanisms of reproductive structure abscission. These are covered in the present paper, before reviewing possible screening techniques that might identify superior genetic material.

Causes of Reproductive Structure Abscission

Environmental stresses such as extremes of temperature, lack of moisture, low light conditions and an imbalance of mineral nutrients are most often cited as causes for flower and fruit drop of pepper. Biotic stresses such as diseases and insect pests may also cause loss of flowers or flower buds.

Temperature Stress

The adverse effect of high temperatures on fruit-set of peppers has been reported by many workers. Cochran (1936) compared growth and fruit-set of bell pepper plants grown in greenhouse

compartments in which both day and night temperatures differed. The highest fruit-set percentage was obtained at 21/16°C (day/night), followed by 27/21°C. At 38/32°C, all flowers and flower buds abscised. Similar results were obtained by Song et al. (1976), who also observed decreased fruit-set as temperatures were raised from 18/13 to 23/18 and 33/28°C.

A comparison of the effect of different night temperatures at constant day temperature also indicated that higher temperatures have adverse effects on fruit-set (Dorland and Went, 1947; Rylski and Spigelman, 1982). With a 27° day temperature, Dorland and Went (1947) found that fruit-set was best at 12.5 and 15.5°C night temperature, and decreased sharply above this level. At 30°C night temperature, flowers failed to reach anthesis, but abscised in the bud stage. Transfer of plants from very high to cool temperatures (38/32 to 16/10°C) at anthesis resulted in 100% fruit-set, although the fruits formed stayed small and were seedless (Cochran, 1936). Rylski (1973) improved the size of such fruits by hand pollination, and advocated this temperature regime for winter production of bell peppers in Israel.

Shade Stress

Temperature effects on fruit-set must be considered together with the light levels under which the plants are grown. For example, under the low light conditions of the Israeli winter in which peppers were grown, temperatures of 35/20°C resulted in 100% abscission (Rylski, 1973; Rylski and Halevy, 1975). Yet the same temperatures in the high light environment of summer under good water management might allow at least some fruit-set.

Light intensity alone may have important effects, apart from its interaction with temperature. Reducing light intensity 70 to 75% by shading has been found by several workers to reduce production of flowers, and to adversely affect fruit-set (Kato and Tanaka, 1971; Park and Jeong, 1976; Sawahata et al. 1980). These experiments imposed long-term shade stress from before anthesis through the fruiting period. Quagliotti et al. (1974) found that season-long shading treatments of 50 or 70% shade reduced flower numbers, but did not however decrease fruit-set. Imposition of one week of 80% shade, starting four days before anthesis, under summer field conditions in Ithaca, New York resulted in abscission of 60% of reproductive structures at the first four nodes, compared to 24% abscission of the controls (Wien, unpublished).

Reducing the ambient light conditions (>600 cal·cm^{-2}·day^{-1}) of the Israeli summer by only 12 or 26% using open-sided screen cages had no detrimental effect on fruit set, and increased total and marketable yields (Rylski and Spigelman, 1986a). Greater light reduction of 47% was detrimental to fruit-set, however, and also reduced branch production and the proportion of fruit on branches. A similar experiment conducted in the winter (400 to 250 cal·cm^{-2}·day^{-1}) however, showed reduced fruit-set at the lowest nodes, and a one-month delay in fruit maturity, when light was reduced by only 25% (Rylski and Spigelman, 1986b). The shaded plants showed a prolonged period of fruit-set, and produced a 22% increase in total yield over the unshaded plants. Scheck (1972) applied 45% shade to pepper seedlings before transplanting and found that the treatment increased plant size. After transplanting to the field, the shaded plants produced 18% more fruit than the controls. In summary, while heavy shade may increase stress and therefore abscission, light shade may benefit pepper growth through reduction in moisture stress and decreased sunscald injury of the fruit.

Moisture Stress

Low plant moisture status has been demonstrated by several workers to decrease fruit-set of pepper. Cochran (1936) demonstrated that low soil moisture status reduced the percentage of fruits set, compared to more adequate levels (Figure 1). Similarly, Bereny (1970) showed that irrigation during dry growing seasons increased the number of flowers formed, and the number of fruit retained on pepper. Others have documented better growth and yield of peppers with supplementary irrigation, but failed to provide data on fruit set percentage (Beese et al. 1982; Hedge, 1987; O'Sullivan, 1972).

The degree of moisture stress required to reduce significantly bell pepper fruit-set appears to be very great. Hernandez-Armenta (1985) showed that not until predawn xylem pressure potentials had decreased to less than -1.5 MPa, a point at which the plants appeared severely wilted, were there measurable increases in abscission of reproductive structures (Table 1). More commonly, restricted moisture supply leads to reduced vegetative growth, fewer flowering nodes and therefore fewer flowers per plant. Although it was difficult to detect reduced plant water status on such plants, in comparison to plants given more water, yields and above ground dry matter were both reduced by 42% (Horton et al. 1982)

At the other extreme, flooding of hot pepper plants was shown by Song et al. (1976) to result in wilting of plants, and an increase in flower abscission. Plants were able to recover, however, even after 40 hours of flooding. AVRDC (1986) also stated that peppers were less susceptible to injury due to flooding than tomato.

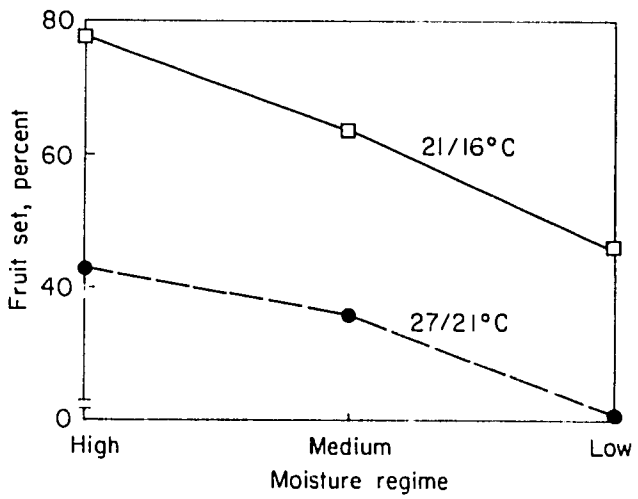

Figure 1.
Influence of air temperature and soil moisture regime on fruit-set of World Beater bell pepper. Results of three-year experiments of Cochran (1936).

Table 1. Effect of cultivar and maximum predawn leaf xylem pressure potential (XPP) on percentage fruit-set under greenhouse conditions[z].

Cultivar	Maximum leaf xylem pressure potential (MPa)			
	-0.3 ± 0.1	-1.5 ± 0.2	-2.7 ± 0.2	Mean
Ace	73.6 ± 7.3 (5)[y]	66.9 ± 10.0 (3)	54.0 ± 4.8 (3)	66.5
Lady Bell	65.2 ± 4.6 (5)	49.8 ± 4.2 (4)	29.5 ± 1.7 (3)	51.2
Shamrock	42.4 ± 3.0 (5)	43.5 ± 6.1 (5)	31.8 ± 2.3 (3)	40.4
Mean	60.45	51.45	38.46	

[z]Main effects of cultivar, linear effect of XPP, and interaction were significant at the 1% level. The quadratic effect of XPP was not significant. Analysis was done on log-transformed data. [y]Mean ± standard error (SE). Number in parentheses corresponds to the number of plants for which the mean was calculated. Percentages are based on 15 to 25 hand-pollinated flowers per plant.

Plant Nitrogen Status

The influence of nitrogen on fruit-set of pepper has been the subject of considerable debate in the literature. Most workers agree that low plant nitrogen status results in poor fruit-set (Cochran. 1936; Hoffman. 1958; Maynard et al. 1962). As nitrogen rates applied to the plants are increased, plant growth, yield and fruit-set are increased. At high rates of nitrogen, some workers have found that yields again decline (Knavel. 1977; Locascio et al. 1981; O'Sullivan. 1979; Thomas and Heilman. 1964), while others noted only a leveling off of yield (Batal and Smittle.

1981; Maynard et al. 1962). Yield decrease at high N levels was ascribed to soluble salts injury by Locascio et al. (1981). The differences in results obtained by different researchers can be ascribed to variation in amounts of N applied, soil types on which the experiments were conducted, and rainfall obtained during the growing season. More work is necessary in this area to monitor plant N status, fruit-set and yield under a number of soil and climatic conditions.

Fruit Load

The general pattern of fruit-setting in pepper under favorable environmental conditions shows an initial period in which most of the flowers set fruit, followed by a period during which the flowers produced abscise (Figure 2). As the early fruits enlarge on the plant, even vegetative growth and flower production are inhibited (Bereny, 1970). As the first fruits mature, vegetative growth, flowering and fruit-setting again resume, repeating the cycle (Kato and Tanaka, 1971; Song et al. 1976). If environmental stress leads to abscission of the early flowers, the period of setting, and the subsequent flower abscission period are respectively delayed (Figure 2). If the growing season is short, due to ending of the rainy season, or onset of cold weather, yield may be permanently reduced by the stress. The cyclic fruit-setting and flower abscission is a phenomenon common to many fruit bearing vegetable crops such as beans (*Phaseolus vulgaris* L.) (Stobbe et al. 1966), cucumbers (de Stitger, 1969) and tomatoes (Hurd et al. 1979). If fruits are removed before they begin the rapid enlargement phase, flowering and fruit-setting become less cyclic. The exact mechanism of this cyclic behavior is not well understood.

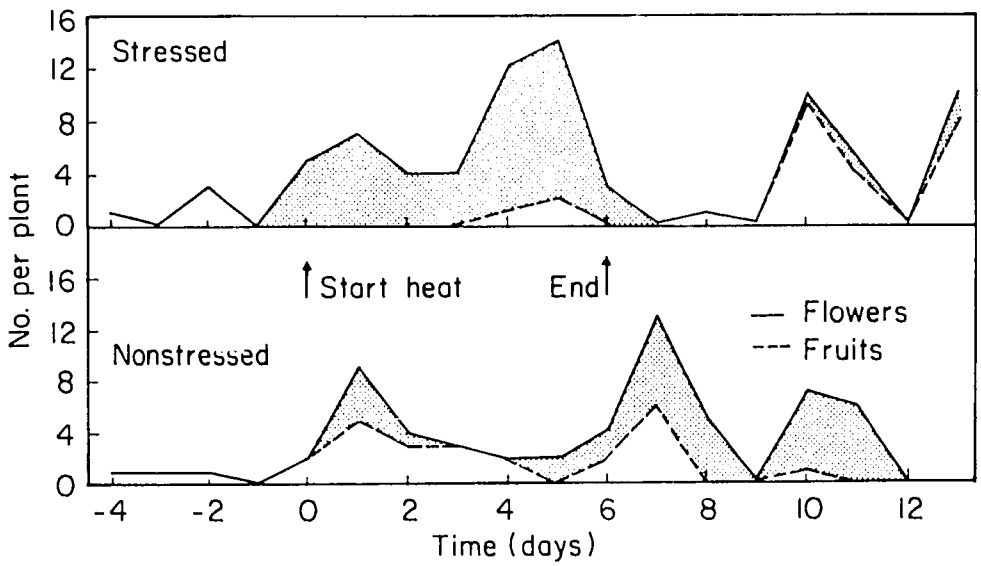

Figure 2. Effect of high temperature (35 25°C day night) for six days during bloom on daily flower production and fruit-set of Canape bell pepper. Shaded areas on each graph represent number of flowers abscised of those that opened that day. Nonstressed conditions consisted of 25 20°C temperatures. Temperature treatments given in reach-in growth chambers. Before and after the six-day temperature treatment, plants were grown in a 27 21°C greenhouse.

Plant Diseases

Viruses. Pepper is attacked by a number of virus diseases, which cause serious economic losses (Boswell et al. 1959; Laborde and Pozo, 1982; Villalon, 1975). Generally, the most

common symptoms expressed by pepper as a result of virus infection are distortion and color changes in the leaves and fruit, and plant stunting. Some viruses that infect peppers, however, have been found to cause flower and flower bud abscission. Cucumber mosaic virus (CMV) in particular has been cited as causing such symptoms on peppers in Mexico (Laborde and Pozo, 1982). Boswell et al. (1959), Agrios et al. (1984) and Joshi and Dubey (1973) noted that CMV causes a severe reduction in fruit numbers of infected pepper plants. The mechanism of this reduction in fruit numbers, and the increased bud and flower drop may be related to the effect of CMV on pollen. Chauhan and Srivastava (1981) found that CMV infection one to two weeks before floral bud initiation led to the production of indehiscent anthers, and a high percentage of sterile pollen. Aillaud et al. (1972) showed that pepper plants developed a number of abnormalities of both the male and female parts of the flowers, including disfunctional pollen and petaloid anthers after inoculation with CMV.

Other viruses attacking pepper may also have similar effects. Lockhart and Fischer (1974) reported that potato virus Y infection of peppers in Morocco resulted in greatly reduced fruit-set. Ohta (1970) induced pollen sterility of pepper having an S-cytoplasm factor by infection with tobacco mosaic virus, broad bean wilt virus or cucumber mosaic.

Fungal and bacterial pathogens. None of the major nonviral diseases affecting pepper appear to cause flower or fruit drop. Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) and powdery mildew (*Leveillula taurica*) both cause severe defoliation of pepper (Bashan et al. 1985; Reuveni et al. 1976). In view of the role of ethylene in causing bud abscission (see below), it is interesting to note that bacterial spot infection is accompanied by an increase in ethylene production by infected leaves (Ben-David et al. 1986). Defoliation from both pathogens was prevented by spray applications of IAA.

Insect Pests

The literature on insect pests of peppers does not mention predation leading to loss of flower buds, flowers or fruits. The sucking insect *Lygus lineolaris* has been shown to reduce fruit-set and yield of tomatoes in New York State, however (Davis et al. 1963). *Lygus* has had similar effects on other crops such as *Phaseolus*, alfalfa, and cotton (Tingey and Pillemer, 1977). In cowpea, Megaluro thrips attack in the late vegetative stage can lead to severe loss of flower buds, greatly delaying or preventing the production of pods (Singh and Allen, 1979). Since loss of flower buds before anthesis is hard to detect in the field, insect-caused bud abscission in pepper may require more attention.

Mechanisms of Bud, Flower and Fruit Abscission

When pepper plants were exposed to environmental stress such as one week of 80% shade during the flowering period, open flowers were the first reproductive organs to be shed, followed by flower buds (Table 2). Applying the same stress to plants two weeks older resulted in more flowers and buds being lost, while young fruit were nearly always retained. The unshaded fruiting plants also suffered some bud and open flower loss, presumably due to the stress imposed by the rapidly developing fruit. Flower bud loss is potentially more serious than loss of flowers because bud drop robs the plant of the capability to flower for several weeks, and thus may prevent fruit production before the end of the growing season.

The mechanism by which the pepper plant causes abscission of its reproductive structures under unfavorable environmental conditions has not been extensively studied. Therefore investigations on other species will be relied upon to supplement our existing knowledge. A general model of the shedding of vegetative or reproductive organs ascribes a central role to the interaction of several plant growth regulators produced by the plant (Beyer, 1973; Morgan, 1984; Osborne and McManus, 1984). This model states that a functional, nonsenescent leaf

or bud produces auxin and other growth promoters which diffuse out of the organ down the pedicel or petiole, and thereby prevent the formation of an abscission layer. Under stress conditions, or under the influence of disease or insect damage, the injured leaf or bud increases the production of ethylene, a gaseous growth regulator which thus reduces the auxin production rate of the organ, decreases the rate of auxin transport down the pedicel or petiole and accelerates the formation of an abscission layer. This simplified model therefore postulates that it is the balance between stress ethylene and auxin and perhaps other growth promoters produced by the developing organ, that determines whether the bud or leaf will be retained or abscised.

There is some evidence for the validity of this model for pepper bud abscission. In some pepper cultivars, if buds are removed, leaving the pedicel stubs attached to the plant, abscission of the stub occurs within two days (Table 3). This abscission was prevented by the application of low levels of the synthetic auxin, NAA, into the stub using a wick system (Table 4). Other growth promoters, such as gibberellic acid and the synthetic cytokinin, benzyl adenine, were much less effective in preventing abscission and did not increase the effectiveness of low levels of NAA. It thus appears that auxin production by pepper buds prevents bud abscission.

Table 2. Abscission of flower buds, flowers and fruits of Ace and Shamrock bell peppers after subjecting plants to seven days of 80% shade at flowering or at two weeks after flowering (fruiting).

Stage of Growth	Shade level (%)	Cultivar	Abscission (%)[z]		
			Buds	Flowers	Fruit
Flowering	0	Ace	0	0	
	0	Shamrock	0	5 ± 13[y]	
	80	Ace	30 ± 9	60 ± 55	
	80	Shamrock	62 ± 16	100 ± 0	
Fruiting	0	Ace	38 ± 39	0	0
	0	Shamrock	98 ± 7	49 ± 37	0
	80	Ace	42 ± 22	79 ± 27	2 ± 7
	80	Shamrock	87 ± 14	98 ± 18	19 ± 24

[z]Data taken seven days after shade removal [y]Mean ± standard error (SE)

Table 3. The effect of bud removal on time to pedicel abscission, and percent pedicel retention for three pepper varieties, grown in pots in the greenhouse.[z]

	Bud no	Time of abscission (days)	Retained (%)[y]
Ace	54	2.28 ± 1.11[x]	13
Lady Bell	60	1.50 ± 0	3
Shamrock	46	1.51 ± 0.07	0

[z]A total of up to six buds were removed per plant, from tiers 1 to 3 [y]Retained for 10 days after bud removal. [x]Mean ± standard error (SE)

Table 4. Effect of NAA concentration on abscission percentage of disbudded pedicel stubs.[z]

NAA conc., molar	Abscission (%)[y]	
	Expt 1[x]	Expt 2[x]
0	83 a	80 a
1×10^{-8}	39 b	69 a
3×10^{-8}	17 bc	62 a
7×10^{-8}	8 c	22 b
1×10^{-7}	0 c	3 b

[z]NAA solution infused into pedicel through a cotton thread-wick dipped in a vial attached to the plant. [y]Average of three cultivars [x]Abscission after seven and 14 days of treatment for Expt. 1 and 2, respectively.

Ethylene also appears to have a role in abscission of shade-stressed pepper buds. If pepper plants were covered with 80% shade cloth for seven days, abscission of reproductive structures was increased significantly, and ethylene evolution by the buds also increased (Table 5). Samples taken for ethylene determination for the data in Table 5 included both abscising and retained buds. If individual abscising buds were measured separately from those not abscising, a more distinct difference in ethylene production was obtained (Table 6). Confirming evidence of the importance of ethylene in abscission of pepper buds comes from the fact that infusion of ACC (1-aminocyclopropane-1-carboxylic acid), the natural precursor of ethylene, caused abscission of peppers buds (Table 7). However, another abscission-causing hormone, abscisic acid (ABA), was not effective in causing bud abscission at concentrations as high as 1×10^{-4} M. Thus ABA seems to play a different role in pepper from its role in tomato (AVRDC, 1987) or cotton (Guinn and Brummett, 1987) with regard to abscission.

Work by others with peppers also indicates the importance of auxin in the retention of flowers and fruit. A foliar spray of 5-10 ppm NAA at flowering was shown by Chandra et al. (1975) to decrease flower drop moderately and increase fruit yields. Patil and Ballal (1980) reported similar results with 20-80 ppm IAA. Judging from the fairly high yields of the untreated controls in this work and in that of Chandra et al. (1975), the plants were not greatly stressed in these experiments. At higher concentrations of NAA (50-150 ppm), however, Rylski (1972) found a suppression and delay of flowering.

Table 5. Abscission of reproductive structures, ACC (1-amino cyclopropane-1-carboxylic acid) content of flower buds, and ethylene evolved by these buds as a result of a seven-day 80% shade treatment in the field.[z]

Treatment	Abscission[y] (%)	Ethylene evolved, (nl/g/h)[x]	ACC (n moles/g)[x]
Open	32	0.171	0.202
80% Shade	44	0.515	0.464
Significance	**	**	NS

[z]Data are averages for three cultivars. [y]Abscission one week after the end of a seven-day shading treatment. [x]ACC and ethylene were measured on day six of a seven-day shade treatment.

Table 6. Ethylene evolution by individual excised pepper buds, as influenced by seven days of 80% shade.[z]

Cultivar	Ethylene (nl/g/h)[y]		
	Unshaded	Shaded, nonabs.	Shaded, absc.
Ace	0.21 ± 0.40	0.05 ± 0.06	0.30 ± 0.26
Lady Bell	0.20 ± 0.22	0.30 ± 0.19	1.19 ± 0.72
Shamrock	0.33 ± 0.24	1.70 ± 2.26	2.19 ± 1.70

[z]Values are averages of eight samples per treatment, incubated for one hour at 20°C in 4.7 ml glass shell vials. Samples taken from field planting three of the field shading experiment [y]Average of eight buds ± standard error.

Table 7. Bud abscission of bell pepper, cv. Shamrock, as a result of infusion of ACC, the precursor of ethylene, into the pedicel using a wick system.

ACC Conc.	Abscission (%)[z]		
	Expt. 3	Expt. 6	Expt. 7
0	0 a	0 x	16 m
1×10^{-3} mM	22 b	0 x	62 n
5×10^{-3} mM	100 c	64 y	100 o
1×10^{-2} mM	100 c	94 z	100 o

[z]Abscission after seven days treatment.

None of our attempts to improve fruit-set of shade-stressed pepper by application of NAA solutions to the developing buds and open flowers has been successful to date. Silveira and Taborda (1986) were also unable to improve fruit-set of pepper growing in unheated greenhouses in Portugal in the winter by treatment with a mixture of the synthetic auxins naphthoxyacetic acid and 2-4D. Again, these results contrast with the efficacy of the synthetic auxins in tomato fruit-set improvement under low temperatures (Mann and Minges, 1947) and under high temperatures (AVRDC, 1987).

While the abscission of pepper flowers at or shortly after anthesis may also have a hormonal mechanism similar to that of flower bud drop, the immediate cause can often be a failure in fertilization of the flower. In contrast to the depth to which the complex series of steps in pollen development, pollen dehiscence, pollination and seedset under adverse conditions has been investigated in tomato (e.g. Kuo et al. 1978), there have been only a few such studies in pepper. Hoffman (1958) found that under low light conditions, pepper flowers showed pollen tube degeneration in the pistil so that little pollen reached the ovules. Nitrogen deficiency often resulted in degeneration of the embryo sacs at anthesis. The elongation of the style beyond the anthers, a frequent symptom of high temperature stress in tomato (Kuo et al. 1978), also occurs in pepper, even under nonstress conditions (Erwin, 1932). Since the morphology of the pepper flower allows pollinating insects easy access to the pollen, style elongation should not normally be a cause for lack of fruit-set. In addition, the pendant attitude of flowers of many pepper types facilitates pollen transfer by gravity.

The finding mentioned previously, that under cool temperature conditions pepper sets fruit without seeds, indicates that seedset is not essential for fruit retention on the plant. The hormonal basis for parthenocarpic fruit-set has to our knowledge not been studied in pepper. In tomato the cell numbers and auxin content of ovaries of parthenocarpic fruit were higher at anthesis than those of normal seeded lines (Mapelli et al. 1978). Work is needed to relate the content of growth promoting and growth inhibiting hormones in developing pepper ovaries to fruit-set under a range of temperatures.

Control of Reproductive Structure Abscission in Pepper

The best strategy for controlling loss of reproductive structures in pepper appears to be to take advantage of the tremendous range of variability that seems to exist in pepper for this trait. Study of the centers of origin of the cultivated *Capsicum* species indicates that some species may be more abscission-resistant under lowland tropical conditions than others (Andrews, 1984; Pickersgill, 1971). *Capsicum frutescens* and *C. chinense* probably originated in the Amazon basin (Pickersgill, 1971) and thus would most likely give rise to cultivars adapted to hot conditions. Mesoamerica is the center of diversity of *C. annuum*, where a range of types is found growing from the warm lowlands to the middle altitudes (Laborde and Pozo, 1982). One could therefore expect to find a range of fruit-set response types within this species. *Capsicum pubescens* was found originally at 2000 to 2500 m elevation in the Andes, and might be a good source of material more adapted to cool weather conditions.

Despite the fact that variability exists within *Capsicum* for ability to set fruit under adverse conditions, it is frequently necessary to combine this trait with other desirable characteristics such as high yield, disease resistance, etc. through breeding. A screening technique is then needed to ensure that the offspring produced in the breeding program is also able to maintain fruit-set under stress. The most direct way to accomplish this is to subject the plants to conditions that cause abscission, as identified earlier. Thus, the hot, humid conditions of the Taiwan summer have been used by AVRDC to develop tomato lines with ability to set fruit under high temperatures (Villareal and Lai, 1978). Unfortunately, temperature variation during the season, and the incidence of diseases and insect pests, may obscure the varietal differences. A combination of heat and shade stress was devised by Villareal and Lai (1978) to screen tomatoes for fruit-set. They grew the tomato lines in a shaded greenhouse in which temperatures frequently exceeded 40°C.

Under the temperate conditions of New York State, we have used plastic-covered tunnels to generate high enough temperatures to subject pepper plants to heat stress just before and during anthesis (Hernandez-Armenta, 1985). In the hot, clear polyethylene-covered tunnels, three cultivars demonstrated superior fruit-set and lower flower bud abscission than the rest (Tables 8 and 9). Temperature control in tunnels is very difficult, however, with the possibility of sudden temperature increases to injurious levels on sunny days. In addition, screening lines close to or at anthesis may necessitate different planting dates for early and late-flowering lines so that all are subjected to the same duration and intensity of stress at a similar growth stage. This would be difficult to achieve in a breeding program in which progeny may be segregating for flowering date.

Another variation on the tunnel technique is the use of shade cloth-covered tunnels for screening for abscission susceptibility. In a field experiment in 1987, a one-week shading with 80% shade fabric at anthesis resulted in marked varietal differences in bud abscission (Table 10). The cultivar most susceptible to high temperature also showed the most abscission due to shade (Tables 9 and 10). Canape and Ace showed resistance to abscission in both tests. Shade cloth-covered tunnels are less subject to excess heat than clear plastic-covered tunnels, but the cost of the cloth would be prohibitive to many breeding programs. Synchronization of flowering and stress imposition would also be difficult with this method.

Table 8. Percentage fruit-set at first three flower nodes of eight bell pepper cultivars in a field trial at Freeville, NY in 1983.

Cultivar	Tunnel cover material		
	None	White poly.	Clear poly.
Canape	99 ± 1[z]	92 ± 2	92 ± 1
Ace	99 ± 1	97 ± 2	87 ± 3
Gypsy	99 ± 1	98 ± 1	8[illegible] ± 7
E. Calwonder	94 ± 0.3	92 ± 2	7[illegible] ± 6
Big Bertha	99 ± 1	91 ± 4	64 ± 6
Lady Bell	94 ± 2	93 ± 3	56 ± 5
Green Boy	98 ± 1	97 ± 2	52 ± 7
Shamrock	92 ± 4	77 ± 3	37 ± 4
Mean max temp., °C[y]	34	41	48
Range m temp., °C	26-37	28-47	33-53

[z]Means of three replications of 10 plants each ± standard error [y]Temperature measured 20 cm above plastic mulch for a 10 day period after start of flowering. Source: Hernandez-Armenta, 1985.

Table 9. Percent bud abscission at first three flower nodes of eight bell pepper cultivars in a field trial at Freeville, NY in 1983.

Cultivar	Tunnel cover material		
	None	White poly.	Clear poly.
Canape	0.6 ± 0.6[z]	0 ± 0	1.0 ± 0.6
Ace	0.3 ± 0.3	1.3 ± 1.3	5.6 ± 1.8
Gypsy	0.3 ± 0.3	1.0 ± 0.6	9.6 ± 5.8
E. Calwonder	2.3 ± 0.3	3.0 ± 1.5	23.6 ± 7.3
Big Bertha	1.0 ± 0.6	6.3 ± 3.4	34.3 ± 6.7
Lady Bell	1.6 ± 1.6	5.6 ± 2.3	39.6 ± 4.1
Green Boy	1.6 ± 0.9	2.0 ± 1.2	45.3 ± 7.2
Shamrock	6.3 ± 3.5	23.0 ± 3.1	61.6 ± 4.7

Source: Hernandez-Armenta, 1985. [z]Means of three replications of 10 plants each ± standard error.

Table 10. Abscission of reproductive structures on the lowest four flowering nodes of eight pepper cultivars when subjected to one week of 80% shade in the field at Freeville, NY in 1987.

Cultivar	Abscission (%)[z]	
	Control	Shaded
Ace	4	39
Canape	20	48
Belrubi	33	49
Lady Bell	15	42
Green Boy	28	67
Big Bertha	26	69
E. Calwonder	32	81
Shamrock	29	87
LSD .05[y]	13	13

[z]Differences between cultivars, between treatments and interaction significant at 1% level. [y]Comparison within shade treatments.

The similar reaction of pepper cultivars to different kinds of stresses (compare Tables 1, 9 and 10) indicates that these stresses may have impact on a common metabolite essential for normal growth of the reproduction tissue. Evidence from work with other species would suggest that shade and high temperature stress both result in low levels of reducing sugars and starch in reproductive structures (Dinar and Rudich, 1985; Guinn, 1976). In cotton, Guinn (1976) found that decreased boll sugar levels were correlated with increased rates of ethylene evolution. If that is also true with pepper, it would suggest that abscission-susceptible cultivars may more quickly deplete bud sugar levels during stress, or translocate less assimilate to them, than more resistant ones.

Stress screening methods based on the physiological mechanism of stress in plants may be simpler and cheaper than direct screening under stress. Since stressed buds evolve ethylene, the application of ethylene-releasing compounds to pepper plants under nonstressed conditions may produce varietal differences in abscission. When Tripp (1986) sprayed ethephon on field-grown bell pepper plants before anthesis, bud abscission was greater on cultivars identified by Hernandez-Armenta (1985) to be heat stress-susceptible than on others with heat stress resistance (Table 11). At 200-300 ppm ethephon, the varietal differences in abscission were eliminated. In a 1987 experiment, there was good correlation between susceptibility to a preanthesis spray of ethephon and susceptibility to shade in eight pepper cultivars (Figure 3). The results of these experiments indicate that pepper cultivars differ in their sensitivity to a given level of stress ethylene. When ACC or ethephon was applied to individual buds directly rather than sprayed on the plant, the varietal differences disappeared. More work is needed to explain the differential results of these two application methods.

Susceptibility to ethephon varies not only between cultivars but also with the age of the reproductive structures. We have found that flowers at anthesis and developing fruits are much less susceptible to ethephon-induced abscission than flower buds. It is therefore important that ethephon be applied preanthesis, if varietal differences in abscission are sought. For materials that vary in flowering date, we begin spraying the entire population two to three days before anthesis of the earliest-flowering line, and continue at five to seven-day intervals until the latest-flowering line has started to flower in the control plot. The concentration of ethephon used is too low to cause leaf abscission.

The correlation between susceptibility to ethephon and stress sensitivity has also been used by Villareal and Lai (1978) to screen for high temperature fruit-set in tomato. Lines which showed a greater tendency to produce adventitious roots on the stem with ethephon application were also more susceptible to heat stress abscission. Wien and Roesingh (1980) found that ethephon application mimicked cowpea flower bud abscission caused by Megaluro thrips damage, and advocated use of ethephon sprays to identify thrips-resistant lines. Initial studies on the abscission

Table 11. Percent of abscission of the lowest two flowering nodes of five bell pepper cultivars sprayed with four concentrations of ethephon in two field experiments at Freeville, NY in 1986.

Cultivar	Ethephon concentration (ppm)			
	0	100	200	300
Expt. 1 Ace	2	23 a[z]	96	99
Canape	2	51 b	99	98
Lady Bell	0	71 c	100	100
Big Bertha	1	89 d	98	97
Shamrock	1	84 d	99	99
	NS	**	NS	NS
Expt. 2 Ace	2	24 a	67 a	94
Canape	8	50 b	68 a	98
Lady Bell	1	54 b	83 b	98
Big Bertha	1	62 bc	86 b	97
Shamrock	13	73 b	98 c	95
	NS	**	**	NS

Source: Tripp, 1986. [z]Numbers within columns followed by different letters are significantly different at the 5% level as determined by LSD values of the arc-sin transformed data

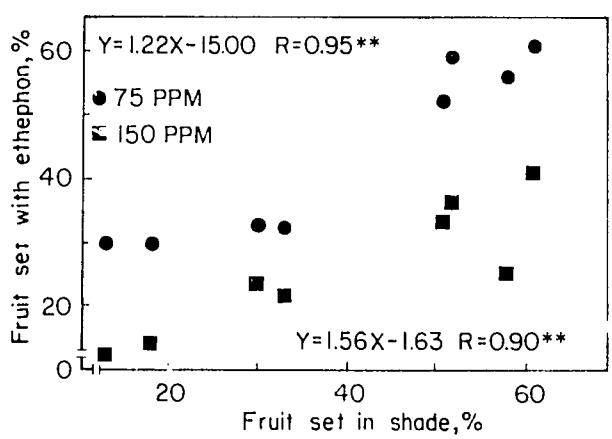

Figure 3.
Relation of percent fruit-set on first four fruiting nodes of eight pepper cultivars after treatment with 75 or 150 ppm ethephon and percent fruit-set when plants were subjected to one week of 80% shade. Ethephon application and shade were started three days before anthesis of the earliest cultivar. Fruit-set data were taken one week after the second weekly ethephon spray. Curvilinear component (quadratic) of the relationship was not statistically significant.

of disbudded pedicels at Cornell indicated that abscission rate of the pedicel stubs was directly correlated with abscission susceptibility (Table 3). A later study which included eight cultivars showed that this relationship is not a general one, however. It is hoped that other convenient screening techniques for abscission resistance will be developed as our understanding of the mechanism of abscission improves.

Conclusions

1. The principal causes of abscission of reproductive structures in pepper are environmental stress factors. Of these, high temperatures appear to be the most important.
2. Combinations of high temperature with drought stress, or with low light conditions cause more severe abscission than any of the individual stresses alone.

3. Abscission of flowers and flower buds may also be caused by disease organisms, notably viruses such as cucumber mosaic virus.
4. The hormonal mechanism of bud and perhaps flower abscission appears to involve ethylene evolution by the abscising structure.
5. The role of auxin and other growth-promoting hormones in prevention of stress abscission of pepper reproductive tissue requires further clarification.
6. Control of stress-induced abscission can be achieved most effectively through the selection of abscission-resistant cultivars. These can be identified by culture under high temperature or shade stress.
7. Preanthesis sprays of ethephon provide a low-cost means of screening for abscission resistance.

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Symposium Discussion

G.Y.H. Grubben: What can be done in the short term (not by breeding) against abscission of flower buds and young fruits in hot pepper fields in Indonesia, apart from better cultural practices (control of viruses, better plant nutrition, insect control)? Is there any prospect for application of growth hormones like auxin? Should we start a research program?
H.C. Wien: We have recently started to work on abscission prevention using hormone sprays but have so far not been successful with NAA. There are some published reports from India that NAA can improve set, and these are cited in my paper. We are working further on this aspect.

Y. Haile: Have you observed fungi, bacteria or *Heliothis armigera* to be the causes of abscission in pepper?
H.C. Wien: Several fungi and bacteria have been found to cause leaf abscission in pepper. We have not encountered bud or flower abscission due to these agents. *Heliothis* has been shown to cause fruit abscission when young fruit are attacked. When larger bell pepper fruit are attacked by *Heliothis*, the damaged fruit is often retained on the plant.

A. Hibberd: It has been noted that some peppers may withhold small, underdeveloped fruit from growth until the earliest-set fruit are at or near full maturity. At that stage, the 'young' fruit then proceed through growth. Please comment on the auxin/ethylene relationships of such pepper flowers/fruit.
H.C. Wien: I don't know of any work that has looked at the hormonal relations of these retarded pepper fruits. Studies by Bangerth in Germany with tomato indicate that complex hormonal relations are involved.

B.A. Kratky: There are reports of increased pepper yields with 30% shading. Is abscission involved in this yield effect?
H.C. Wien: The work by Rylski and Spigelman in Israel indicates that the yield increases from moderate shade result from reduction in sunscald injury and a prolonged fruiting period. Abscission does not appear to increase under moderate shade.

G. Kuo: Shading usually would lower aerial temperature; Have you any indication of a shading threshold (critical light intensity) which lowers temperature without causing abscission (by shading)?
H.C. Wien: We have not done this sort of study, but work by Rylski and Spigelman, as well as by El-Aidy (this volume) indicates that 12 to 40% light reduction under Middle East summer conditions will result in increased yields compared to unshaded controls. Since unshaded controls are subjected to slight moisture stress and therefore some heat load on the leaves, the moderate shade may alleviate a slight moisture stress and lower plant temperature. Thus under high light environments, shading of 10 to 40% is beneficial. The same may not be true in more cloudy environments.

B. Villalon: What are the optimum conditions for maximum fruit-set and maximum fruit size development? Please give both day and night environmental factors.
H.C. Wien: Maximum fruit-set is obtained under relatively cool conditions, in which daytemperatures are in the 20s and night temperatures from 17-20°C. Under such conditions, some cultivars may set too many fruit, so that fruit size is not optimal. A combination of day/night temperatures of about 30/20, good light, and nonlimiting water and nutrients will be better for optimal fruit size.

R.L. Villareal: Have you done any regression analysis to determine which factors contribute more to the abscission problem in pepper?
H.C. Wien: We know too little about the factors involved to be able to do regression analysis.

./166

17

Salt Tolerance in Tomato: Sodium Accumulation, Uptake and Recirculation in *Lycopersicon esculentum* and *L. pennellii*

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Abstract

Regulation of Na^+ content in the foliage has been proposed as an important component of the salt tolerance mechanism in hybrids of the cultivated tomato *Lycopersicon esculentum* and the wild, salt-tolerant species *L. pennellii*. The kinetics of Na^+ uptake in intact plants of both species treated with 25 mM NaCl was followed for eight days. Sodium uptake per unit root weight was similar in both species up to day four, but thereafter it was lower in the cultivated tomato. In the cultivated tomato, short-term ^{22}Na uptake was similar before and after six days of salt treatment, suggesting that the plant's internal Na^+ content does not influence Na^+ uptake. Na^+ uptake experiments using leaf discs from salinized plants support a similar conclusion. In the cultivated species, discrepancies between the results of shortand long-term uptake experiments suggest the occurrence of significant Na^+ efflux in the presence of unchanged influx. Preferential basipetal phloem translocation of Na^+ was observed in *L. esculentum* and a role for this mechanism in the regulation of foliar Na^+ content is suggested.

Introduction

Tomato is considered to be a moderately salt-tolerant crop (Maas and Hoffman, 1977). The relatively small range of salt tolerance found in tomatoes (Epstein et al. 1980) has led to the incorporation of compatible wild species into breeding programs aimed at increasing salt tolerance (Epstein et al. 1980; Sacher et al. 1983; Tal and Shannon, 1983). The two species which have been mainly used for this purpose are *Lycopersicon cheesmanii* and *L. pennellii*, and hybrid lines with good horticultural qualities have been obtained (Sacher et al. 1983).

Lengthy selection programs could be shortened by selecting for specific features linked to salt tolerance. It has been proposed that the regulation of Na^+ content in the foliage is one important mechanism by which tomatoes tolerate salinity (Sacher et al. 1983), and it was also suggested that in salt-tolerant hybrids of *L. esculentum* and *L. pennellii* ionic homeostasis was provided by the cultivated tomato. An understanding of how this regulation is achieved could provide information for breeding programs aimed at selecting physiological traits causally linked to salt tolerance in this species.

Results from studies into ion accumulation in isolated leaves, leaf discs, shoot apices (Taleisnik et al. 1983), roots (Taleisnik and Tal, 1986) and calli derived from various organs of these two plant species (Tal et al. 1978) have not always correlated with ion accumulation reported in intact plants (Tal and Shannon, 1983). These discrepancies have been ascribed to the removal of these parts from the major sites controlling the balance of ions in the whole plant (Taleisnik et al. 1983). This paper reports the results from work on intact plants of *L. esculentum* and *L. pennellii* aimed at identifying possible points of leaf Na^+ content regulation.

Materials and Methods

Seedlings of tomato *L. esculentum* Mill. cv. Cal. J and *L. pennellii* (Correll) D'Arcy, accession Atico, were obtained as described by Tal and Shannon (1983), and were grown in vermiculite in a growth room. Plants bearing one or two leaves were transferred to aerated, half-strength Hoagland (1/2 HS) solution as previously described (Taleisnik et al. 1983). Illumination at plant level was approximately 200 μmol m^{-2} s^{-1}, (provided by a mixture of White Osram fluorescent and incandescent lights). Photoperiod was 16 h and temperature was 24°C. Salt treatments were given by adding NaCl to the 1/2 HS to a concentration of 25 mM .Neither species exhibits significant alterations in growth or day weight production at this salt concentration (Taleisnik, 1987).

Sodium uptake and distribution within intact plants after various uptake periods were assessed by determining the Na^+ content in dried plant parts. Roots were washed for 10 min in cold 0.5 mM $CaSO_4$ in order to remove ions from the free space prior to drying. Ions were extracted by acid digestion of the tissues. Plant samples were suspended in 0.1 N HNO_3 for 72 h and the Na^+ content of this extracting solution was determined with a Corning 435 flame photometer.

^{22}Na Uptake by Intact Plants

This experiment was performed in order to evaluate whether short-term Na^+ uptake rate differed in plants grown under control conditions (1/2 HS) and those subject to a saline treatment (25 mM NaCl) for six days (1/2 HS+NaCl). Plants, bearing six leaves, were transferred to 250 ml beakers containing the appropriate growth medium. At the onset of the experiment, the medium was replaced by 1/2 HS+NaCl labeled with ^{22}Na. Uptake proceeded for 30 min under the light bank described above. Plants were then dissected into shoots and roots. Roots were rinsed for 10 min in cold, unlabeled 1/2 HS+NaCl. Shoots and roots were weighed, dried and counted for gamma emission in a Beckman 4000 counter. The experiment was performed at least three times on each species, on batches of five plants every time.

Na^+ Uptake by Excised Root Segments and Leaf Discs

Sodium uptake was measured in 3 cm apical root segments obtained from plants growing in 1/2 HS. Segments were cut and allowed to remain in this solution for an hour. At the onset of the uptake period, root segments were placed into 25 ml erlenmeyer flasks containing ten ml 1/2 HS+NaCl labeled with ^{22}NaCl. Flasks were incubated at 28°C in a shaking (80 cycles min^{-1}) water bath. At the end of the uptake period, the roots were rinsed briefly with distilled water and then washed for 10 min in ice-cold unlabeled 1/2 HS+NaCl. Roots were blotted carefully before being transferred to capped, preweighed Kahn tubes. Samples were weighed and gamma emission was measured without further processing in a Beckman 4000 counter. Results are expressed as μmol Na^+, g f.wt^{-1}, using the specific activity of the uptake solution to convert ct min^{-1} to μmol.

To determine uptake in leaf tissue, discs of 6 mm diameter were punched out from the third fully developed leaf of plants bearing six to seven leaves grown either in 1/2 HS or in 1/2 HS+NaCl. At the onset of the incubation period, the discs were introduced into 25 ml erlenmeyer flasks and labeled 1/2 HS+NaCl was introduced. Discs were then subject to very gentle vacuum for 15 sec to ensure infiltration. Incubation and further processing were as described for root tips, except that discs were not weighed. A sample from each species was processed and counted immediately after infiltration and used as blank in each case. Each sample contained 10 discs obtained from four different plants. The experiment was performed twice.

Na^+ Recirculation

This experiment was performed in order to assess whether the two species differ in their capacity to translocate Na. Plants bearing 9 or 10 leaves and grown in 1/2 HS were used, and

the experiments were carried out under the light bank described above. Plants were placed individually in 250 ml foil-covered beakers containing aerated 1/2 HS. A 10 μl drop of 1/2HS + NaCl, containing approximately 600,000 ct min^{-1} ^{22}Na was applied to the abaxial surface of the terminal leaflet of the sixth developed leaf. Two days later, plants were dissected into individual leaves, the whole stem above and below the treated leaf, tops (apical meristem and youngest, unexpanded leaves) and roots. Plant parts were dried at 80°C for 48 h and counted for gamma emission, along with an aliquot of the root medium. The experiment was repeated twice, on batches of three or five plants.

Results and Discussion

Sodium Accumulation in Intact Plants

Sodium accumulation was followed for eight days in intact plants of *L. esculentum* and *L. pennellii* treated with 25 mM NaCl. *L. pennellii* accumulated higher Na^+ concentrations than the cultivated tomato in stems and petioles, and the opposite was observed in roots (Figure 1). Concentration in petioles was higher than in the rest of the plant, and leaves had the lowest levels, except after eight days of salt treatment.

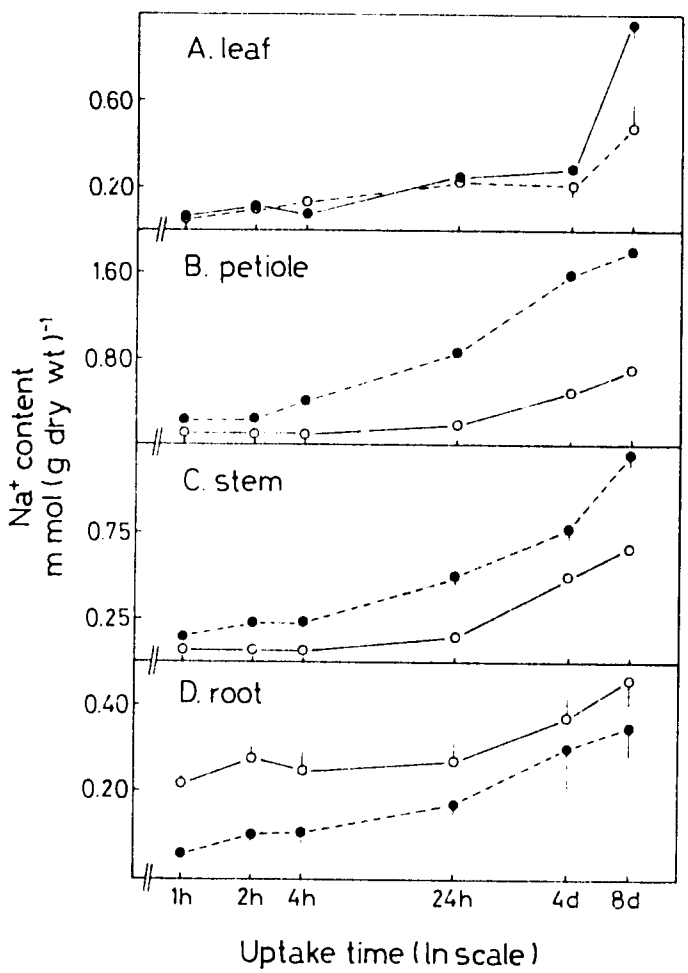

Figure 1.
Sodium accumulation in leaves (A), petioles (B), stems (C) and roots (D) of *L. esculentum* (full line) and *L. pennellii* (broken line) plants treated with 25 mM NaCl. Each point is the mean ± SE of three plants.

Accumulation rates (the slope of the accumulation curve) in stems and roots were approximately similar in both species (Figure 1B, C and D). Petioles from *L. pennellii* appeared to have higher accumulation rates than those of *L. esculentum*. In leaves (Figure 1A), accumulation and accumulation rates were similar up to four days of uptake, afterwards both parameters were higher in *L. pennellii* than in the cultivated species. Sodium uptake per dry weight of root tissue, measured in whole plants, was almost identical in the two species up to day four, but at eight days it was lower in the cultivated tomato (Figure 2). At this time, short-term ^{22}Na uptake in the cultivated species, was not different between salt-treated plants and controls (Table 1), suggesting that in this species, at the present salinity level, Na^+ uptake is not regulated by the plant's Na^+ content.

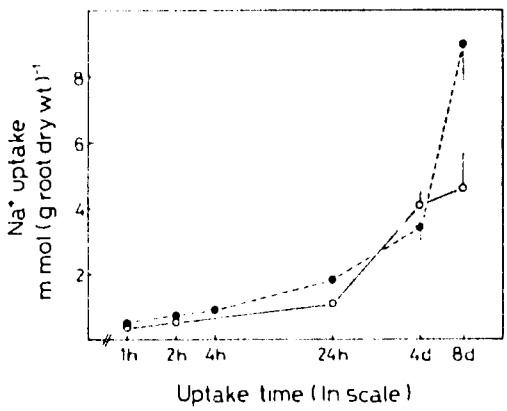

Figure 2.
Sodium uptake rate by whole plants of *L. esculentum* (full line) and *L. pennellii* (broken line) treated with 25 mM NaCl. Each point is the mean ± SE of three plants.

Table 1. Sodium uptake in *L. esculentum* and *L. pennellii* intact plants grown under control (1/2 HS) or saline (1/2 HS + NaCl) conditions.

	Sodium uptake[z,y]	
	Control	Salinized
		μmol (g root f. wt)⁻¹
L. esculentum	1.27 ± 0.1	0.97 ± 0.12
L. pennellii	1.45 ± 0.15	1.19 ± 0.10*

[z]Uptake proceeded for 30 min at 25°C under a light bank. Uptake solution was 1/2 HS + NaCl labeled with ^{22}Na [0.06Bq (mmol Na)⁻¹]. [y] Means of five plants ± SE. *Significantly different from control.

Sodium Uptake by Excised Organs

As uptake rates by whole plants were similar up to the fourth day (Figure 2), differences in Na^+ accumulation between plant parts of both species (Figure 1) could be related to differences in dry weight distribution. However this was not the case, as the pattern of dry weight distribution among plant parts was similar in both species (results not shown). Sodium uptake rates measured in leaf discs (Figure 3), were higher in *L. pennellii* than in *L. esculentum*, both under control and saline conditions, suggesting a higher capacity for Na^+ accumulation in the leaf tissue of the wild species. In the cultivated species, but not in the wild species, the uptake rate was similar in leaf discs obtained from control and salt-treated plants (Figure 3). Na^+ uptake rates in detached root segments were higher in the cultivated tomato than in *L. pennellii* (Figure 4). The higher Na^+ accumulation found in roots of the cultivated tomato in this study could account for the lower translocation rate to shoots (Table 2).

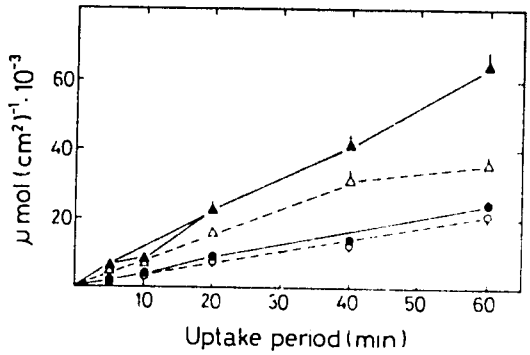

Figure 3.
Sodium uptake by leaf discs obtained from control (full line) and salt treated (25 mM NaCl, six days; broken line) plants of *L. esculentum* (●) and *L. pennellii* (▲). Discs were incubated in growth medium containing 25 mM NaCl (1/2 HS+NaCl), labeled with ^{22}Na. Each point is the mean ± SE of 5 samples of two discs each. SE not shown, it did not exceed the symbol mark.

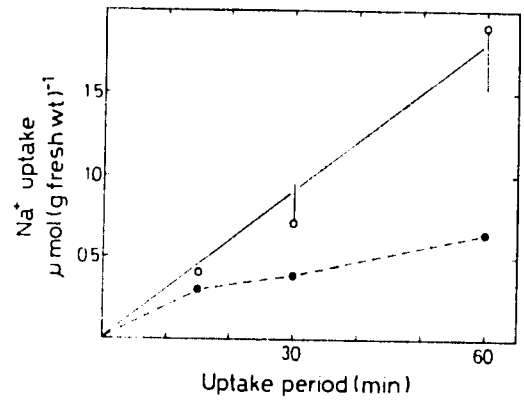

Figure 4.
Rate of ^{22}Na uptake by root segments obtained from *L. esculentum* (full line) and *L. pennellii* (broken line) plants. Uptake was from 1/2 HS + NaCl labeled with ^{22}Na. Each point is the mean ± SE of three samples. SE not shown, it did not exceed the symbol mark.

Table 2. Relative sodium accumulation in shoots (Na^+ content in shoot in the entire plant) × 100 in *L. pennellii* and *L. esculentum* at various times from the initiation of the salt treatment (25 μM NaCl).

Time	Relative sodium accumulation[z]	
	L. pennellii	*L. esculentum*
1 hour	78.53 ± 3.13[y]	37.99 ± 4.56
2 hours	84.62 ± 2.40[y]	50.13 ± 3.19
24 hours	90.54 ± 2.25	78.56 ± 4.75
8 days	95.47 ± 2.29	86.19 ± 3.60

[z]Means of three plants ± SE [y]Significant difference between the two species

Sodium Recirculation

Differences between the trends revealed in short and long-term uptake experiments (Table 1, Figure 2) could also be related to the capacity of each species to mobilize, retranslocate and extrude Na^+. An experiment aimed at evaluating this hypothesis was performed in plants grown under control conditions in order to avoid uncertainties attributable to differences in specific activity (as Na^+ accumulation in shoots of salt-treated plants was higher in the wild species). When a drop containing ^{22}Na was applied to the sixth leaf from the top of plants bearing 10 leaves, the ratio of radioactivity found above and below the treated leaf (including the root

medium) was 0.29 + 0.02 in *L. esculentum* and 0.93 + 0.02 in the wild species. The results are significantly different at $P < 0.001$.

L. esculentum plants accumulated lower Na^+ concentrations than *L. pennellii* in shoots, and the opposite trend was observed in roots (Figure 1). Among aerial parts, the highest concentrations were observed in petioles of both species and the lowest in leaves. This pattern agrees, except for roots, with results reported by Tal and Shannon (1983) for plants grown at higher salinity levels. The discrepancy is probably related to the higher salt concentrations in the root medium used by those authors.

The lower translocation rate to shoots observed in *L. esculentum* at the beginning of the salt treatment could be related to the higher Na^+ accumulation rates found in roots of this species. Restricted Na^+ translocation caused by selective Na^+ accumulation in xylem parenchyma cells of roots (Kramer et al. 1977) and stems (Rains, 1969) has been reported in beans and cotton. It is very likely that a similar situation occurs in tomato where petioles exhibit the highest Na^+ concentrations (Figure 1). In this species, replacement of K^+ by Na^+, and thus Na^+ accumulation, takes place mainly in petioles (Besford, 1978).

In the cultivated species, Na^+ uptake by whole plants took place at a lower rate than in the wild species between four and eight days of salt treatment. The possibility that the Na^+ content in the plant regulates its uptake seems to be ruled out by the results from short-term experiments where uptake rates measured in salinized *L. esculentum* plants were not different from controls (Table 1). These results indicate that Na^+ content does not regulate Na^+ uptake in this case. Na^+ efflux might be one mechanism responsible for the difference between short and long-term uptake experiments. This possibility has often been mentioned in the literature in studies carried out in other plant systems where sodium exclusion could not be attributed to a reduction in uptake (Jeschke and Jambor, 1981; Cheesman, 1982; Cheesman et al. 1985; Ortega and Rodriguez-Navarro, 1986). This aspect is under study in the current plant system. A regulation of Na^+ uptake in leaves of the cultivated species by their Na^+ content also seems to be unsubstantiated (Figure 3).

Relative exclusion of Na^+ from leaves is comparatively more common than exclusion of Cl^- and is based on several mechanisms including efflux pumps located in the roots (Jeschke and Jambor, 1981), preferential accumulation in root vacuoles, resorption in the xylem parenchyma (Kramer, 1983) and retranslocation out of the leaves (Jacoby, 1979) and subsequent extrusion into the rooting medium. Some of these components of the complex picture of salt tolerance require studies using intact plants. In the cultivated tomato, basipetal transport of Na^+ was higher than in the wild species. Using whole plants, basipetal transport of Na^+ in the phloem has been reported in beans (Jacoby, 1979), *Lupinus albus* (Jeschke et al. 1986) and *Trifolium alexandrinum* (Winter, 1982). In a study involving nine species and cultivars, Lessani and Marschner (1977) observed that basipetal translocation was favored in species with lower salt tolerance. The actual significance of basipetal Na^+ transport in the regulation of Na^+ balance in the foliage of the cultivated tomato deserves further attention.

The results from the experiments reported here suggest that in the cultivated tomato, Na^+ supply to the foliage is not regulated by the uptake of the element, either by the roots or the leaves. Discrepancies between short and long-term uptake experiments suggest the occurrence of significant Na^+ efflux in the presence of unchanged influx. The existence of compartments acting as sequestering systems along the xylem stream may also account in part for the lower Na^+ levels found in leaves. Preferential basipetal phloem translocation of Na^+ could likewise participate in the regulation of Na^+ balance in the foliage. The assessment of these aspects requires additional studies in intact plants.

Acknowledgments

Support from the International Foundation for Science (grant C/952-1) and SECYT (Secretaria de Ciencia y Tecnica of Argentina) (grant 268/86) is gratefully acknowledged.

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Symposium Discussion

I.D. Erinle: What are the practical implications of your results?

E.L. Taleisnik: The definitive criterion for salt tolerance of any crop is yield. However, as yield is a complex character of low heritability, it has been suggested that selecting for yield

under conditions of stress would not be easy nor practical. Rather, it is generally accepted that breeding for physiological traits causally linked to it can be more economical of time and effort. This involves three steps:(a) demonstration of a significant association between plant productivity under stress and various possible physiological components of stress resistance, (b) determination of genetic variation for a particular character or response, (c) demonstration that breeding for this character is possible and effective (see Blum et al. 1983, Plant Cell and Environment 6:219-225 and references therein, for an extended discussion of these aspects). In the case of tomatoes, one aspect to which salt tolerance has been correlated (among others) is the ability to regulate sodium content in the leaves. If the components of the regulation mechanism are identified (hopefully, down to a molecular level) conceivably the whole mechanism could be improved by selecting for a particular component (or several). Of course, the relevance of such component(s) for improving regulation would have to be tested in a hybrid population exhibiting a range of variation in foliar sodium content regulation.

R.T. Opeña: Salt tolerance work with *L. cheesmanii* by Epstein and his co-workers has been going on since the mid-late 60s. Do you know if any usable commercial cultivar or enhanced genetic stock has come out from that program?

E.L. Taleisnik: No, I am not aware of any.

18

Biological Activities of BAS 112 W and BAS 113 W on Fruit-setting and Fruit Development in Tomatoes

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Abstract

Two new auxin-type bioregulators of BASF Aktiengesellschaft coded BAS 112 W and BAS 113 W and formulated as aqueous solutions of 1.0 and 2.0 g/l, respectively, were tested on tomato in the off-season in Japan and Taiwan. BAS 112 W was found to be more active than BAS 113 W. Both compounds improved fruit-setting, fruit size and fruit maturity. Yields were significantly increased, especially under unfavorable growing conditions such as high or low temperatures. In Japan, where the compounds were tested on fresh market tomato in the off-season (cool temperature) under glasshouse conditions, the best effect was achieved by spray or dip-application of clusters at the anthesis stage. Optimal rates of cluster spraying were 1-4 ppm a.i. for BAS 112 W and approximately 8-40 ppm a.i. for BAS 113 W. In southern Taiwan the two compounds were tested on fresh market tomato under field conditions with extremely high temperature in the off-season and with moderate temperature in the crop season. Cluster-spray application rates of BAS 112 W and BAS 113 W were 1-2 ppm a.i. and 32 to 64 ppm a.i., respectively, under southern Taiwan conditions.

Introduction

The cultivation of tomato in Japan and in Taiwan is limited to distinct crop seasons. In Japan, tomato is generally grown during the warm season from May to September/October, when temperatures range from 21°C to 29°C. In the cold season where temperatures range from 3°C to 17°C, tomato is grown in glass or vinyl houses. Under such conditions of low temperature, insufficient light intensity and lack of insect pollinators, the crop often fails to produce marketable fruits (Picken, 1984; Lee, 1986; Katsura, 1987).

In Taiwan the normal crop season is from October to April/May where moderate temperatures prevail with average day temperatures of approximately 29°C and average night temperatures of 15°C. In the off-season, which is characterized by high average day and night temperatures of 35°C and 30°C, respectively, reduced fruit-set and even complete failure of fruit-setting make tomato production unprofitable.

Exogenous applications of natural plant hormones as well as synthetic plant growth regulators are known to improve fruit-set and fruit yield where it otherwise fails. They promote and accelerate uniform ripening for easy harvest (Kuo et al. 1986). Exogenous auxins and gibberellins have been shown to be most effective. They have also been used to achieve fruit-set with larger fruits than produced by natural pollination (Picken, 1984). Foliar treatment of 2,4-D is known to increase fruit yield in tomato (Joseph and Peter, 1980).

In Japan, exogenous application of synthetic auxins such as Cloxyfonac, Tomatolane S 9.8% (sodium-4-chloro-2-hydroxy-methyl-phenoxyacetate) is an important practice, especially in the cold season to increase fruit-set and fruit size. In Taiwan, Tomatotone S 0.15% (4-chlorophenoxy acetic acid, CPA) is applied in the crop season for the same purpose and also to avoid negative influences from brief periods of extreme temperature deviation.

BAS 112 W and BAS 113 W are two new plant growth regulators developed by BASF Aktiengesellschaft Ludwigshafen, Federal Republic of Germany. Their characteristics are shown in Table 1. The active ingredients of BAS 112 W and BAS 113 W are absorbed through leaves and roots and transported acro- and basipetally. *In vitro* and *in vivo* studies have indicated, that both bioregulators are acting auxinlike (Berghaus and Wuerzer, 1985).

Table 1. Characteristics of BAS 112 W and BAS 113 W.

Item	BAS 112 W	BAS 113 W
Chemical name	3,7-dichloro-8-quinoline carboxylic acid	7-chloro-3-methyl-8-quinoline carboxylic acid
Common name	Quinclorac	Quinmerac
Empirical formula	$C_{10}H_5Cl_2NO_2$	$C_{11}H_8ClNO_2$
Molecular weight	242.1	211.6
Toxicity (LD 50): (mg a.i./kg body weight)		
acute oral (rat)	2,680	>5,000
dermal (rat)	>2,000	

Materials and Methods

Cool Season Greenhouse Tests in Japan

The tests were conducted in the off-season of Japan (October-March), when below optimum temperatures prevail. Single potted plants of the indeterminate fresh market cv. Homare 114 were used with at least 4-6 replicates. The plants were potted when the first flower bud had developed. Axillary shoots were removed periodically during the period of each experiment. Fertilizer application was 1.7 g N, 1.1 g P_2O_5, and 1.7 g K_2O per pot (27 cm diameter and containing 1 plant). There were three applications: 40% of the total before transplanting, 30% when cluster no. 1 started to bear fruits, and 30% when fruits of cluster no. 3 had matured.

The two compounds, BAS 112 W and BAS 113 W were tested at the rates of 0.25-20.0 ppm a.i. and 3.0-30.0 ppm a.i., respectively. They were applied either as a foliar spray, by spraying the entire plant when the first flowers had opened, with a spray gun at a volume of 10 ml per pot (1 plant) or directly spraying individual clusters or flowers at 0.5 ml/cluster, by using a hand atomizer to prevent unnecessary foliage contamination by the compounds. Volumes stated above refer to 500-850 l/ha. Direct spraying to individual clusters was done when 2-3 flowers had opened.

The effect of the compounds on parthenocarpy was tested by removing the anthers prior to anthesis, followed by a dip treatment of the individual flowers. Harvesting was started when fruits began to turn red, and was continued at intervals of approximately 3-5 days, depending on the season. The plants were topped at certain stages of development, depending on the target of the individual experiment. For example, if clusters no. 1-4 were required, topping was done at the beginning of flowering of cluster no. 6.

Assessments were based on number of mature fruits/ cluster, total fruit weight/ cluster, marketable fruits, fruits after anthesis, fruit abortion, and flower abortion. Crop tolerance towards the tested substance was assessed by measuring the percentage of the foliage that showed deformation. Data were statistically analyzed by Duncan's multiple range test (DMRT).

Hot Season and Normal Growing Season Field Trials in Taiwan

Experiments in Taiwan started later than those in Japan with a certain advantage of information. The experiments were conducted in the main tomato producing area in southern Taiwan using the heat sensitive, indeterminate fresh market cultivar Known-You 301. Experimental plots consisted of single bed rows of 5.4 x 1.2 m, with a plant spacing of 0.45 m (12 plants per plot, approximately 18,500 plants per ha). The trials were conducted with 4-5 replications.

Transplanting to the field was carried out when the plants were at the 4 true-leaf stage. Axillary shoots were removed at regular intervals. Fertilizer application was 180 N, 180 P_2O_5, 63 K_2O kg/ha, half of which was applied at the beginning of flowering of cluster no. 1 (approximately 1 week after transplanting), the other half at cluster no. 3. The plants were topped at approximately 2-3 weeks after cluster no. 5 had developed.

Application was by direct spraying once to each cluster when 2-3 flowers per cluster had opened. Spraying with 1.0 ml solution was done by a hand atomizer.

Application rates were 0.125-2.0 ppm a.i. for BAS 112 W and 2.0-64.0 ppm a.i. for BAS 113 W. A commonly used bioregulator, Tomatotone (4-CPA), at the recommended rate in Taiwan of 15.0 ppm a.i., was also included in each experiment, for comparison of efficacy. Assessment was done on 6-8 randomly chosen plants per plot. The same parameters described above for the greenhouse experiments in Japan were measured. In addition, marketable fruit, graded into three classes of <5, 5-6, and >6 cm fruit diameter (corresponding to small, medium and superior class), were recorded. Data were statistically analyzed by DMRT.

Results

Cool Season Greenhouse Tests in Japan

Foliar and first cluster application. Foliar and first cluster application of BAS 112 W increased the total fruit weight and the average weight of the individual fruits, but decreased the total number of fruits (Figure 1). Direct spraying at the first cluster significantly increased fruit weight of the sprayed cluster, but produced fewer and smaller fruits on the following clusters. This phenomenon was emphasized (Figures 1 and 2) at higher application rates, especially in

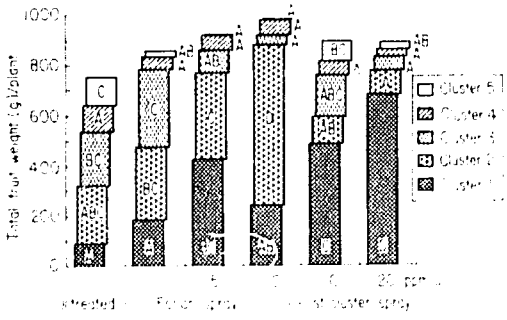

Figure 1. Effect of BAS 112 W applied as foliar and first cluster spray on total fruit weight of tomato. (Same clusters of different treatments which are followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

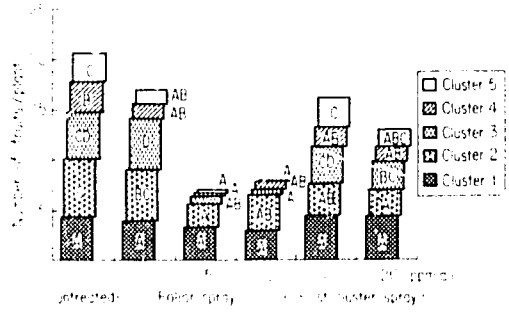

Figure 2. Effect of BAS 112 W applied as foliar and first cluster spray on total fruit number/plant. (Water volume: 800 liter/ha. Same clusters of different treatments which are followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

the foliar application. Deformation of newly developed leaves was observed in all treatments with BAS 112 W but not with BAS 113 W.

Foliar spray treatments at 5 and 10 ppm a.i. increased fruit weight of the first and second cluster, but decreased fruit weight of the third to fifth cluster (Figure 1). The number of fruits in the second to fifth cluster was reduced. Reduction in fruit number was most pronounced in the third to fifth cluster (Figure 2). Foliar application up to 10 ppm a.i. and directed spraying to clusters at 20 ppm a.i. resulted in some leaf cupping and leaf size reduction. Some abnormal development of the flower organs was also observed. The degree of crop injury was considerably less when application was directed to clusters (Figure 3).

Individual flower spray application. BAS 112 W significantly increased the total fruit weight at all application rates (Figure 4). However, with increasing application rates, there was a trend towards decreased fruit number. The average fruit weight was generally larger in the treated plants and best results were observed with 4 ppm a.i.

All treatments, except the lowest rate (0.25 ppm a.i.), accelerated the fruit ripening process by 7-12 days, thereby achieving a higher total fruit weight (Figure 5). BAS 112 W showed a higher activity than BAS 113 W. Crop injury was not observed.

Single cluster spray application. In this trial, application was limited to 1 cluster to enable direct comparison between treatments. BAS 112 W applied to a whole cluster at 3 ppm a.i. increased fruit number and fruit size of the treated cluster. Only three out of five flowers of the treated clusters developed into fruits. The other two flowers failed to develop fruits during the experiment (Table 2). A higher number of matare fruits was also noted.

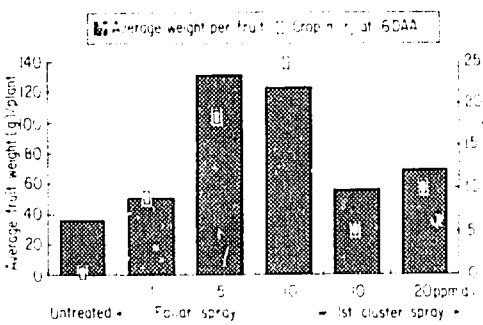

Figure 3. Effect of BAS 112 W applied as foliar and first cluster spray on average fruit weight. (Crop injury measured as % of the foliage that showed deformation. YWater volume: 800 liter/ha.)

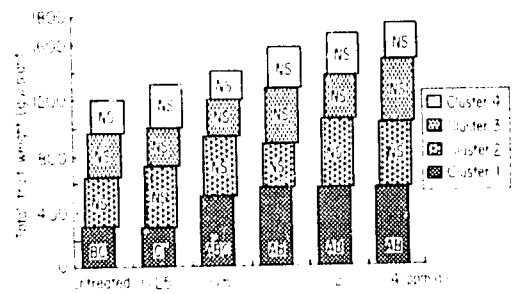

Figure 4. Effect of BAS 112 W (spray application of all flowers) on total fruit weight. (NS = not tested. Same clusters of different treatments which are followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

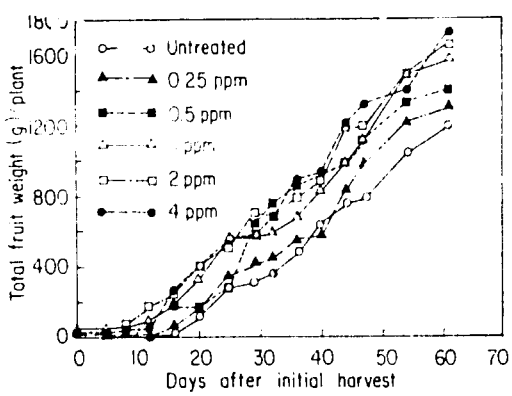

Figure 5.
Effect of BAS 112 W (individual flower spray application) on total fruit weight per plant.

Dip application of individual flowers. When the compounds were applied to emasculated flowers, parthenocarpic fruits developed, whereas no fruits developed from water-treated flowers without anthers. Fruit-set and fruit enlargement of flowers treated with the two compounds was higher than those of the open or artificially pollinated flowers (Table 3).

Table 2. Effect of BAS 112 W (first cluster spray) on tomato fruit size.

Treatment	Buds cluster (no.)	Fruits/ cluster (no.)[z]	Total fruit wt. (g)[z]	Average fruit wt./ plant (g)[z]	Average fruit weight (g) at cluster positions[z]				
					1	2	3	4	5
Control	5.0	2.7	113.5	42.5	55.0	41.7	9.8	7.0	3.4
BAS 112 W (3.0 ppm a.i.)	5.0	3.2	201.6	63.0	84.8	57.5	54.9	4.4	0
4-CPA (30.0 ppm a.i.)	5.0	2.8	195.6	69.9	75.9	69.0	44.3	3.9	3.1

[z]Calculated from fruits weighing more than 10 g.

Table 3. Effect of BAS 112 W and BAS 113 W (individual flower dip application) on fruit-set.

Treatment	Average no. of flowers treated	Average no. fruit plant (>10 g)	Average no. fruit plant (<10 g)	Total fruit wt. plant (g)	Average fruit weight (g)
Control	3.0	0.3	2.7	11.5	3.8
Emasculated	2.3	0	2.3	2.2	1.0
Emasculated, artificially - pollinated	3.0	0.2	2.8	10.1	3.4
BAS 112 W (3 ppm a.i.) - emasculated	2.3	0.8	1.5	72.3	31.4
BAS 113 W (30 ppm a.i.) - emasculated	2.3	1.3	1.0	84.4	36.7
4-CPA	2.2	1.3	0.8	75.4	34.3

Hot Season and Normal Season Field Experiments in Taiwan

Both compounds (Figures 6 and 8) applied as a directed spray to individual clusters significantly increased fruit-set at each individual cluster in both seasons. The increase of fruit-set in comparison with the untreated check was from 290% to 360% in the crop season, and from 280% to 420% in the off-season, based on graded fruits of >5 cm fruit diameter.

The two compounds significantly increased yields and gradings. During the crop season BAS 112 W increased yields by 360% to 530%, whereas in the off-season experiment, yields increased 380% to 680% with respect to the untreated check.

One of the trials (Figure 7) conducted during the early crop season passed through three periods of distinctly different day/night temperature levels. Fruit-set of clusters 1-3 had rather hot temperatures with little day/night differences; cluster 4 had optimal temperature, and cluster 5-6 experienced decreasing, lower night temperature. Treated plants continued to produce clusters during each period, with anthesis and flower setting, whereas in plants of the untreated control plots fruit-set and fruit development clearly reflected the three periods of different temperature conditions.

A clear rate response by BAS 112 W at all application rates was observed, both in the offseason as well as in the crop season. BAS 112 W was more effective per unit active ingredient than BAS 113 W and 4-CPA (Figures 6, 7 and 8).

A total of 70% to 90% of the fruit fell into the medium and superior class of marketable fruit (>5 cm diameter), whereas in the untreated check only 50% to 65% of the harvested fruit fell into the medium and superior class (Figure 7). Furthermore, the fruit size of treated plants was more uniform and fruits matured several days earlier.

At all clusters the shape of fruits, filling of fruits, and the distribution of juice were normal at optimal application rates in both seasons. Due to parthenocarpic activity of the compounds,

the seed was smaller than the normal size. Seeds were, however, fully developed and seed numbers were unaffected. At lower application rates only the seed size of fruits of clusters no. 4 and 5 was affected, while seeds of fruits from clusters no. 1-3 were of normal size.

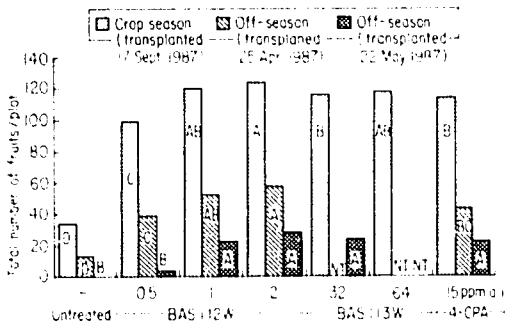

Figure 6.
Effect of BAS 112 W and BAS 113 W cluster spray application on fruit-set. (NT = not tested. Trial was conducted under unfavorable conditions, including 800 mm rainfall in June/July; only fruits of three clusters were fully matured at the time of harvest. Columns of the same trial marked with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

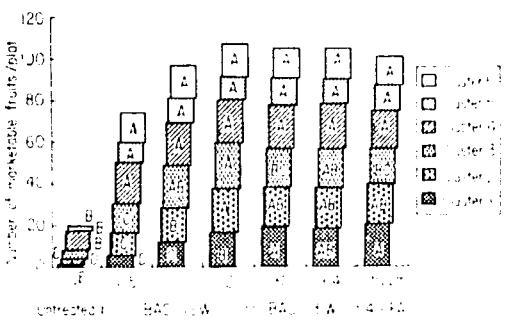

Figure 7. Effect of BAS 112 W and BAS 113 W (cluster application) on number of marketable fruits (> 5 cm diameter) in the early crop season (Sept. 17 transplanting). (Same clusters of different treatments which are followed by the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

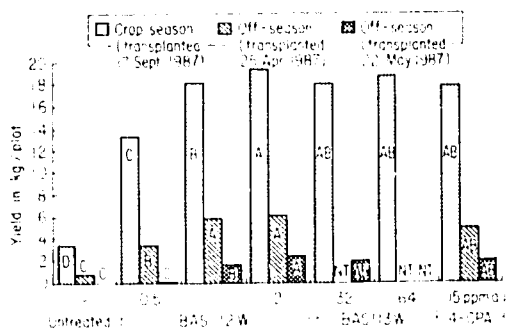

Figure 8. Effect of BAS 112 W and BAS 113 W (cluster spray) on yield of fresh market-tomato. (Applied when 2-3 flowers were opened. Trial was conducted under unfavorable conditions, including 800 mm rainfall in June/July; only fruits of three clusters were fully matured at the time of harvest. Columns of the same trial marked with the same letter are not significantly different at P = 0.05 according to Duncan's multiple range test.)

Discussion

For the off-season cultivation of tomato, either during the cold period under glass or plastic in Japan, or during the hot period in the field in Taiwan, a stable yield of marketable fruits and a long period of productivity is required for economical production. This might be achieved by application of auxin-type growth regulators, such as the two compounds tested.

The two compounds increased fruit-set, fruit number and fruit size during the off-season (cool condition) of Japan and during both the normal growing season, and the off-season (hot condition) of Taiwan. Fruits matured earlier, the ripening process was accelerated and fruit coloring was stimulated. The two compounds may thus prove to be useful to extend the main crop season beyond the optimum climatic condition into the hotter or cooler period of the year.

BAS 112 W was found to be more active than BAS 113 W. Preliminary results of greenhouse trials in Japan suggest application rates at 1 to 4 ppm a.i. for BAS 112 W, and 8 to 30 ppm a.i. for BAS 113 W. Phytotoxicity, such as curling and deformation of the newly developed leaves up to three weeks after application was observed at high application rates of BAS 112 W. A similar reduction of leaf area had been observed (Joseph and Peter. 1980), following foliar application of 2,4 D in tomato. For repeated applications it is, therefore, necessary to spray directly on the flower or cluster, in order to reduce drift of the compound to the leaves. When BAS 112 W was sprayed directly to five individual clusters, phytotoxicity only became apparent after the application to the third cluster, or later, depending on the season. Foliar application should not exceed 0. 5 ppm a.i. of BAS 112 W to avoid leaf deformation. BAS 113 W applied at optimal rates does not cause crop injury, although, at application rates of 64 ppm a.i. it caused some leaf curling up to two weeks after application.

Under field conditions in Taiwan, the recommended rates for cluster spraying of BAS 112 W are between 0.25 to 1.0 ppm a.i. in the crop season (under moderate temperatures), and between 1.0 to 2.0 ppm a.i. under high temperature conditions. The optimal rate for BAS 113 W seems to be 32 ppm a.i. Foliar spray testing is underway in field experiments on the determinate processing type tomato in Taiwan as well as experiments to determine whether the compounds will also increase flowering and yield of heat tolerant lines recently developed by the Asian Vegetable Research and Development Center (AVRDC). The optimum timing (i.e. plant growth stage) for the application of the compound has not yet been determined.

The average fruit weight was increased under the cool season greenhouse condition of Japan, although the number of fruit was reduced. However, in field trials in Taiwan, both during the hot temperature off-season as well as in the crop season, this effect was not observed.

Trials with emasculated flowers proved that both compounds have parthenocarpic activity, which is not surprising since the effect of pollination and fertilization in tomato can be substituted by auxins (Bangerth and Ho. 1984; Picken. 1984).

The experiments suggested a certain amount of translocation of the bioregulators in the plant. From alternate cluster spraying it was observed, that untreated clusters, which had followed a treated cluster also showed increased fruit-set and yield. Treatments in which all clusters were treated, further support this finding. Although only two to three open flowers were treated, flowers of the same cluster that opened later also developed into fruits.

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Symposium Discussion

I.D. Erinle: The chemicals appear very promising but is the fruit safe to eat?
A. Watanabe: The long-term toxicological studies of these compounds are almost completed. The preliminary results indicate that there are no safety problems.

C.H. Hung: (1) Do you evaluate the fruit quality of tomatoes when you spray with BAS 113W? (2) In Taiwan farmers frequently spray Tomatotone in the summer season, but the fruit quality is not good, such as fewer seeds, small size, nonuniform skin color and hollow cavity, etc. Did you observe any of these in your trials with BAS 112 W or BAS 113 W?
A. Watanabe: (1) We have evaluated the fruit quality after treatments with these compounds. (2) Tomatotone, as well as BAS 112 and BAS 113 W, cause parthenocarpic fruits. Parthenocarpy generally produces fewer and smaller seeds. However we do not consider this as a factor of minor fruit quality. We have observed hollow cavity only when application rates were too high. At optimal application rates fruits have a normal filling. We did not observe nonuniform skin color after treatment with either BAS 112 of BAS 113 W.

R.T. Opeña: Did you use a heat-tolerant variety in the field experiments in Taiwan? If not, could you compare heat-sensitive and heat-tolerant cultivar response in some future studies?
A. Watanabe: Testing of the two compounds on heat-tolerant lines is planned.

Diseases and Pests

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184

19

Resistance to Anthracnose (*Colletotrichum* spp.) in Pepper

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Abstract

Anthracnose is a severe problem in pepper production in Korea. Two species of anthracnose fungi *Colletotrichum gloeosporioides* and *C. dematium* are found in Korea. *Colletotrichum gloeosporioides* infects both green and red ripe fruits whereas *C. dematium* infects mainly red ripe fruits. A total of 106 lines and cultivars of pepper were screened for resistance to the two species of *Colletotrichum* by artificial inoculation of green and red ripe fruits. The local Korean cultivars Cheongryong, Kwangju and PI 224433 were resistant to *C. dematium* on green pods and red ripe fruits where lesion and acervulus development was inhibited. However, lines highly resistant to *C. gloeosporioides* were not found. On fruits of Gosung PI 201232, PI 123469, and PI 201234 lesion expansion by *C. gloeosporioides* was slowest, but acervulus development was not prevented. These lines are also known to be resistant to *Phytophthora capsici*.

Introduction

Anthracnose is one of the limiting factors for pepper production in Korea. Two distinct species of *Colletotrichum* have been reported to affect pepper, *C. dematium* (Pers. ex Fr) Grove and *C. gloeosporioides* Penz. (Chung and Chang, 1984; Kim et al. 1986). The first causes damage mainly to red ripe fruits. The latter, *C. gloeosporioides*, causes circular sunken spots on both green and red ripe fruits, and in moist weather produces acervuli on the lesions, often in concentric circles, bearing orange masses of spores. Two strains of *C. gloeosporioides* are found in Korea: strain G, which is highly virulent, causes damage to both green and ripe fruits and does not form perithecia and setae; and strain R, which is low in virulence, causes damage mainly to red ripe fruits, and forms perithecia and setae (Kim et al. 1986). In 1984, *C. gloeosporioides* strain G devastated pepper in the Chungbuk area and now is found all over the country, causing severe damage to pepper production.

Although fungicides are recommended for control, the breeding of resistant cultivars remains a fundamental goal of plant breeders. Several commercial hybrid cultivars were reported resistant to *C. dematium* (Chang and Chung, 1985). However, resistance to *C. gloeosporioides* has not been reported so far. The purpose of this study was to search germplasm that is resistant to either or both strains of *C. gloeosporioides* and to *C. dematium*.

Materials and Methods

Plant Material

A total of 106 pepper lines were tested, consisting of: 36 PI lines, which had been originally received from the Southern Regional Plant Introduction Station, Experiment, Georgia, USA;

25 lines selected for resistance to either Phytophthora blight or bacterial spot; and 45 Korean local cultivars. Seeds were planted in compost soil in seedling trays on January 25, 1986 and transplanted to the University experiment field on May 10, 1986. Spacing was 75cm between rows and 45 cm between plants. No fungicides were applied to the plants at any time during the growing season. For inoculation, green fruits harvested about 25 to 30 days after anthesis, and red ripe fruits with 90% or more red pigmentation apparent, were used.

Inoculation and Disease Rating

Strain G (Isolate No. 4) of *Colletotrichum gloeosporioides*, which had been collected in Goesan, Chungbuk province of Korea, and Isolate No. 1 of *C. dematium*, which had been collected from the Kyungpook University experiment farm, were used throughout the experiment.

The fungi were cultured on potato dextrose agar plates for nine days under fluorescent light. A spore suspension was obtained by washing the plates with distilled water and filtering the washing through four layers of cheesecloth. The spore concentration of the suspensions was adjusted to $3.5 \times 5.6 \times 10^{5}$ conidia per ml. Ten fruits per line, harvested from 10 different individual plants were placed in a humidity box (23 × 15 × 7.5 cm) with 20 ml of water at the bottom. An inoculation pin, consisting of a plastic rod of 4.5 mm in diameter with a fine needle protruding about 1 mm, was dipped into the conidial suspension. The fruits were pricked from the center of the pods with the inoculation pin holding the conidial suspension, leaving a small hole with a drop of the suspension. The boxes were incubated at room temperature (26 to 29.5 °C). Lesion diameter was measured nine days after inoculation.

Results and Discussion

The results from twelve lines, selected for smallest mean lesion diameters on the green fruits caused by either *Colletotrichum* species, are shown in Table 1. A high level of resistance to *C. gloeosporioides* was not found. All lines developed lesions over 1 cm in diameter, with acervuli, after inoculation with *C. gloeosporioides*. PI 201232, PI 257044, Kwangju, PI 201234, Gosung, and PI 123469 appeared to be the least diseased lines. Many of these twelve lines are

Table 1. Lesion diameter on green fruits of pepper, nine days after inoculation with a conidial suspension of two species of *Colletotrichum*.

Line	Selection no	Lesion diameter (cm)[z]		Remarks[y]
		C. gloeosporioides	*C. dematium*	
PI 201232	B13-3	1.11 a[x]	1.08 c	R to Pb
PI 257044	51	1.20 a	0.96 c	
PI 201232	B13-4	1.26 a	0.63 bc	R to Pb
PI 201232	B13-2	1.37 ab	1.20 c	R to Pb
Kwangju	178	1.60 ab	0.00 a	
PI 201234	B14-2	1.66 ab	0.91 c	R to Pb
Gosung	194	1.71 ab	0.00 a	R to Pb
Anjilbaengi	196	1.74 ab	0.00 a	
PI 201234	B14-1	1.89 ab	0.82 c	R to Pb
PI 123469	B1-2	1.94 ab	0.66 bc	R to Pb
PI 224433	28	2.15 bc	0.52 abc	
PI 244670	47-14	2.75 cd	3.91 d	R to Bs
Chungryong	190	2.80 cd	0.07 ab	
PI 241670	43-4	3.29 d	4.43 e	R to Bs

[z]Data represent the mean of 10 fruits harvested from 10 individual plants. [x]Mean separation within columns by Kramer's multiple range test, 5% level. [y]R to Pb and Bs = resistant to Phytophthora blight and bacterial spot, respectively.

selections for resistance to Phytophthora blight (*P. capsici*) (Kim, 1986; 1987). Anthracnose resistance therefore may be considered together with Phytophthora blight resistance in a breeding program where these lines are used. Lesion development by *C. dematium* was prevented on the green fruits of Kwangju, Gosung and Anjilbaengi, and was almost absent on Chungryong. The high level of resistance to *C. dematium* is attributed to those lines on the basis that *C. dematium* causes only minor or no damage to immature green fruits.

Twenty lines selected for smallest mean lesion diameters on the red ripe fruits are listed in Table 2.

PI 224450 was the line least affected by *C. gloeosporioides*, but a high level of resistance to *C. gloeosporioides* was found neither in green fruits nor in red ripe fruits of the lines tested. However the four lines in which green and red ripe fruits were least affected by this fungus were PI 123469, PI 201232, Kwangju and PI 201234. Lesion development although slower was observed on these lines. The lesions expanded with time and acervuli also developed. Development of lesions caused by *C. dematium* was inhibited on red ripe fruits of PI 123469, Kwangju, Chungryong, PI 297490, and PI 224433. Previously the same four lines had been found to be resistant in both immature green and red ripe fruit stages (Park et al. 1986).

Another method for testing resistance to anthracnose would have been to measure the percentage of diseased fruits by additional screening under natural epiphytotic conditions in the field. However, in our experimental field, *C. gloeosporioides* was not found at all and only a meager amount of anthracnose caused by *C. dematium* occurred. Placing a spore suspension of the pathogens on the fruits without wounding was also tried, but disease development was not sufficiently high to allow determination of resistance (Choi and Pae, 1987). Puncture

Table 2. Lesion diameter on red ripe fruits of pepper nine days after inoculation with a conidial suspension of two species of *Colletotrichum*.

Line	Selection no	Lesion diameter (cm)[z]		Remarks[x]
		C. gloeosporioides	*C. dematium*	
PI 224450	33-2	0.31 a[y]	1.21 abcd[y]	
PI 257119	65	0.73 ab	0.70 ab	
Chungryong	190	0.86 ab	0.64 ab	
PI 123469	1	0.89 ab	1.42 bcd	R to Pb
PI 123469	B1-2	0.92 b	0.43 a	R to Pb
Kwangju	178	0.98 b	0.46 a	
PI 297493	108	1.01 b	1.06 abc	
PI 201234	14-4	1.04 bc	0.76 ab	R to Pb
PI 201232	B13-4	1.05 bcd	1.43 bcd	R to Pb
Riogrande		1.08 bcd	1.87 de	R to Pb
PI 201232	13	1.16 bcd	1.77 cde	R to Pb
PI 257099	62	1.21 bcd	0.77 ab	
Gosung	194	1.22 bcd	1.22 abcd	R to Pb
PI 271322	79-1	1.35 bcd	1.13 abcd	R to Bs
PI 201232	B13-3	1.36 bcd	1.43 bcd	R to Pb
PI 297490	105-1	1.39 bcd	0.65 ab	
PI 257044	51	1.68 cde	0.91 ab	
PI 249634	49-2	1.71 cde	0.76 ab	
PI 224433	28	1.86 cdef	0.67 ab	
PI 224445	163-2	1.89 def	0.68 ab	R to Pb
PI 244670 (susc. check)	47-14	2.09 ef	4.26 f	R to Bs
PI 241670 (susc. check)	43-4	2.41 f	2.43 e	R to Bs

[z]Data represent the mean of 10 fruits harvested from 10 individual plants. [y]Mean separation within columns by Kramer's multiple range test, 5% level. [x]R to Pb and Bs = resistant to Phytophthora blight and bacterial spot, respectively.

inoculation as used in our screening has been commonly used for testing resistance to anthracnose in tomato (Barksdale, 1970; 1971; 1972; Barksdale and Koch, 1969; Stevenson et al. 1978). The lines selected for showing little evidence of disease in the laboratory will be planted in an isolated field and their resistance status confirmed. The search for a high level of resistance to the two *Colletotrichum* species continues.

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Symposium Discussion

L.L. Black: The falcate-spored fungus which Dr. Kim referred to as *C. dematium* is undoubtedly the same as the one referred to as *C. capsici* in the paper by Hadden and Black. Mycological authorities disagree on the appropriate name for this fungus. Furthermore, based on previous discussions with Dr. Kim at this meeting and information presented in his talk today, it is our opinion that the fungus to which he referred to as *C. gloeosporioides* strain G is the same fungus labelled *C. acutatum* in the paper by Hadden and Black.

B.S. Kim: I agree with you that *C. dematium* in my paper is the same as *C. acutatum* referred to in Hadden and Black's paper. I will discuss the nomenclature with the Korean plant pathologist who was involved in the fungus identification. After discussion with mycologists in Korea, I found that Korean mycologists follow Verma, M.L. (Phytopath. Medit. 1982. 21:97-100). According to Verma, *C. dematium* and *C. capsici* are synonyms. Korean plant pathologists separate *C. gloeosporioides* and *C. acutatum* on the basis of spore shape. They say that conidia of *C. acutatum* are more sharp-pointed than those of *C. gloeosporioides*. They maintain that

the causal fungus of the anthracnose infecting green fruits is *C. gloeosporioides*. They also acknowledge that *C. acutatum* and *C. gloeosporioides* are very similar to each other.

B.H. Chen: Do you find any relationship between resistance to anthracnose disease and the capsaicin content?
B.S. Kim: I have not studied the relationship between resistance to anthracnose and the capsaicin content. Pungency may not be directly related to resistance to anthracnose because many very hot cultivars or lines were susceptible to anthracnose. However when I tested the relationship between pungency and bacterial spot resistance, I found a significant negative correlation between the number of bacterial spots and capsaicin content. Pungency contributed some field resistance but the relationship was very loose.

I.D. Erinle: Although anthracnose is a widely recognized problem on many plants, it is usually a problem of ripe pepper. Were there any special predisposing factors which encouraged the severe infections in Korea in the field?
B.S. Kim: Warm, wet weather conditions as present in the Korean summer, and high inoculum potential, are the predisposing factors for severe anthracnose problems. Farmers grow pepper continuously year after year without rotation. This cropping system has also increased the inoculum potential of anthracnose in the growing areas.

T.C. Wang: (1) Did you find out any relationship between fruit size and lesion diameter? (2) Can you explain your rating system? (3) Does anthracnose cause serious damage only on fruits or also on leaves of hot pepper?
B.S. Kim: (1) On some small fruited lines, lesion expansion was limited by fruit size but small fruited lines were not necessarily resistant to either *Colletotrichum* species. (2) Based on our inoculation methods, those lines on which lesion expansion was limited and sporulation was poor were considered as resistant. I do not like to clearly delineate highly resistant, resistant, moderately resistant, moderately susceptible, susceptible, etc. (3) Leaf damage by anthracnose is minor. The major damage by anthracnose in Korea is on fruits.

181

20

Anthracnose of Pepper Caused by *Colletotrichum* Spp.*

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Abstract

Anthracnose of pepper incited by *Colletotrichum* spp. causes severe losses in *Capsicum* spp. due to pre- and postharvest fruit decay. Four *Colletotrichum* species (*C. gloeosporioides*, *C. capsici*, *C. acutatum*, and *C. coccodes*) have been identified as causal agents of pepper anthracnose in Louisiana. The major incitants are *C. gloeosporioides* and *C. capsici*. Potential sources of inoculum in cayenne pepper were evaluated in field studies using various combinations of 'clean seed', 'infected seed', 'clean field', and 'infested field' treatments. Throughout the two seasons the clean seed-clean field combination averaged 9% infected pods, whereas the use of infected seed or planting in an infested field resulted in 66% and 62% infected pods, respectively. Detached mature red bell pepper and tomato fruits were inoculated with 22 *Colletotrichum* isolates from pepper and tomato representing *C. gloeosporioides*, *C. capsici*, *C. acutatum*, and *C. coccodes*. The fruits were inoculated with a conidial suspension (25 µl, 10^6 conidia/ml) and were incubated at 24°C for nine days after which the percentage of fruits showing lesion development was recorded and lesion diameters were measured. All isolates, regardless of their original host, caused characteristic anthracnose symptoms on fruit of both hosts. Field applications of chlorothalonil (Bravo 500 at 3.8 ml/liter) and maneb (Manex 4F at 1.9 ml/liter) were made to cayenne and bell pepper to determine the efficacy of these fungicides for the control of anthracnose. Spray applications were made to the point of runoff at time intervals ranging from one to four weeks. A significant reduction in the incidence of pod infections was obtained with both fungicides applied at one- and two-week intervals. Seventy-six percent of the pods were diseased in the unsprayed check treatments, while only 25% and 37% of the pods were diseased in the weekly sprayed chlorothalonil and maneb treatments, respectively.

Introduction

Anthracnose caused by *Colletotrichum* spp. is an economically important disease of pepper (*Capsicum* spp.). Under conditions favorable for disease development, pre- and postharvest fruit losses of up to 50% have been reported (Higgins, 1930; Smith and Crossan, 1958). This disease is mainly a problem on mature pepper pods; however, symptoms on the foliage and immature pods have been reported by some investigators (Dastur, 1921; Halsted, 1890; Higgins, 1926;

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Smith. 1958). Typically, symptoms first appear on mature pods as small, water-soaked, yellow or dark sunken lesions which rapidly expand. The lesions may enlarge to 3 or 4 cm in diameter and sometimes coalesce, encompassing a large portion of the fruit (Figure 1). Fully expanded lesions are sunken and range from dark red to light tan in color with varying amounts of visible dark stromatic fungal tissue. Generally, numerous setose or glabrous acervuli-bearing pale buff to salmon spore masses occur scattered or in concentric rings on the lesions (Dastur. 1921; Halsted. 1890; Halsted. 1891; Higgins. 1923; Smith. 1958).

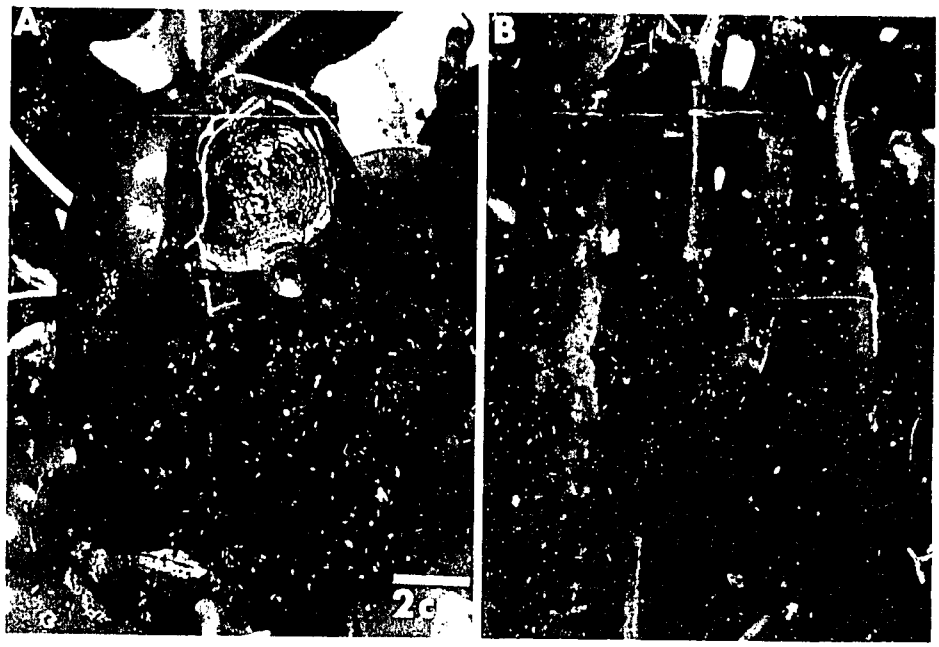

Figure 1. (A) Bell and (B) cayenne pepper (*Capsicum annuum*) showing symptoms of anthracnose caused by *Colletotrichum* spp.

Four species, *C. gloeosporioides* (Penz.) Sacc., *C. capsici* (Syd.) Butl. & Bisby, *C. acutatum* Simmonds, and *C. coccodes* (Wallr.) Hughes, were shown recently in this laboratory to incite anthracnose of pepper (Hadden and Black. 1987). These species also are reported to cause tomato anthracnose (Barksdale. 1972; Mordue. 1967; Miller et al. 1984; Simmonds. 1965). In a survey of pepper-growing areas in south Louisiana, all species except *C. coccodes* were isolated from pepper pods exhibiting symptoms of anthracnose (J.F. Hadden. 1987. unpublished). *Colletotrichum gloeosporioides* and *C. capsici* were the most frequently isolated species in the present study, but *C. acutatum* predominated in some fields. Although *C. coccodes* was not isolated from infected pepper fruit, a previous study in this laboratory showed that isolates from tomato were capable of producing typical anthracnose symptoms on pepper fruit (Hadden and Black. 1987). Other *Colletotrichum* spp. such as *C. piperatum* (Grover and Bansal. 1968; Smith. 1958; Smith and Crossan. 1958), *C. dematium*, *C. graminicola*, *C. nigrum*, and *C. atramentarium* (Halsted. 1891; Verma. 1973) as well as *Gloeosporium* spp. (Halsted. 1890; Higgins. 1923; Higgins. 1926) have been reported to cause similar symptoms on peppers. Considerable confusion exists in the literature as to the proper naming of these organisms and their possible synonymity (Smith. 1958; Smith and Crossan. 1958; Sutton. 1980) with the species included in the current study.

Colletotrichum piperatum (Grover and Bansal. 1968; Smith. 1958; Smith and Crossan. 1958) and *Gloeosporium piperatum* E. & E. (Higgins. 1926; Higgins. 1930), which now appear to

be synonymous with *C. gloeosporioides*, along with *C. capsici* (Dastur. 1921; Grover and Bansal. 1970; Verma and Krishi. 1974) are reported to be seedborne by way of both infected and infested seed. In a study of seed extracted from cayenne (*Capsicum annuum* L.) pepper pods coinfected with *C. capsici* and *C. gloeosporioides*, *C. capsici* was found to infect the seed coat and occur as a surface contaminant, while *C. gloeosporioides* occurred only as a surface contaminant (J.F. Hadden. 1984. unpublished).

It is generally believed that seeds and crop debris from infected plants provide inoculum that leads to development of anthracnose on pepper pods. However, little work has been done to establish a link between these sources of inoculum and the fruit rot phase of the disease. In fact, Chowdhury (1957) stated that *C. capsici*-infected seed plays little part in development of riperot of chillies in India. Several workers (Grover and Bansal. 1968; Grover and Bansal. 1970; Smith. 1958) have shown the importance of seedborne inoculum in pre- and postemergence damping-off of pepper seedlings. Halsted (1896) and Higgins (1926) stated that *G. piperatum*-infested field debris is of little importance in the development of anthracnose, but Smith and Crossan (1958) have shown more recently that *C. piperatum*-infested crop debris is an important source of inoculum.

Losses due to pepper anthracnose in Louisiana are minimized by numerous hand harvests to remove fruit of cayenne and tabasco (*C. frutescens* L.) from the field as soon as it matures, followed by immediate processing of the harvested fruit. These procedures effectively reduce disease losses because the fruit is removed and processed before symptoms have a chance to develop on the pods. With the trend towards mechanical harvesting, anthracnose has the potential of becoming a limiting factor in the production of pepper, because mature pepper pods would have to remain in the field for much longer prior to harvest. Under these circumstances, serious disease losses can be expected unless other control strategies are employed.

Dithiocarbamate fungicides, such as maneb, have been shown to provide some protection (Chowdhury. 1957; Narain and Panigrahi. 1971; Smith. 1958) and are recommended for control of the disease in Louisiana (Whitam et al. 1988). Chlorothalonil, in addition to the dithiocarbamate fungicides, is recommended for control of tomato anthracnose (Whitam et al. 1988), a disease which appears to be caused by the same organisms that cause pepper anthracnose. Although not yet approved for use on peppers, this fungicide is fairly stable over a wide range of environmental conditions (Fry. 1982) and may offer pepper growers an alternative material for management of the disease when and if it is approved for this use.

The objectives of this paper were: (a) to determine the role of inoculum sources in disease development, (b) to evaluate two fungicides at various application intervals for their efficacy in controlling anthracnose, and (c) to examine the pathogenicity and virulence of *Colletotrichum* spp. isolates from pepper and tomato in cross-inoculation studies.

Materials and Methods

Inoculum Source Studies

A study was initiated to determine the importance of seed and crop debris as sources of inoculum which contribute to the development of anthracnose on mature pepper pods. Three treatments consisting of 'clean seed' in a 'clean field' (CS-CF), 'clean seed' in an 'infested field' (CS-IF), and 'infected seed' in a 'clean field' (IS-CF) were employed.

Seed for the 'infected seed' treatment was extracted from pods of cayenne, selection LSU 16, coinfected with *C. capsici* and *C. gloeosporioides*. Seed of the same selection produced in an arid area without overhead irrigation was used in the 'clean seed' treatments. The 'clean field' treatments were located in fields in which there had been no pepper production for more than 20 years. The 'infested field' treatment was located in an area in which pepper heavily infected with *C. capsici* and *C. gloeosporioides* had been grown the previous year.

Six-week-old pepper transplants were produced in the greenhouse in model 200 'TODD' planter flats (Speedling Inc., Sun City, Florida) using Jiffy Mix-Plus (Jiffy Products of America, West Chicago, Illinois) as the growing medium. The plants from 'infected seed' treatments and the plants from 'clean seed' were maintained on separate greenhouse benches. The plants were transplanted into the field with a 38 cm in-row spacing on rows which were on 1.2 m centers. The rows were raised, shaped beds covered with aluminum-painted plastic film mulch. Treatments were replicated four times. Each replication consisted of two rows 30.5 m in length. Treatments were located in different fields physically separated by a minimum of 150 m. The experiment was repeated once.

The effect of the treatments on disease incidence was evaluated on two harvest dates in 1984 and on three harvest dates in 1985. The percentage of diseased pods was determined by counting a 50-pod subsample of the total harvest of each replication. At least 15 lesions from each subsample were examined microscopically to determine the species of *Colletotrichum* involved.

Fungicide Studies

A fungicidal spray study was conducted to evaluate two fungicides and the frequency of their application for anthracnose control in bell pepper (Bell Boy) and cayenne pepper (selection LSU 16). Two fungicides, maneb (Manex) and chlorothalonil (Bravo 500), were applied at 1.9 ml/liter and 3.8 ml/liter, respectively. Fungicides were applied at a pressure of 7 kg/cm^2 (100 psi) to the point of runoff with a tractor-drawn drop-boom spray system using three to five TX26 hollow cone nozzles (Spraying Systems Co., Wheaton, Illinois). Applications of fungicides at one to four-week intervals began on June 26 when a majority of the plants were at the first bloom stage, and continued throughout the season, ending on November 2. A treatment which received no spray application was maintained as a control for each fungicide studied.

Peppers were direct-seeded by the plug-mix method (Hayslip, 1974) with a 38 cm spacing between plants on raised rows on 1.2 m centers covered with aluminum-painted plastic film mulch. Unplanted alleys of 1.2 m were maintained between treatment replications. Each replication was 6.9 m long and consisted of approximately 18 plants. The experiment was arranged in a randomized complete block design with four blocks and five treatments per fungicide. The research plot was planted in a field in which a pepper crop severely affected by anthracnose had been grown the previous year.

Disease incidence was determined by counting the number of diseased pods in a 50-pod subsample from the total harvest of each replication. Bell peppers were hand harvested five times and cayenne peppers eight times. A pod was considered diseased if a single lesion was found. Diseased and symptomless pods in the 50-pod subsample were weighed to determine the percentage of the yield that was marketable in each replication. Only pods free of lesions were considered marketable.

Cross Inoculation Studies

Conidia of 22 isolates including representatives of *C. capsici*, *C. gloeosporioides*, *C. acutatum*, and *C. coccodes* that had been obtained from pepper or tomato were inoculated into both tomato and bell pepper fruit. Yolo Wonder pepper and Heinz 1350 tomato fruit were detached at the ripe red stage and inoculated to determine the pathogenicity and virulence of each isolate on both hosts.

The inoculation techniques were adapted from those used by others (Barksdale, 1970; Barksdale and Koch, 1969; Robbins and Angell, 1968; Robbins and Angell, 1970) in tomato anthracnose resistance studies. All cultures were single-spored and stored on silica gel (Perkins, 1962) immediately after isolation. Prior to each study, fresh cultures of each isolate were recovered from silica gel and grown on Difco potato dextrose agar (39 g/l) under continuous fluorescent light at room temperature (approx. 24°C). Seven-day-old cultures were washed with distilled

water to make a conidial suspension which was filtered through two layers of cheesecloth to remove mycelial and agar fragments. Spore suspensions were diluted and adjusted to approximately 10^6 conidia/ml using a hemacytometer. Three pepper and three tomato fruits were inoculated in three sites with each isolate by injecting 25 l of conidial suspension using a 1 ml syringe fitted with a 22 gauge hypodermic needle. The fruits were incubated for nine days at room temperature on a laboratory table, during which time they were examined for lesion development and lesion diameters were measured.

Results

Influence of Inoculum Source

Infected seed and crop debris were studied in 1984 and 1985 for their role as sources of inoculum for the development of pepper anthracnose. The three treatments compared for their influence on disease development were CS-CF, CS-IF, and IS-CF. Anthracnose developed in all three treatments, but occurred at a much lower incidence on pods in the CS-CF treatment (Table 1). The incidence of diseased pods ranged from 3 to 6% in the September and October harvests of both years. Pod infections examined in this treatment during both years were due to *C. gloeosporioides* with the exception of a single pod found to be infected with *C. capsici* (Table 2).

Table 1. Influence of inoculum source on the incidence of anthracnose in cayenne pepper, selection LSU 16.

Treatment[y]	Percent diseased pods[z]				
	9/27/84	10/5/84	9/11/85	10/2/85	11/1/85
Clean seed/Clean field	3 a[x]	4 a	6 a	5 a	27 a
Infected seed/Clean field	52 b	36 b	70 b	81 b	92 b
Clean seed/Infested field	64 b	46 c	44 ab	65 b	93 b

[z]Mean percentage of diseased pods was determined from a 50-pod subsample from each of the four replications at each harvest. [y]Clean seed = western grown disease-free seed, infected seed = seed from pods infected with *C. capsici* and *C. gloeosporioides*; clean field = field with no past history of pepper production; infested field = field in which the previous year's pepper crop was infected with *C. capsici* and *C. gloeosporioides*. [x]Mean separation within columns on harvest dates by Duncan's new multiple range test (P = 0.05).

Table 2. Influence of inoculum source on the prevalence of *C. capsici* and *C. gloeosporioides* causing anthracnose in cayenne pepper, selection LSU 16.

Treatment[y]	Percentage of anthracnose lesions caused by *C. capsici* (Cc) and *C. gloeosporioides* (Cg)[z]									
	9/27/84		10/5/84		9/11/85		10/2/85		11/1/85	
	Cc	Cg	Cc	Cg	Cc	Cg	Cc	Cg	Cc	Cg
Clean seed/Clean field	5 a[x]	95 a	0 a	100 a	0 a	100 a	0 a	100 a	0 a	100 a
Infected seed/Clean field	41 b	59 b	60 b	40 b	77 b	23 b	100 b	0 b	97 b	3 b
Clean seed/Infested field	53 b	47 b	53 b	47 b	97 b	3 b	97 b	3 b	95 b	5 b

[z]Mean percentage of each pathogen was determined from 15 lesions on pepper in the 50 pod subsample from each of the four replications at each harvest. [y]Clean seed = western grown disease-free seed; infected seed = cayenne seed from pods infected with *C. capsici* and *C. gloeosporioides*; clean field = field with no past history of pepper production; infested field = field in which the previous year's pepper crop was infected with *C. capsici* and *C. gloeosporioides*. [x]Mean separation within columns on harvest dates by Duncan's new multiple range test (P = 0.05).

Incidence of infected pods in the CS-IF and IS-CF treatments ranged from 36 to 81% in September and October of 1984 and 1985. Numbers of lesions on the pods caused by *C. capsici* and *C. gloeosporioides* were about equal during 1984, but in 1985 they were caused predominantly by *C. capsici* even though both species were present in the fields throughout the harvest season (Table 2).

Fungicide Studies

Chlorothalonil or maneb applied at one- and two-week intervals significantly reduced the incidence of anthracnose in both bell and cayenne peppers when compared with the unsprayed control (Tables 3 and 4). Application of either chemical at three or four-week intervals had little effect on the incidence of anthracnose when compared with the control (Tables 3 and 4).

Cayenne pepper plants receiving applications of chlorothalonil and of maneb at one- and two-week intervals produced yields of 15.1, 11.4, 11.4, and 8.9 kg of marketable fruit per replication, respectively, while untreated plants produced only 4.0 kg per replication (Figure 2). Differences in yield of marketable fruit between treated and untreated plots were noted as early as the second harvest date. Cayenne peppers receiving these four treatments produced significantly higher yields of marketable fruit than the control, while yields of peppers receiving applications of chlorothalonil and maneb at three and four-week intervals were not significantly different from the control.

Accumulated marketable fruit yields of bell pepper followed a trend similar to that of cayenne pepper. Bell pepper plants receiving applications of chlorothalonil at one and two-week intervals produced the highest yields followed by those plants receiving one and two-week interval applications of maneb. Statistical differences in yield of accumulated marketable fruit of bell pepper were observed only on the September 11 harvest date. On this date treatments receiving applications of chlorothalonil at one and two-week intervals had produced significantly more marketable fruit when compared with the unsprayed control. Although statistical differences

Table 3. Effect of fungicides applied at various intervals on the control of anthracnose in cayenne pepper, selection LSU 16, during 1984.

Interval/fungicide	Percent diseased pods[z]							
	8/23	9/7	9/11	9/19	9/26	10/2	10/17	11/9
1 week								
Chlorothalonil	18 a[y]	21 a	24 a	16 a	5 a	11 a	42 a	60 a
Maneb	25 a	44 b	46 b	18 a	10 a	11 a	61 b	86 b
2 week								
Chlorothalonil	22 a	30 ab	29 a	11 a	10 a	16 a	63 b	94 cd
Maneb	46 a	72 c	61 b	25 a	18 ab	17 a	79 b	95 cd
3 week								
Chlorothalonil	92 b	96 d	83 c	55 b	34 bc	39 bc	87 c	97 cd
Maneb	79 b	98 d	91 c	58 b	33 bc	40 bcd	91 c	94 cd
4 week								
Chlorothalonil	83 b	86 cd	86 c	53 b	32 bc	37 b	85 c	97 cd
Maneb	92 b	94 d	88 c	54 b	40 cd	61 d	89 c	96 cd
No spray								
Chlorothalonil – Control	85 b	92 d	79 c	54 b	43 cd	47 bcd	89 c	91 bc
Maneb – Control	82 b	94 d	89 c	62 b	55 d	59 cd	95 c	100 d

[z]Mean percentage of diseased pods was determined from a 50-pod subsample from each of the four replications at each harvest. [y]Mean separation within columns on harvest dates by Duncan's new multiple range test (P = 0.05).

Table 4. Effect of fungicides applied at various intervals on the control of anthracnose in bell pepper, Bell Boy, during 1984.

Interval/fungicide	Percent diseased pods[z]					
	8/9	8/23	9/7	9/11	9/19	9/26
1 week						
Chlorothalonil	14 a[y]	35 a	28 a	41 ab	19 a	0 a
Maneb	9 a	25 a	72 b	41 ab	13 a	3 a
2 week						
Chlorothalonil	20 a	21 a	68 b	31 a	26 ab	0 a
Maneb	20 a	50 ab	86 b	74 bc	32 abc	29 a
3 week						
Chlorothalonil	27 a	93 c	97 b	67 bc	52 bcd	21 a
Maneb	15 a	75 bc	76 b	65 bc	66 d	26 a
4 week						
Chlorothalonil	41 a	89 c	98 b	83 c	64 cd	19 a
Maneb	32 a	86 c	96 b	70 bc	73 d	44 a
No spray						
Chlorothalonil – Control	30 a	87 c	100 b	82 c	71 d	0 a
Maneb – Control	23 a	81 c	99 b	85 c	77 d	34 a

[z]Mean percentage of diseased pods determined from a 50-pod subsample from the four replications at each harvest. [y]Mean separation within columns on harvest dates by Duncan's new multiple range test (P = 0.05).

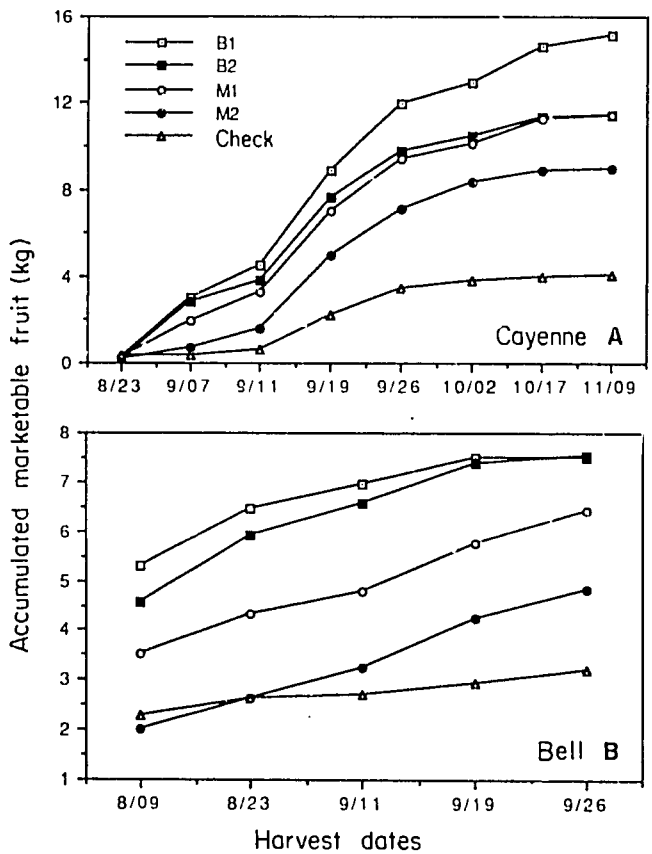

Figure 2.
Accumulated marketable fruit weight of (A) cayenne and (B) bell peppers as influenced by weekly and biweekly applications of chlorothalonil (Bravo 500 at 3.8 ml/liter; B1 = chlorothalonil weekly, B2 = chlorothalonil biweekly) and maneb (Manex 4F at 1.9 ml/liter; M1 = maneb weekly, M2 = maneb biweekly; Check = no application).

between treatments were not observed at the latter harvest dates, bell peppers treated with chlorothalonil at one and two-week intervals continued to produce the highest yields of marketable fruit.

Cross Inoculation Studies

Isolates of the four *Colletotrichum* spp., regardless of host origin, produced lesions on both pepper and tomato fruit (Table 5). Mean lesion diameters ranged from 9.4 to 19.3 mm on bell pepper fruit and from 17.8 to 43.4 mm on tomato fruit. Lesions incited by any given isolate were larger on tomato than those by the same isolate on pepper.

Mean lesion diameters incited by the four *C. gloeosporioides* isolates ranged from 9.4 to 15.0 mm on pepper and 22.5 to 36.7 mm on tomato. There was no statistical difference in virulence, based on lesion size, among the isolates tested on either host.

Virulence among isolates within each of the other three species – *C. acutatum*, *C. capsici*, and *C. coccodes* – varied significantly when compared on pepper fruit and also when compared on tomato fruit (Table 5). However, the level of virulence of each isolate was not always the

Table 5. Mean lesion diameters caused by isolates of *Colletotrichum* spp. on ripe bell pepper and tomato fruit.

Species/Isolates	Isolate origin	Original host	Mean lesion diameter[Z] (mm)	
			Pepper[Y]	Tomato[X]
C. gloeosporioides				
C-15	Avery Island, LA	Pepper	15.0 a[W]	22.5 a
C-5	Baton Rouge, LA	Pepper	12.4 a	29.0 a
C-3	Baton Rouge, LA	Pepper	11.7 a	36.7 a
CFTS	Avery Island, LA	Pepper	9.4 a	31.0 a
Check Distilled water		–	0.0 b	0.0 b
C. acutatum				
C-4	Pointe Coupee, LA	Pepper	17.3 a	39.1 a
TB-101	Bridgeton, NJ	Tomato	13.7 ab	34.8 a
C-8	Grundy County, TN	Pepper	12.1 ab	30.2 b
TB-128	Montrose, VA	Tomato	11.3 b	35.4 a
Check Distilled water		–	0.0 c	0.0 c
C. capsici				
FCLS	Baton Rouge, LA	Pepper	19.3 a	33.5 ab
C-19	Baton Rouge, LA	Pepper	17.7 ab	33.2 ab
C-11	Baton Rouge, LA	Pepper	16.2 ab	40.3 a
C-2	Baton Rouge, LA	Pepper	16.0 ab	34.0 ab
C-1	Baton Rouge, LA	Pepper	14.1 abc	24.8 bc
TB-132	Montrose, VA	Tomato	14.0 bc	40.3 a
TB-59	Charleston, SC	Tomato	10.9 c	37.7 ab
C-6	Baton Rouge, LA	Pepper	10.0 c	17.8 c
Check Distilled water		–	0.0 d	0.0 d
C. coccodes				
TB-4	Beltsville, MD	Tomato	17.3 a	43.4 a
TB-145	Rock Springs, PA	Tomato	11.3 b	37.7 ab
TB-126	Bridgeton, NJ	Tomato	10.0 b	25.8 c
TB-9	Beltsville, MD	Tomato	9.9 b	30.9 bc
Check Distilled water		–	0.0 c	0.0 d

[Z]Fruit inoculated by injection with a 10^6 conidia ml suspension; lesion diameter measured after 9 days. [Y]Yolo Wonder. [X]Heinz 1350. [W]Mean separation within columns for isolates of each *Colletotrichum* sp. and host combination by Duncan's new multiple range test ($P = 0.05$).

same on pepper and tomato fruit. Mean lesion diameter of *C. acutatum* – incited lesions ranged from 11.3 to 17.3 mm on pepper and 30.2 to 39.1 mm on tomato fruit. Mean lesion diameter of *C. capsici* – incited lesions ranged from 10.0 to 19.3 mm on pepper and 17.8 to 40.3 mm on tomato fruit. Mean lesion diameter of *C. coccodes* – incited lesions ranged from 9.9 to 17.3 mm on pepper, and 25.8 to 43.4 mm on tomato fruit.

Discussion

One of the objectives of the current study was to examine various sources of inoculum for their impact on anthracnose development in pepper fields. During both years of the study, low levels of anthracnose occurred in fields with no known source of inoculum i.e., the CS-CF treatment. Pod infections in these fields ranged from 3 to 6% during the earlier harvests and rose to a high of 27% in one late season harvest during 1985. The incidence of pods with anthracnose symptoms that were grown in the fields with infested crop debris (CS-IF) and those grown from infected seed (IS-CF) ranged from 36 to 96% at various harvests throughout the season. The occurrence of anthracnose in the fields in which an effort was made to eliminate the inoculum sources (CS-CF) suggests that there is a local source of the pathogen. However, the possibility of a low level of undetected seed infection and/or movement from other pepper fields, although they were separated by 150 m or more, cannot be ruled out. *Colletotrichum gloeosporioides* was the primary pathogen associated with pod lesions in this treatment. Based on the wide host range and the ubiquitous nature of *C. gloeosporioides* (Mordue, 1971; Sutton, 1980), it seems likely that this pathogen is endemic to the area and that the inoculum came from some local weed host.

The high incidence of anthracnose-infected pods from the infested field (CS-IF) and infected seed (IS-CF) treatments implicates crop debris and seed as important sources of anthracnose inoculum. Both *C. gloeosporioides* and *C. capsici* were present in crop debris plowed under to establish the CS-IF treatment and in the infected seed used to plant the IS-CF treatment. Although the percentages of lesions caused by each of the species were not the same each year, both *C. gloeosporioides* and *C. capsici* were incitants of pod infections in the experimental fields. These results suggest that both *C. gloeosporioides* and *C. capsici* can be carried from season to season by crop debris and seed and that any disease management scheme must take these factors into account.

The residence of the pepper anthracnose fungi from the seedling stage until pods are produced remains a question. Vegetative infections of cotyledons, leaves, and stems have been reported (Dastur, 1921; Higgins, 1930) and logically could serve as a link between primary inoculum on infected seed or crop debris to provide secondary inoculum for fruit infection. In the current study, vegetative symptoms of the disease were observed only once, occurring on leaves late in the 1984 season (J.F. Hadden, 1984, unpublished). A few scattered leaf lesions incited by *C. capsici* and *C. gloeosporioides* occurred long after pod symptoms had appeared. The lesions were small (1-3 mm) circular spots with dark borders and light centers. Damage to the leaves was insignificant, and due to their sporadic and late season occurrence it is difficult to visualize a role for these lesions in perpetuating the disease cycle.

Both chlorothalonil and maneb were effective against anthracnose, but the time interval between applications greatly affected their efficacy. Application intervals of 21 days or more with chlorothalonil or maneb were ineffective in controlling the disease. Requirements for fruit to be accepted as marketable in the current study were fairly stringent (one lesion = unmarketable) which might have resulted in lower marketable yields than might be expected in normal production conditions. Applications of chlorothalonil or maneb at 7- or 14-day intervals reduced anthracnose severity and increased the yield of marketable fruit in bell and cayenne pepper (Tables 3 and 4 and Figure 2). The most effective treatment was weekly applications of chlorothalonil, and biweekly applications of this material provided protection equal to or better than weekly applications of maneb. The results with maneb agree with previous studies in which seven- or

14-day application intervals were effective in controlling anthracnose (Narain and Panigrahi, 1971; Smith, 1958; Smith and Crossan, 1958). Chlorothalonil is relatively persistent under a variety of environmental conditions (Fry, 1982). This characteristic may explain its increased effectiveness over maneb and allow a reduced number of sprays while maintaining an acceptable level of disease control. Even though chlorothalonil is labelled on many other vegetable crops, it is not labeled for use on peppers in the United States at this time. Presently, efforts are being made to obtain a registration for use of chlorothalonil on pepper. Registration of chlorothalonil on pepper crops would give the pepper grower a valuable alternative in the choice of fungicides to control anthracnose.

One purpose of the present study was to determine if host specificity occurred among isolates of these four *Colletotrichum* species obtained from pepper and tomato. Virulence among isolates within each fungal species to pepper and tomato was determined by comparing mean lesion diameters on each host, independently (Table 5). All isolates tested caused larger lesions on tomato than on pepper fruit, but this was interpreted to be due to the different fruit types rather than a difference in host preference by the fungal isolates. Some isolates within species varied significantly in their virulence to pepper or tomato, and the level of virulence for any given isolate was not necessarily parallel on both hosts. Nevertheless, all isolates, regardless of their original host, were pathogenic to both pepper and tomato fruit in cross-inoculation tests, thus showing no evidence for host specific isolates.

The appearance of *C. gloeosporioides* – infected peppers in the CS-CF treatment suggested that other hosts in the area, such as weeds or other crop plants, may serve as an inoculum source. It is not likely, therefore, that pepper anthracnose can be eliminated from Louisiana pepper fields by crop rotation and the use of disease-free seed, but the initial disease incidence can be greatly reduced by implementing these practices. Through crop rotation and use of disease-free seed perhaps the inoculum level can be kept sufficiently low to allow for more successful chemical control.

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Symposium Discussion

I.D. Erinle: As a way of further reducing the number of sprays, have you used benomyl?
J.F. Hadden: No. We only evaluated maneb and chlorothalonil. In other *Colletotrichum*-incited diseases such as anthracnose crownrot of strawberry benomyl-resistant strains have occurred. For this reason, we chose not to include benomyl in this test.

200

21

Genetic Resistance to Bacterial Spot in Tomato

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Abstract

Resistance in tomato (*Lycopersicon esculentum*) for leaf spot and fruit spot phases of bacterial spot incited by *Xanthomonas campestris* pv. *vesicatoria* was controlled by separate genetic systems. Hawaii 7998 had a good level of field resistance to foliar infection for five years, but was not resistant to fruit infection. PI 270248-Sugar was susceptible to foliar infection but highly resistant to fruit spot infection. In foliar infection studies, hybrids between resistant parents and susceptible parents were intermediate to the parents. There were no reciprocal cross differences for either foliar or fruit spot indicating a lack of cytoplasmic inheritance. In fruit infection studies hybrids between resistant parents, and tolerant or susceptible parents were similar in disease infection to the resistant parent, indicating a high degree of dominance for this trait. Seedling screening procedures for foliage resistance have not been adequately developed. These tests may not be reliable in differentiating resistance levels within and among genotypes. Lesion size in seedling tests was more highly correlated with field resistance than was lesion number. A modified backcrossing approach, allowing for selection of homozygous resistance before crossing, is suggested to incorporate foliar resistance into acceptable cultivars.

Introduction

Bacterial spot, incited by *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye, is the most serious foliar disease of tomato (*Lycopersicon esculentum* Mill.) in Florida (Pohronezny and Volin, 1983). It is also a problem in some other production areas where temperatures are high (Nayudu and Walker, 1960) and rainfall is frequent (Cox, 1966). The disease affects both foliage and fruit. Defoliation results in reduced marketable fruit weight for both staked and unstaked tomatoes (Dougherty, 1978; Pohronezny and Volin, 1983). Defoliation causes fruit size reduction and sunscald, while bacterial spot lesions on fruit caused 12% of the culls in one experiment (Pohronezny and Volin, 1983). Chemical control measures are often not effective when environmental conditions favor the disease (Conover and Gerhold, 1981; Marco and Stall, 1983). Partially resistant, henceforth referred to as tolerant, germplasm has been reported in tomato (Coyne and Schuster, 1967; Crill et al. 1972; Knzeva and Kunnukh, 1979; Lawson and Summers, 1984; Sotirova and Beleva, 1975). However, all cultivars currently grown in Florida are susceptible (Scott and Jones, 1984). There has been difficulty in breeding tolerant germplasm (Crill et al. 1972; Volin, 1979). More recently, resistance to bacterial spot on foliage (Scott and Jones, 1985; 1986; Jones and Scott, 1986) and fruit (Scott et al. 1987) has been discovered. This has provided hope for developing acceptable cultivars with useful resistance to either replace or enhance chemical control measures.

One difficulty in developing bacterial spot resistant cultivars has been the lack of a good seedling screening technique. Several studies have utilized seedling screening techniques, but correlations with field performance have been lacking. The objective of this paper is to present information to assist those interested in working on bacterial spot resistance in tomato.

Materials and Methods

General Culture and Design for Field Experiments

Field experiments were conducted during the summers from 1982 through 1986 and late summer in 1987. Seeds for these experiments were sown in an inert medium and transplanted to Todd[R] planter flats with 3.8 cm^3 cells 10 to 14 days later. After one month, transplants were set in the field on 15 cm-high by 75 cm-wide beds of EauGallie fine sand which had been fumigated with methyl bromide:chloropicrin (67%:33%) two weeks earlier and covered with white polyethylene mulch. The beds were 137 cm from center to center and plants were spaced 61 cm apart within the rows. Recommended fertilizer and insecticide practices were employed and chlorothalonil was used to control fungal pathogens without inhibiting bacteria. The plants were watered with seepage irrigation. In 1985, there were two replications but all other field experiments consisted of three replications. Weather for the field trials was hot and humid with frequent rainfall, often during thunderstorms. Day temperatures typically ranged from 31° to 34°C and night temperatures from 21° to 23°C.

Inoculum Preparation and Use

Inoculum of *Xanthomonas campestris* pv. *vesicatoria* was prepared from cultures that had been grown on nutrient-yeast-dextrose agar (Jones et al. 1981) for 48 hours at 28°C. The bacteria were washed from the plates, suspended in 0.01 M $MgSO_4$ and adjusted to 10^8 colony forming units (cfu)/ml. Plants were inoculated by spraying a bacterial suspension on the plants a few weeks after field setting in the early mornings.

Foliage Infection Studies

Genotypes were rated for the percentage of infected foliage in each experiment, except in 1983 when the Horsfall-Barratt scale (Horsfall and Barratt, 1945) was used. The percentage data were transformed to the arcsine of the square root for analysis.

The resistance of various genotypes was tested in several field experiments. 'Walter' and Hawaii 7998 (H7998) were grown in the summers of 1983, 1984, 1985, and 1986 with the hybrids of the two grown in the latter three seasons. In another field experiment in 1986, the above three genotypes were tested as were: Ohio 4014-3 (tolerant); 'Campbell 28' (C28) (tolerant); PI 270248 'Sugar' (susceptible foliage but resistant to fruit spot); Hawaii 7997 (susceptible); 'Lyconorma' (very susceptible); and hybrids between several of these inbreds.

Fruit Infection Studies

In 1985, H7998, Sugar, and reciprocal hybrids H7998 × Sugar and Sugar × H7998 were grown. The plants were rated for foliar infection as described previously and for fruit infection (%) by picking the fruit and scoring the presence of lesions.

In late summer 1987, the following genotypes were rated for fruit spot: Walter, H7998, Sugar, Walter × Sugar, Walter × H7998, H7998 × Sugar and Sugar × H7998. The field experiment consisted of a randomized block design with three blocks and 10 plants per plot of each genotype. Plants were inoculated as previously described. Fruit were harvested from the top half of the plants and scored for fruit spot infection. There was no fruit infection on the lower half of the plants. In a greenhouse experiment, eight plants of each genotype were transplanted into 30.5 cm pots and grown in a completely randomized design. When the oldest fruit were 30 days old, a bacterial spot suspension was misted onto each cluster of fruit with a hand held atomizer. The plants were then moved into growth chambers, held at 27°C, and greater than 90% RH, and 12 h/day for 72 h. The plants were removed to the greenhouse and fruit was scored for infection three weeks later.

Seedling Screening Studies

Several seedling screening experiments were conducted in greenhouses and/or growth chambers in 1983. Genotypes used were: Walter, C28, Ohio 4014-4, Ohio 4013-3, Heinz 1538, PI 203232, L 2024, [(Subartic Delite × Fla. MH 1) Heinz 603] F_5, Texas 204, PI 414172, 6204 × Cl 11d, Heinz 2990, Lyconorma, and Early Red Rock. Several of these had some tolerance in previously reported field screening tests (Scott and Jones, 1985). The above ground parts of five-week-old plants, five per genotype, were immersed in a suspension of *Xanthomonas campestris* pv. *vesicatoria* in a dessicator. A vacuum was pulled for approximately 20 to 30 seconds and then released abruptly to create water soaking (Jones, McCarter and Smitley, 1981). Two weeks later lesion numbers per plant and lesion size of 10 typical lesions per plant were recorded in three experiments. Lesion size alone was recorded in the fourth experiment. These data were analyzed for their correlations with data recorded in field experiments for the same genotypes in 1982 and 1983 (Scott and Jones, 1985).

In April 1986, seed of Walter, Lyconorma, C28, Ohio 4014-4, and H7998 were planted in an inert medium and transplanted to Todd[R] planter flats cut into sections. At seventeen and 31 days after sowing (d.a.s) the transplants were preconditioned and not preconditioned. Preconditioning consisted of moving the plants into a 100% RH chamber for 12 hours the day before inoculation. For inoculation, plants were moved to a growth chamber at 27°C and 90% RH and were inoculated with 10^8 cfu/ml *Xanthomonas campestris* pv. *vesicatoria*. After two days, the plants were moved back to the greenhouse. Eight days later each plant was rated for disease infection using the Horsfall-Barratt scale.

In 1987, seedlings of the five genotypes just listed plus two bacterial spot resistant breeding lines Fla. 317 and Fla. 325 were grown. Each genotype was grown with and without preconditioning as described previously. When the plants were 31 d.a.s., they were moved to the growth chamber and inoculated as previously described. After two days at high humidity, the plants were grown in the growth chamber for 14 days at 27°C day and 24°C night temperatures. Plants were rated for disease infection using the Horsfall-Barratt scale.

Results and Discussion

Over several years, Hawaii 7998 had a high level of field resistance to the foliar phase of bacterial spot when compared to the susceptible cultivar Walter (Table 1). The resistance is not absolute and there are some lesions on H7998 especially when disease pressure is high as in the 1986 experiment reported in Table 1. Hybrids between Walter and H7998 were intermediate between the parents each year. The acceptability of the hybrid resistance level depends on the disease pressure. On our scale, 25% infection is considered to be susceptible. Thus the hybrids would have had good resistance levels in 1984 and 1985, but not in the 1986 experiment (Table 1). In a separate experiment in 1986 disease pressure was also high, but judging

Table 1. Bacterial spot disease severity for tomato genotypes Walter, Hawaii 7998, and their hybrid grown over several seasons in the field at Bradenton, Florida.

Genotype	Infected foliage			
	Summer 1983 (HB)[z]	Summer 1984 (%)[y]	Summer 1985 (%)	Summer 1986 (%)
Walter	5.5 a[x]	38.7 a	39.2 a	52.2 a
Hawaii 7998	2.0 b	1.1 c	3.4 c	9.0 c
Walter × Hawaii 7998	–	10.2 b	11.9 b	29.8 b

[z]Horsfall-Barratt rating scale: 2 = 1% to 3%; 5 = 12% to 25%; 6 = 25% to 50%. [y]Percentage data converted to arcsine sq. root for analysis which was based on an experiment with a larger number of genotypes. [x]Mean separation in columns by Duncan's multiple range test, 5% level.

by the reaction of H7998 and the H7998 × Walter hybrid, not as severe as in the 1986 experiment reported in Table 1 (Table 2). In past work, C28 was tolerant to bacterial spot (Crill et al. 1972; Scott and Jones. 1986). The hybrid of H7998 × C28 had a very good resistance level, both numerically and statistically similar to that of H7998 (Table 2). In 1985, the H7998 × C28 F_1 had significantly less disease than H7998 × Walter and H7998 × Sugar (Scott and Jones. 1985. unpublished data). All other H7998 hybrids had relatively low disease severity regardless of the susceptibility level of the other parent. For instance, the hybrid with very susceptible Lyconorma was not more susceptible than other H7998 F_1 's in this experiment (Table 2). Thus hybrids with two resistant parents would be highly resistant. Resistant × tolerant hybrids would have the next best resistance, and resistant × susceptible F_1 's would provide a lower level of resistance, somewhat similar to the tolerance of C28 (Table 2). We have no evidence that resistant × very susceptible parents result in less resistant F_1's than the F_1 from resistant × susceptible parents, but this should be studied further.

In work to be published elsewhere, genetic control of resistance from H7998 involved several (three to six) genes with mostly additive gene action and fairly high heritability (.7 to .9). A modified backcrossing scheme is suggested to incorporate this resistance. It is important to obtain homozygous resistance before crossing in order to retain all the resistance alleles. Several tests of resistance are suggested to determine resistance in breeding lines. Field screening under high disease pressure is preferable at this time. More will be discussed regarding other screening methods later.

There appears to be a separate genetic mechanism controlling resistance to the fruit spot phase of the disease. In earlier work, PI 270248-Sugar had good fruit spot resistance, whereas Walter was susceptible, and H7998 was intermediate (Scott et al. 1987). In a field experiment Sugar had significantly less fruit spot infection, but significantly more foliar infection than H7998 (Table 3). Fruit spot infection levels of the reciprocal hybrids of Sugar × H7998 were not significantly different from those of Sugar (Table 3). For foliar infection, the reciprocal hybrids were intermediate to the parents as was the case for resistant × susceptible hybrid data already

Table 2. Bacterial spot ratings for tomato inbreds and hybrids at Bradenton, Florida, during summer 1986.

Genotype	Disease reaction[z]	Bacterial spot (%)
Lyconorma	VS	90.0 a[y]
Walter × Lyconorma	S × VS	63.3 b
Hawaii 7997 (H7997)	S	53.7 bc
Walter	S	53.3 bc
Walter × Ohio	S × T	46.7 bc
Lyconorma × Ohio	VS × T	45.0 bc
Lyconorma × C-28	VS × T	38.3 cd
Walter × Sugar	S × S	35.0 c-e
Walter × C-28	S × T	25.0 d-f
Sugar	S	25.0 d-f
C-28	T	23.3 d-f
Ohio × C-28	T × T	18.3 d-g
H7998 × Sugar	R × S	17.3 e-h
H7998 × Walter	R × S	16.7 e-h
H7998 × Lyconorma	R × VS	15.7 e-h
Ohio 4013-3 (Ohio)	T	8.7 f-h
H7998 × Ohio	R × T	8.3 f-h
H7998 × H7997	R × S	6.0 gh
H7998 × C-28	R × T	4.3 h
Hawaii 7998 (H7998)	R	3.7 h

[z]VS = very susceptible, S = susceptible, T = partially resistant (tolerant), R = resistant. Rating is based on previous testing of parental lines. [y]Mean separation by Duncan's multiple range test, 5% level, data transformed to arcsine sq. root for analysis.

presented. The significantly greater disease for the F_1 with H7998 as the female parent was not expected but suggests the absence of cytoplasmic inheritance. Two experiments on fruit spot resistance in 1987 indicated that hybrids between resistant (Sugar) × susceptible (Walter) or resistant × tolerant (H7998) parents had resistance similar to Sugar (Table 4). These data support the idea that fruit spot resistance is controlled by a high degree of dominance, but a detailed genetic study has not been carried out. Fruit spot infection has been more difficult to obtain than foliar infection. Thus, in rating plants or lines of unknown fruit spot resistance, care should be used or erroneous conclusions may result. Repeated testing in the field is suggested unless an improved inoculation method is devised for either greenhouse or field screening. At present, we feel that if resistance to the foliar phase of the disease is obtained, the bacterial populations will be low and losses due to fruit spot will be minimal. Both resistance systems together would provide better insurance for this, but the breeding effort to incorporate both would be substantial.

A reliable greenhouse and/or growth chamber seedling screening procedure would be a boon to breeding efforts for foliar resistance. The reliability of existing procedures has yet to be proven. In some earlier work with 14 genotypes, there was little relationship between lesion number and field resistance (Table 5). The size of the lesions provided a better correlation with field ratings (Table 5). Other unpublished data tend to support this conclusion, but the proper inoculation procedure is critical to obtaining lesion size differences and care should be used in interpreting disease reactions. Preconditioning before inoculation resulted in better disease infection than not conditioning the plants (Tables 6 and 7). The preconditioned treatment separated genotypes with known resistance levels fairly well while the nonconditioned plants had little disease, especially in the 1987 experiment. However, differences between resistant and tolerant genotypes were not always apparent (Tables 6 and 7). Typical problems are illustrated by the

Table 3. Bacterial spot severity on fruit and foliage of tomato genotypes Hawaii 7998, Sugar and their reciprocal hybrids inoculated in the field at Bradenton, Florida, during summer 1985.

Genotype	Bacterial spot severity	
	Fruit (%)	Foliage (%)
Hawaii 7998	16.8 a[z]	3.4 d
Hawaii 7998 × Sugar	10.8 ab	31.6 b
Sugar × Hawaii 7998	5.6 b	24.1 c
Sugar	5.2 b	37.5 a

[z]Mean separation in columns by Duncan's multiple range test, 5% level, data transformed to arcsine sq. root for analysis. [y]Statistics based on an experiment with a larger number of genotypes.

Table 4. Incidence of fruit infection by *Xanthomonas campestris* pv. *vesicatoria* for several tomato genotypes grown in greenhouse and field experiments during late summer 1987 at Bradenton, Florida.

Genotype	Generation	Greenhouse fruit		Field fruit	
		Total	Infected (%)	Total	Infected (%)
Walter (W)	P	89	20.6 b[z]	1259	11.0 a[z]
Hawaii 7998 (H)	P	179	5.6 c	3187	0.2 b
Sugar (S)	P	922	1.5 c	7605	0.1 b
(W × S)	F_1	422	1.6 c	3647	0.6 b
(W × H)	F_1	78	35.5 a	1218	2.0 b
(H × S)	F_1	427	0.6 c	3663	0.0 b
(S × H)	F_1	315	0.2 c	2991	0.0 b

[z]Mean separation, performed only in these two columns, by Duncan's multiple range test, 5% level, data transformed to arcsine sq. root for analysis.

Table 5. Correlation coefficients (r) between bacterial spot lesion number and size in greenhouse seedling experiments with field ratings of large plants grown under summer conditions at Bradenton, Florida.

Experiment	Parameter	Field rating[z] 1982	Field rating[z] 1983
1	Spot No.	.14	.28
2	Spot No.	-.10	.00
3	Spot No.	.20	.30
1	Spot Size	.73**	.72**
2	Spot Size	.74**	.71**
3	Spot Size	.41	.65*
4	Spot Size	.57	.84***

[z]Scott and Jones 1985.

Table 6. Effect of preconditioning (see text) seedlings of genotypes with various levels of bacterial spot resistance before inoculation by spray with 10^8 cfu/ml *Xanthomonas campestris* pv. *vesicatoria* and incubation at 27°C and at greater than 90% RH for two days at Bradenton, Florida, autumn 1987.

Genotype	Subjective field rating[z]	Disease severity[y] Preconditioned	Disease severity[y] Not preconditioned
Lyconorma	VS	5.2 a[x]	1.7
Walter	S	5.0 a	1.7
Ohio 4014-3	T	3.6 b	1.7
Campbell 28	T	3.4 bc	1.5
Florida 317	R	2.7 cd	1.5
Florida 325	R	2.2 de	1.5
Hawaii 7998	R	1.8 e	1.1

[z]VS = very susceptible, S = susceptible, T = partially resistant (tolerant), R = highly resistant. [y]Horsfall and Barratt. 1945. [x]Mean separation in columns by Duncan's multiple range test, 5% level. Larger numbers indicate more disease.

Table 7. Mean and ranges of disease severity for preconditioned and not-preconditioned seedlings of tomato genotypes with various resistance levels when inoculated by spray with 10^8 cfu/ml of *Xanthomonas campestris* pv. *vesicatoria* and incubated at 27°C and at greater than 90% RH for two days.

Genotype	Subjective field rating[z]	Disease severity[y] Preconditioned Mean	Preconditioned Range	Not preconditioned Mean	Not preconditioned Range
Lyconorma	VS	4.59 a[x]	2-8	2.13 a	1-5
Walter	S	4.46 a	2-8	2.27 a	1-4
Campbell 28	T	3.65 ab	2-6	1.88 ab	1-3
Hawaii 7998	R	3.13 b	1-7	2.02 ab	1-3
Ohio 4014-4	T	2.93 b	2-7	1.70 b	1-2

[z]VS = very susceptible, S = susceptible, T = partially resistant (tolerant), and R = resistant. [y]Horsfall and Barratt. 1945. [x]Mean separation in columns by Duncan's multiple range test, 5% level. Larger numbers indicate more disease.

overlapping ranges of individual plants from various genotypes with known differences in resistance (Table 7). Even with preconditioning, the ranges between genotypes did not differ appreciably. Thus, genotypic differences may not be clear in these tests. In conclusion, further work is needed to devise reliable, repeatable seedling screening procedures for bacterial spot. Unless improvements are made, the chances of error are great. Good resistance may be lost

and susceptible escapes may be saved. If seedling screening procedures are used, they should be used in conjunction with field screening of large plants under adequate disease pressure. It seems that seedling procedures may be better for rating breeding lines rather than for individual plant segregation within lines at this point. As for field screening, care should be used in controlling foliar fungal pathogens which can cause misinterpretation. Furthermore, if carried out under high temperature, there is little chance of bacterial speck confusing the ratings. In Florida, the summers with high temperatures and rainfall provide good screening conditions. Working with this disease resistance in less favorable environments could hinder progress considerably.

Acknowledgments

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Symposium Discussion

I.D. Erinle: What is the significance of seasons on your evaluation of genotypes of tomato in growth chamber studies?
J.W. Scott: Probably none. The plants were grown in the greenhouse until the fruits were inoculated by spray and placed in the growth chamber at 27°C and over 90% RH for three days. Seasonal headings were simply used to identify experiments and probably have no other significance.

H. Nagai: Can you comment on the race situation for *Xanthomonas campestris* pv. *vesicatoria* on tomato?
J.W. Scott: Until we discovered resistance in Hawaii 7998 there was no way to assess the possibility of races in *Xanthomonas campestris* pv. *vesicatoria* of tomato. This resistance has held up well in all areas of Florida and some other areas of the world but we have recently tested a strain from Brazil which appears to overcome the resistance. Thus, even though this is a polygenic resistance, it is possible that there may be virulent races on this host. The resistance should be field-tested in many locations, including Brazil, to determine if there are in fact such virulent races.

R.T. Opeña: Our brief experience in selecting for bacterial spot resistance in tomato F_2's and BC_1F_2's indicated the difficulty of deriving progenies with as high a level of resistance as Hawaii 7998, the resistant parental stock. The evidence presented so far indicates however that BS resistance has high heritability; thus, it should be theoretically possible to find BS resistant individuals in F_2's or BC F_2's with high breeding value. How do you reconcile this discrepancy in selection experiments versus expectation from heritability studies?
J.W. Scott: In our breeding work I had no success in recovering good resistance from backcrossing F_1 material. We have found less than 10% of F_2's segregate resistant types and many of these don't breed true in the F_3 generation. Although heritability estimates are rather high, the number of genes involved is too great to breed efficiently if crosses are made too soon. Furthermore, there are some environmental considerations. Thus, to accrue all resistant alleles, I suggest multiple tests be conducted to insure homozygous resistance is obtained in at least the F_3 generation before making the next cross.

208

22

Relationship of Lesion Development on Resistant and Susceptible Tomatoes to Internal Populations of *Xanthomonas campestris* pv. *vesicatoria*.

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Abstract

Recently, the tomato line Hawaii 7998, was determined to have a high degree of resistance to *Xanthomonas campestris* pv. *vesicatoria*, the causal agent of bacterial spot of tomato. Hawaii 7998 tested positive for a hypersensitive reaction and consistently had lower bacterial spot severity in field studies than all other tomato genotypes tested. However, spots which were typical of bacterial spot developed on the foliage. In greenhouse studies, 'Walter' (susceptible), PI 270248 'Sugar' (susceptible), 'Campbell 28' (tolerant or partially resistant), Hawaii 7998, and the F_1's of Hawaii 7998 and the other genotypes listed were inoculated with *Xanthomonas campestris* pv. *vesicatoria*. Two weeks later, diameters of lesions were measured and assayed for internal populations of the bacterium. Although Hawaii 7998 developed leaf lesions, populations in lesions were 9 to 342 times lower than populations in leaf lesions of Walter. Lesion development on Hawaii 7998 appears to be a hypersensitive rather than susceptible reaction. Bacterial populations in lesions of the F_1's were intermediate. Seedling screening procedures have been inconsistent for identifying resistance. As an alternative, lesions could be assayed for internal populations by quantifying bacterial populations using direct plating or immunofluorescence. These procedures could facilitate the incorporation of bacterial spot resistance in tomato breeding programs.

Introduction

Bacterial spot of tomato (*Lycopersicon esculentum* Mill.) incited by *Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dye is a major problem in some tropical and subtropical climates. High temperatures and frequent rains are conducive to disease development and potentially to significant yield losses (Conover and Gerhold, 1981; Pohronezny and Volin, 1983; Nayudu and Walker, 1960). Bactericides generally are not effective when conditions are optimal for bacterial spot development (Conover and Gerhold, 1981).

Partial bacterial spot resistance has been observed in a number of genotypes (Coyne and Schuster, 1967; Crill et al. 1972; Knzeva and Kunnukh, 1979; Lawson and Summers, 1984). However, incorporation of such resistance into commercial lines has proven difficult (Crill et al. 1972; Volin, 1979). More recently, several genotypes that significantly reduced disease severity were identified (Scott and Jones, 1986). One line, Hawaii 7998, had a high degree of field resistance. That particular genotype was further tested to determine whether a hypersensitive response (Jones and Scott, 1986) was associated with the genotype. Based on electrolyte leakage, population levels in leaflets and confluent necrosis, Hawaii 7998 was determined to contain a gene or genes for the hypersensitive reaction (Cook and Stall, 1968) and may be useful in a breeding program for bacterial spot resistance.

Development of a seedling screening procedure for bacterial spot has been difficult. Parameters determined for use in selection of resistance must be reliable and repeatable. Greenhouse and growth room procedures have been variable. Our work on population dynamics of *Xanthomonas campestris* pv. *vesicatoria* in lesions of susceptible and resistant genotypes has proven most successful. This paper reports on some of the work associated with measuring bacterial spot resistance in greenhouse studies.

Materials and Methods

Seeds of Hawaii 7998 (resistant to *Xanthomonas campestris* pv. *vesicatoria*), 'Walter' (susceptible), PI 270248 'Sugar' (susceptible), 'Campbell 28' (partially resistant or tolerant), and various F_1 genotypes derived from crossing Hawaii 7998 with susceptible or tolerant genotypes were sown in an inert medium in flats and covered with a layer of vermiculite. Ten days after sowing, seedlings were transplanted to 10 cm pots on a greenhouse bench. Approximately one month after transplanting, plants were inoculated by gently misting the plants until runoff with a suspension of *Xanthomonas campestris* pv. *vesicatoria*. Inoculum was prepared by incubating a Florida pepper strain of the bacterium (XCV 34) for 48 hours on nutrient-yeast-dextrose agar plates at 28°C (Jones et al. 1981). Bacterial growth was suspended in 0.01 M $MgSO_4 \cdot 7H_2O$ and adjusted to approximately 108 = 10^8 cfu/ml with a turbidimetric procedure using a spectrophotometer. After inoculation, plants were incubated in a growth chamber for 48 hours at 27°C and nearly 100% relative humidity, and then returned to the greenhouse.

Approximately two weeks after inoculation, randomly selected mature leaflets with lesions were collected from five plants. Ten lesions per genotype were measured with calipers and then macerated in tissue grinders in a peptone buffer (KH_2PO_4 5.3 g, Na_2HPO_4 8.61 g, and Bacto peptone 1 g/L deionized water) or 0.85% saline solution. Serial tenfold dilutions were performed in phosphate buffer (900 ml deionized water, 50 ml 0.15 M KH_2PO_4, 50 ml 0.15 M Na_2HPO_4, 1 g NaCl, and 0.005 g $CaCO_3$), with 0.1 ml of the appropriate dilution being plated on Tween A, a selective medium for *Xanthomonas campestris* pv. *vesicatoria* (McGuire et al. 1986). Plates were incubated for five days at 28°C and then colonies were enumerated. Lesion counts per leaf were obtained from plants that were grown as described above. One leaf per plant from each of 10 plants was selected and bacterial spot lesions were counted. Analyses of variance was performed on all data, and means were separated by Duncan's multiple range test ($p=0.05$). Log_{10} transformations were used for all lesion *Xanthomonas campestris* pv. *vesicatoria* population data analyses, and data presented are the antilogs of the data analyzed. Lesions where no *Xanthomonas campestris* pv. *vesicatoria* cells were isolated were disregarded in the analysis and considered missing data.

Results and Discussion

Xanthomonas campestris pv. *vesicatoria* populations in lesions were from 9 to 342 times lower in the resistant Hawaii 7998 genotype than in susceptible genotypes (Table 1). In the first and third experiments, performed in December 1986 and 1987, respectively, populations were significantly greater in susceptible and tolerant lines than in the F_1's and the resistant genotype. Results were not as clear cut with the second experiment, performed in June 1986, with two F_1's having similar populations to Hawaii 7998 and one similar to the susceptible and tolerant lines. When the data of the three experiments were combined, Hawaii 7998 lesions had lower populations than Walter, Sugar, Campbell 28, or Hawaii 7998 × Campbell 28.

Due to the variation found in the populations from lesions on the same genotype, individual lesions, rather than bulked lesions, were chosen for sampling. Individual lesion sampling provides better differentiation of genotypes. Further work is necessary to more effectively create conditions for consistent separation of resistant and susceptible plants based on population levels in lesions.

Table 1. Populations of *Xanthomonas campestris* pv. *vesicatoria* in lesions on a range of tomato genotypes.

Genotype	Reaction[y]	*Xanthomonas campestris* pv. *vesicatoria* cells per lesion[z]			
		Experiment 1	Experiment 2	Experiment 3	Average of three experiments
Walter	S	3.93×10^6 a[x]	9.08×10^5 a	5.66×10^6 a	2.72×10^6 a
Sugar	S	8.07×10^5 b	1.94×10^6 a	4.71×10^6 a	1.95×10^6 a
Campbell 28	T	4.90×10^6 a	1.60×10^6 a	NT[w]	2.80×10^6 a
Hawaii 7998 × Sugar	R × S	2.83×10^5 c	1.35×10^6 a	1.88×10^6 b	3.17×10^5 ab
Hawaii 7998 × Walter	R × S	1.97×10^5 c	1.41×10^5 b	1.45×10^6 b	3.43×10^5 ab
Hawaii 7998 × Campbell 28	R × T	2.79×10^5 c	6.40×10^4 b	1.80×10^6 b	8.95×10^5 a
Hawaii 7998	R	1.15×10^4 d	1.05×10^5 b	1.31×10^5 c	5.41×10^4 b

[z]Numbers are antilogs, data were analyzed as log numbers. [y]S = susceptible, R = resistant, T = tolerant or partially resistant. [x]Values in a column followed by the same letter are not significantly different using Duncan's multiple range test (P = 0.05). Each number represents the average of 10 replications. [w]NT = not tested.

A greater magnitude of difference between populations in resistant and susceptible genotypes was observed in experiments run during cooler conditions. This factor along with other factors should be more critically evaluated.

Indirect immunofluorescence (IIF) studies, using a previously described method (Schaad, 1978), were used to verify results of the population studies (Somodi et al. 1987, unpublished). Preliminary studies done in conjunction with the population plating studies, using the same lesions, showed a positive correlation between *Xanthomonas campestris* pv. *vesicatoria* populations on plates and cells counted on immunofluorescent slides. The possibility exists that IIF might be useful as a screening method, especially if it is faster than the population plating method.

Diameters of lesions caused by *Xanthomonas campestris* pv. *vesicatoria* generally were similar on all lines, with a tendency for susceptible and tolerant genotypes to have lesions of greater diameter than Hawaii 7998 (Table 2). A screening procedure based on lesion diameter may be of little use in identifying resistant and susceptible genotypes. The conditions under which plants are grown throughout the course of the study can influence the size and range of lesion diameters. Although there was a trend for susceptible and tolerant genotypes to have more lesions per leaf than Hawaii 7998, these differences were not always significant (Table 3). These results demonstrate the unreliability of lesion counts and measurements to identify resistance.

The observation that populations of *Xanthomonas campestris* pv. *vesicatoria* in lesions on Hawaii 7998 are consistently lower than those in susceptible or tolerant lines is of great significance. Methods for screening for resistance to bacterial spot resistance in tomato appear to have shortcomings for a number of reasons. Growth chamber studies in which plants are misted with *Xanthomonas campestris* pv. *vesicatoria* and subsequently rated for disease as well as studies in which lesions are counted and measured can give variable results depending upon environmental parameters. Our work measuring *Xanthomonas campestris* pv. *vesicatoria* populations in lesions has proven superior. Consistent separations between resistant and susceptible genotypes are obtained. Under cooler conditions differentiation between F_1's and resistant and susceptible genotypes frequently is possible. Work continues on refining seedling screening procedures that can be used accurately and rapidly in preliminary screens. This is being done in conjunction with efforts to quantify bacterial populations by direct plating or by immunofluorescence.

Table 2. Diameters of bacterial spot lesions caused by *Xanthomonas campestris* pv. *vesicatoria* on a range of tomato genotypes.

Genotype	Reaction[y]	Lesion diameter (mm)[z]			
		Experiment 1	Experiment 2	Experiment 3	Average of three experiments
Walter	S	1.56 a[x]	0.94 a	1.13 a	1.21 a
Sugar	S	0.94 b	0.89 a	1.09 a	0.97 a
Campbell 28	T	1.56 a	0.96 a	1.09 a	1.20 a
Hawaii 7998 × Sugar	R × S	0.79 b	0.83 a	0.94 abc	0.85 a
Hawaii 7998 × Walter	R × S	0.83 b	0.96 a	0.87 bc	0.89 a
Hawaii 7998 × Campbell 28	R × T	0.84 b	0.83 a	1.07 ab	0.91 a
Hawaii 7998	R	0.92 b	0.84 a	0.79 c	0.85 a

[z]Average of 10 lesions measured with calipers. [y]S = susceptible, R = resistant, T = tolerant or partially resistant. [x]Values in a column followed by the same letter are not significantly different using Duncan's multiple range test (P = 0.05).

Table 3. Number of bacterial spot lesions per leaf caused by *Xanthomonas campestris* pv. *vesicatoria* on a range of tomato genotypes.

Genotype	Reaction[y]	Number of lesions per leaf[z]	
		Experiment 1	Experiment 2
Walter	S	276.1 a	350.2 a[x]
Sugar	S	363.2 a	131.0 b
Hawaii 7998 × Sugar	R × S	140.7 a	121.9 b
Hawaii 7998 × Walter	R × S	147.0 a	197.2 b
Hawaii 7998	R	114.3 a	169.7 b

[z]Average of 10 leaves. [y]S = susceptible, R = resistant, T = tolerant or partially resistant. [x]Values in a column followed by the same letter are not significantly different using Duncan's multiple range test (P = 0.05).

Acknowledgments

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Symposium Discussion

R.L. Villareal: How variable is *Xanthomonas campestris* pv. *vesicatoria*?

J.B. Jones: Until recently we have seen no variability of strains in response to Hawaii 7998. However, we recently received a strain from H. Nagai in Brazil that has been shown to be virulent on Hawaii 7998. It will be necessary to determine the extent of variability among strains.

-27

23

Quantitative Resistance to Bacterial Leafspot of Pepper Compared in Mono and Polycyclic Disease Progress Tests

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Abstract

Infiltrations of leaves with inocula of *Xanthomonas campestris* pv. *vesicatoria* were used to characterize resistance to race 1 in twelve cultivars and breeding lines of bell pepper (*Capsicum annuum* L.). Resistance was quantitatively measured in repeated tests by lesion numbers and lesion diameters at timed intervals after inoculation with suspensions containing 2×10^3 cells/ml. Quantitative variables were transformed to areas under disease progress curves and to linearized rates of disease severity increase. Transformed variables among the entries ranged from very low (highly resistant) to very high (highly susceptible) and rankings of entries were repeatable between tests. Progress of disease proportions was followed in repeated field plantings of inoculated plants of the same entries. Rates of polycyclic disease increase in the fields were effectively linearized by the Gompertz transformation of disease proportions, and ranged from low to very high among the entries. Rankings of entries in both the monocyclic and polycyclic tests were consistent. Fruit yields increased with level of resistance in both field plantings, but the actual increase could not be predicted from the measured levels of resistance.

Introduction

Bacterial leafspot is a major disease of bell pepper (*Capsicum annuum* L.) in warm, humid climates where the causal bacterium, *Xanthomonas campestris* pv. *vesicatoria*, (Doidge), Dye (Xcv) is endemic. Wind-blown rains spread the pathogen from field to field so that control of the disease by sanitation and chemical sprays is difficult (Kucharek et al. 1986). There is hope for control of the disease by breeding for genetic resistance because many accessions of pepper have been identified that contain resistance (Sowell, 1960; Sowell and Langford, 1963; Sowell and Dempsey, 1977).

Three independent, dominant genes for qualitative resistance have been identified from wild collections of pepper (Hibberd et al. 1987). These have the designations of *Bs1*, *Bs2*, and *Bs3*. However, races of the pathogen in the field (Cook and Stall, 1969; 1982) and mutants in culture (R.E. Stall, Plant Pathology Dept., Univ. of Florida, USA, personal communications, 1986; 1987) have been identified which defeat these genes. Therefore, single gene resistance must be managed if it is to be effective (Vanderplank, 1968).

The problems perceived in managing single, dominant gene resistances have led to an appraisal of quantitatively assessed resistances in the hope that these would be more durable. The extent of disease control obtained with quantitatively assessed resistance varies, however. Relatively small differences in disease severity among bell pepper cultivars are sometimes reported (Jones and Jones, 1986; Maynard, 1986). The correlation of leaf drop with yields of such cultivars

may not be strong (Hibberd and Gillespie. 1982b; Jones and Jones. 1986). More effective resistance than found in some bell peppers has been identified from wild collections.

Most of these resistant accessions do not have the dominant genes *Bs1*, *Bs2*, or *Bs3* (Cook and Stall. 1969; Kim and Hartmann. 1985), but some have resistance which has been long lasting (Adamson and Sowell. 1983; Borchers. 1965). Several have been used as parents in genetic crosses to breed resistant bell peppers (Borchers. 1965; Hibberd and Gillespie. 1982a). It is a feature of some breeding programs that highly resistant segregates were obtained only in F_2 and self-pollinated backcross populations (Adamson and Sowell. 1983; Borchers. 1965; Hibberd and Gillespie. 1982a). Thus; resistance was not a dominant genetic trait, and required careful evaluation. Evaluation of plants has sometimes followed epidemics of the disease in field-grown progenies (Borchers. 1965; Hibberd and Gillespie. 1982a) or monocyclic disease severity tests in glasshouse environments (Adamson and Sowell. 1983).

The most rapid progress in breeding for effective, quantitatively assessed resistance occurs when single plants are reliably identified in monocyclic tests of disease progress. In these tests, plants in controlled conditions are inoculated and the extent of disease which develops in the inoculated tissue in a given time is measured. However, quantitative variables are influenced by environments which may result in a range of values even with homozygous resistant plants. In addition, factors other than genetic resistance to the pathogen may be important in polycyclic disease epidemics in field plantings. For example, leaf chlorosis and fall following the stress induced by disease may be sooner in a plant sensitive to endogenous ethylene than in an insensitive one (Tripp and Wien. 1986). In many species genetic differences which occur for ability of mesophyll to congest naturally with water are correlated with differences in field resistance to bacterial disease (Johnson. 1947). Congested tissue allows easier bacterial ingress (Panopoulus and Schroth. 1974). Techniques for screening plants for quantitatively assessed resistance in the monocyclic system have not received much attention because such screening is laborious. The purpose of this paper is to report on a monocyclic test for quantitatively assessed resistance that appears to correlate well with polycyclic disease progress in the field.

Materials and Methods

Inoculum Preparation

The Xcv strains used were isolated from the field in Queensland in 1986 and stored short-term in 15% glycerol kept at -15°C. Inocula were prepared from late log-phase nutrient broth cultures derived from single colonies. After centrifugation of cultures at 1000 x g , bacterial pellets were suspended in sterile tapwater and standardized photometrically to 0.3A at 600 mμ wavelength, which approximated a density of 3×10^8 cells/ml. These suspensions were serially diluted to final concentrations of approximately 1×10^3 to 3×10^3 cells/ml. These concentrations were confirmed by replicated colony counts from 0.05 ml subsamples spread on nutrient agar plates. All inoculations were by infiltration of intercostal leaf tissues of fully expanded leaves. All strains of Xcv were determined to be race 1 (Hibberd et al. 1987).

Plant Culture

Cultivars and breeding lines used were Early Calwonder (ECW), Agronomico 10G (10G), Andalus, Cordoba, David, Bell Tower, Skipper, Shamrock, Yolo Wonder, Redlands Sweet Sue (RSS), Green King, Line 15 and Line 23. The genes *Bs1*, *Bs2*, and *Bs3* were confirmed absent from these cultivars which were nevertheless expected to represent the range of plant responses to Xcv. For example, Early Calwonder is reputed to be less susceptible than other bell cultivars (Dahlbeck et al. 1979); and RSS is an inbred cultivar selected for partial resistance from progeny of the cross of cultivars Hungarian Yellow Wax and Yolo Y. The cultivars Andalus and Cordoba were also thought to be partially resistant (D. Toyer. Northrup King Seed Company, Brisbane,

Queensland, Australia, personal communication, 1986). Lines 15 and 23 are homozygous inbreds derived by selection for bacterial spot resistance in backcross progenies of PI 322719 and susceptible bell pepper (Hibberd and Gillespie, 1982a).

For the monocyclic experiments in the glasshouse the cultivar David was not included. Plants were raised in steamed sand-peat-eutrustox soil (2:1:1) in 10-cm diameter plastic pots arranged in rows of six on the glasshouse benches (temperature range 18 to 30 o C). The plants were watered as required, and were fertilized four times with soluble 23:4:18 N:P:K fertilizer. There were three replicates of 12 plant plots in a randomized block design. For the polycyclic field experiments, seedlings were raised in containers and there were two field plantings 12 days apart (9 and 21 January, 1987). The Line 23 was not included in the planting of 21 January. Plots were single rows of 12 plants arranged in three randomized blocks in both plantings. Row and plant spacings were 85 and 33 cm, respectively. Fertilizing, irrigation, weed and insect control were standard practice. Copper sprays were not applied.

Quantitative Assessment of Disease

For the monocyclic tests in the glasshouse the same plants were inoculated on two occasions, 24 days apart. The strain XV86-2 of Xcv was used for the first test, and strain XV86-6 for the second. In both tests, inoculum was infiltrated into single spots of 4 to 5 cm^2 in each of two adjacent leaves. The leaves in the second test were of an older physiological age than in the first test. At regular intervals of two or three days, commencing with the day lesions became visible, the two leaves of a single plant in each of three replicates of each cultivar were harvested. The leaves were used to represent the disease severities of the cultivars for that day. Sampling was ceased 22 days after inoculation in the first test, and 28 days in the second test. Disease severity was estimated from lesion numbers and diameters. The number of lesions within a perimeter imprinted by a cork-borer of 2 cm^2 was counted at each inoculation site while viewed with a dissecting microscope of 2.5X. The diameters of five random lesions per site, or of all lesions where fewer than five were present were measured using a graduated eyepiece in the microscope. The data were used to compute the area of diseased leaf tissue on the basis that most lesions were of circular periphery. In time, lesions on some plants of susceptible cultivars coalesced to become indistinguishable. With these, a careful visual estimate of the area of diseased tissues in each 2 cm^2 of leaf was made. Mean values of diseased area per 2 cm^2 of leaf were obtained for each plant.

For the polycyclic field tests, a single leaf of each seedling was infiltrated on the day prior to transplanting with strain XV86-7 of Xcv standardized to 3×10^3 cells/ml. Disease was allowed to progress naturally. The approximate proportion of diseased tissue was rated visually on each of 10 plants per plot at timed intervals after transplanting. For example, if 20% of leaves of the plant were judged to have fallen in response to disease, and the average area occupied by lesions on remaining leaves was approximately 1% of leaf area, then the proportion of leaf tissue affected by disease was 21% (0.21). Mean values of each plot were obtained from the 10 plants. Yield was assessed by weight of marketable fruit.

Evaluation of Disease Progress Data

Various transformations of diseased areas were tested to compute an effective linearized rate of disease increase in the monocyclic glasshouse experiments, but none was particularly effective. The area under the disease progress curve (AUDC) was then computed as the primary basis for evaluation. The area of diseased tissue from the second test also was regressed against time to compute rate of disease increase for each cultivar as a secondary basis of evaluation. For data from the polycyclic field experiments, disease proportions at the final ratings and rates of disease increase were used to compare cultivars. The Gompertz transformation of disease proportions (Berger, 1981) was used to compute rates of disease progress as it resulted in better and more reasonable linearization than the logistic transformation.

Results and Discussion

Monocyclic Disease Progress Tests. AUDC Values

Disease was more severe on plants in the first test than in the second test in the glasshouse (Table 1). This is thought to represent greater susceptibility of the younger leaf tissue rather than a difference in aggressiveness of the two strains of Xcv. Data from the second test was accumulated over a longer time span than the first.

In the monocyclic tests AUDC values of cultivars Yolo Wonder, Shamrock, Bell Tower, Green King, Cordoba, 10 G and Andalus were high (Table 1). The AUDC values of these cultivars either did not differ significantly or were not meaningfully different. These entries were considered susceptible. Cultivar Skipper was relatively more susceptible in the first test than the second (Table 1). The AUDC values of cultivars RSS and ECW were intermediate to and significantly different from those of both the susceptible group of cultivars and the most resistant Line 15, (Table 1), but they did not differ significantly from each other. Thus RSS and ECW were partially resistant in both tests. Of particular interest are the AUDC values for Line 23 (Table 1), which were significantly greater than for RSS in the first test but significantly lower than for both RSS and ECW in the second test. In both tests, AUDC values of Line 23 were significantly greater than for Line 15. Thus, younger leaves of Line 23 in the first test were significantly more susceptible than were the older leaves in the second monocyclic test of the same plants.

Table 1. Areas under disease progress curve[z] and progress rates of bacterial leafspot of glasshouse-grown pepper cultivars with different degrees of resistance to *Xanthomonas campestris* pv. *vesicatoria*.

Pepper cultivar or line	Area under disease progress curve [ln (y + 1) transformation]		Rate of increase in diseased areas	
	Test number[w]		Rate[y]	r^2[x]
	1	2	Test number 2	
Yolo Wonder	6.15 ab	6.25 b	1.88*[v]	0.17
Shamrock	6.13 ab	6.05 b	1.58*	0.37
Bell Tower	6.24 ab	5.83 b	1.15*	0.58
Green King	6.36 ab	5.80 b	1.43*	0.91
Cordoba	6.28 ab	5.79 b	1.65*	0.36
Andalus	6.76 ab	5.73 b	1.10*	0.54
10 G	5.65 bc	5.67 b	0.97*	0.55
Skipper	6.91 a	5.45 bc	0.95*	0.53
RSS[u]	3.89 e	4.67 cd	0.63*	0.76
Early Calwonder	4.44 de	4.48 d	0.44*	0.71
Line 23	5.21 cd	2.69 e	0.04	0.05
Line 15	2.10 f	0.95 f	0.00	0.00

[z]Numbers in each column followed by a common letter are not significantly different ($P \geq 0.05$) according to Duncan's multiple range test. [y]Rate of increase in non-transformed areas of diseased tissue. [x]r^2 is coefficient of determination of linear regression. [w]First test was of recently fully expanded leaves inoculated with strain XV 86-2 of Xcv; second test was of older leaves inoculated with strain XV 86-6. [v]*Indicates value is significantly greater than zero at $P < 0.05$. [u]Cultivar Redlands Sweet Sue.

Rates of Disease Progress

Rates of disease increase in the second monocyclic test of the entries were consistent with the AUDC values of both tests (Table 1, Figure 1). Computed rates were greatest for the group of susceptible cultivars, intermediate for cultivars RSS and ECW, and lowest for Lines 15 and 23. The rates of disease increase in this test of both Lines 15 and 23 did not differ significantly

from zero. With the possible exception of cultivar Green King, coefficients of determination (r^2) of regression of disease severity against time were low (Table 1). Thus regression did not effectively linearize the data, but neither did any other tested transformation. This reflected considerable plant-to-plant variation in disease severity, especially in susceptible cultivars. Disease severity increase in cultivar Green King was, however, unusually consistent and lacked such unpredictable variation.

These data clearly established that consistent differences in disease severities occur between chosen entries in monocyclic tests of resistance in the glasshouse. It remains to be determined whether these differences reflected field performance in polycyclic field epidemics of bacterial spot.

Polycyclic Disease Epidemics

Disease proportions on most cultivars were high in both field plantings (Table 2). Rating periods continued until 49 and 61 days after the first and second planting dates, respectively, and greater disease observed in the second planting probably was due to this difference in time.

Statistically significant differences occurred between disease proportions at the final ratings of both field plantings (Table 2). The cultivars Green King, Shamrock, Yolo Wonder, 10 G, David, Andalus, Skipper, Bell Tower and Cordoba were the most severely diseased in both field plantings but with slight differences between themselves. The Line 15 was the most resistant in both plantings, and intermediate levels of disease occurred on cultivars RSS, ECW, and Line 23 (Table 2). Relative rankings of disease severities of all entries are consistent in both the monocyclic and polycyclic tests of resistance (Tables 1 and 2).

The coefficients of determination were high for regression of the Gompertz transformed disease proportions against time (Table 2). Thus, this transformation reliably described disease progress of the cultivars. There were significant and consistent differences between the slopes of the Gompertz-transformed disease progress lines of the cultivars in both field plantings (Table 2, Figure 2). The slopes were greatest for the susceptible cultivars, intermediate for the partially resistant cultivars RSS, ECW and Line 23, and least for the most resistant Line 15. The slopes of these lines were an accurate reflection of disease proportions.

Yields of fruit from susceptible cultivars were very low or nil in both field plantings (Table 2) but were higher in the more resistant cultivars. Relatively high and low yields were obtained from cultivars RSS and ECW, respectively. These two cultivars were equally but partially resistant (Tables 1 and 2).

No measurable resistance to bacterial leafspot was detected in the repeated tests of two cultivars, Andalus and Cordoba, which are reputed to be partially resistant in Queensland. The plant habit of these two cultivars is taller, with less densely displayed foliage than other susceptible bell cultivars. This habit may allow easier coverage of foliage by routine chemical sprays which were not applied in these experiments. Routinely sprayed plants (Kucharek et al. 1986; Marco and Stall, 1983) of Andalus and Cordoba may therefore appear more resistant than other cultivars, but this aspect of pepper plant protection has not been investigated.

The main thrust of this paper was to link disease severities measured in mono and polycyclic tests of resistance to bacterial leaf spot. The association was positive and close, irrespective of the strain of Xcv used, but was more reliable when recently fully expanded leaves were inoculated for the monocyclic tests. The expected trend for fruit yields to increase with level of resistance did occur but the actual increase was also highly cultivar specific. The difference in fruit yields of cultivars RSS and ECW could not be predicted from a knowledge of their partial resistance. The cultivar RSS has the natural ability to set many, smaller fruit than in bell peppers. It is likely that physiological stress imposed by equal disease severities may differ with host genotype. The fruit yields obtained with the most resistant entries were also low. This fact highlights the need to carefully select horticultural attributes in strategic field plantings of resistant lines. The present data confirm that lines resistant to polycyclic disease epidemics are identifiable in monocyclic tests.

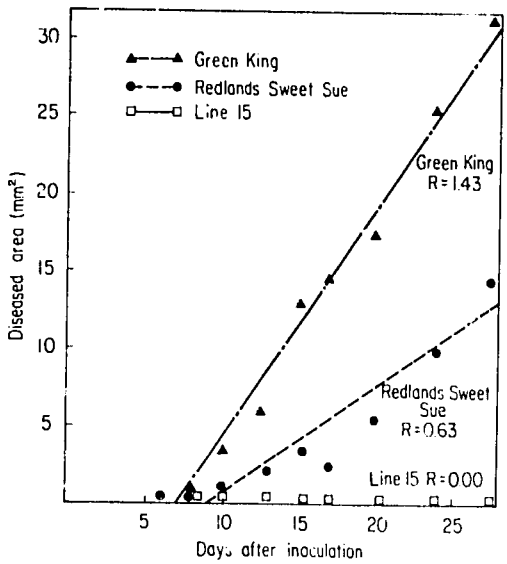

Figure 1. Progress and rates of increase (R) of bacterial leafspot in a monocyclic test of pepper cultivars and breeding lines with different degrees of resistance to *Xanthomonas campestris* pv. *vesicatoria*.

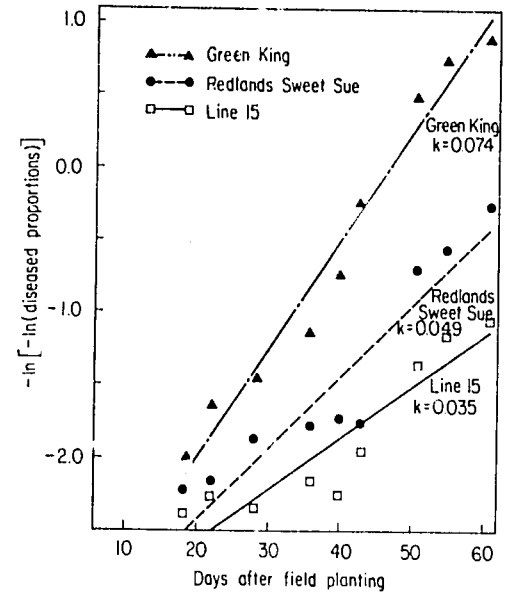

Figure 2. Progress and rates of increase (K) of transformed disease proportions from a field planting of inoculated pepper cultivars and breeding lines with different degrees of resistance to *Xanthomonas campestris* pv. *vesicatoria*.

Table 2. Disease proportions and progress rates[z] of bacterial leafspot, and fruit yields on field planted pepper cultivars with different degrees of resistance to *Xanthomonas campestris* pv. *vesicatoria*.

Pepper cultivar or line	Field planting date							
	9 January 1987				21 January 1987			
	Disease[y] proportion	Rate[x] k	Rate[x] r^2	Fruit yield (t/ha)	Disease[y] proportion	Rate[x] k	Rate[x] r^2	Fruit yield (t/ha)
Green King	0.42 b	0.06 a	0.95	0.0	0.67 b	0.07 bc	0.97	0.0
Shamrock	0.36 bc	0.06 ab	0.93	0.4	0.62 bc	0.07 bcd	0.91	0.8
Yolo Wonder	0.40 b	0.06 abc	0.94	0.0	0.60 bcd	0.07 bcd	0.95	0.0
10 G	0.38 b	0.06 abc	0.88	1.2	0.57 bcde	0.07 cde	0.95	4.2
David	0.31 cd	0.05 bc	0.90	0.0	0.62 bc	0.07 bcd	0.89	0.0
Andalus	0.40 b	0.05 bc	0.90	0.0	0.65 bc	0.08 b	0.90	0.3
Skipper	0.38 b	0.05 bc	0.92	0.0	0.55 cde	0.07 cde	0.93	0.3
Bell Tower	0.29 d	0.05 bc	0.93	0.0	0.50 de	0.07 de	0.93	0.0
Cordoba	0.31 cd	0.05 c	0.86	0.4	0.48 e	0.06 e	0.92	0.6
Line 23	0.08 ef	0.04 d	0.59	5.7	not available			
RSS[w]	0.06 ef	0.03 de	0.64	20.6	0.28 f	0.05 f	0.89	20.9
ECW[w]	0.12 e	0.03 ef	0.85	0.6	0.32 f	0.05 f	0.83	1.8
Line 15	0.02 f	0.02 f	0.29	13.7	0.06	0.04	0.84	19.9

[z]Numbers in each column followed by a common letter are not significantly different (P = 0.05), according to Duncan's multiple range test. [x]Proportion of leaf area diseased, observed at end of rating period. Each value is the mean of 30 observations (10 plants × 3 replications). Final ratings were 49 and 61 days after first and second plantings, respectively. [x]Rates of disease progress (k) using Gompertz transformation of - ln[-ln (proportion)]: and coefficient of determination (r^2) of regression of transformed proportions against time. [w]Cultivar Redlands Sweet Sue; and ECW is Early Calwonder.

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24

Additive Gene Action Controlling Resistance to Bacterial Leafspot in a Pepper Plant Introduction Line

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Abstract

Resistance to race 1 of *Xanthomonas campestris* pv. *vesicatoria* in leaves of selection 189-5 of PI 163189 was characterized after infiltration with bacterial suspensions of approximately 2×10^3 cells/ml. Cell populations of strain XV 86-2 multiplied in leaves of *Capsicum annuum* 189-5, Early Calwonder (ECW), a susceptible cultivar, and F_1 (189-5 × ECW). Multiplication ceased in leaves of 189-5 and F_1 between two and four days and four and six days, respectively, after inoculation, but continued through 14 days in leaves of ECW. Cell populations at 14 days were approximately 10^5, 5×10^6, and 10^8 cells/cm^2 in leaves of 189-5, F_1, and ECW, respectively. Resistance appeared to be hypersensitivity controlled by additive gene action. In inheritance studies in populations from the cross 189-5 × ECW, resistance to strains XV 86-2 and XV 86-7 was quantitatively assessed by lesion numbers and diameters two weeks after inoculation. Segregation within the backcross F_1 × ECW was continuous and did not fit a major gene ratio. Means of lesion diameters of F_1 and F_1 × ECW generations equaled respective mid-parent means while generation means of lesion numbers exceeded mid-parent values. An additive gene action appeared to control resistance to race 1. Implications for breeding for resistance are discussed.

Introduction

There are numerous accessions from the wild collections of pepper (*Capsicum annuum* L.) that are resistant to *Xanthomonas campestris* pv. *vesicatoria* (Doidge), Dye (Xcv), the causal agent of bacterial leafspot (Kim, 1983; Sowell, 1960; Sowell and Langford, 1963; Sowell and Dempsey, 1977). From these, only two dominant genes for resistance have been identified with certainty (Cook and Stall, 1963; Kim and Hartmann, 1985). Another dominant gene was introgressed from *C. chacoense* by crossing and selection (Cook and Guevara, 1984). These genes, which have designations *Bs1*, *Bs 2*, *Bs 3* (Kim and Hartmann, 1985), are independent and they control hypersensitive reactions (HR). The three forms of HR are qualitative. The breeding of bell pepper with these genes is therefore straightforward. However, races of the pathogen in the field (Cook and Stall, 1969; Hibberd, Stall and Bassett, 1987) and mutants in culture (R.E. Stall, Plant Pathology Dept., Univ. of Florida, USA, personal communications, 1986 and 1987) have been identified that defeat these genes. The genes are therefore 'weak' in the sense used by Vanderplank (1968) and their use must be managed.

It is a fact that most of the resistant accessions lack these dominant genes (Cook and Stall, 1969; Kim, 1983), and some have resistance which has been long-lasting in different regions (Adamson and Sowell, 1983; Borchers, 1965; Hibberd and Gillespie, 1982). Several of these accessions have been used in genetic crosses to breed resistant peppers (Adamson and Sowell, 1983; Hibberd and Gillespie, 1982). Their use as parents often preceded knowledge about the inheritance of resistance (Sowell and Dempsey, 1977) and may have been based in part on other horticultural considerations.

Few assessments of the inheritance of this form of resistance have been made. In all cases inheritance has been quantitative (Adamson and Sowell. 1983; Hibberd. 1985; Hibberd and Gillespie. 1982; Kim. 1983; Stall. 1981) and resistance has been assessed by different methods. Methods of assessment included visual ratings and measurement of disease severity on plants grown in the glasshouse or in the field. Resistance is identifiable in monocyclic tests of disease progress on plants grown in a glasshouse (Hibberd. 1989), but quantitative variables are influenced by environment to the extent that a range of values results even on homozygous resistant plants. Variability may mask simple inheritance (Falconer. 1960).

In one study, inheritance of resistance in PI 163189 was consistent with additive gene action which was simply inherited (Hibberd. 1985). Heterozygotes were identifiable by disease severity which was intermediate to parental values. This finding was consistent with other studies in which the most resistant segregates of genetic crosses where found in F_2 and inbred backcross populations (Adamson and Sowell. 1983, Hibberd and Gillespie. 1982; Stall. 1981), and with heterozygotes being of intermediate phenotype (Hibberd and Gillespie. 1982). Thus inheritance was not dominant in all studies, and resistance required careful evaluation. Segregation of plants into discrete phenotypic classes expected for a single gene was difficult to assess (Hibberd. 1985). This paper attempts to confirm simply inherited resistance, together with additive gene action which is reflected in intermediate populations of bacteria in leaf mesophyll of heterozygotes

Materials and Methods

Inoculum Preparation

At the time of this study, only race 1 of Xcv had been identified from diseased pepper in Queensland (M.E. Moffett. Plant Pathology Branch, Queensland Dept. of Primary Industries, Australia. personal communication. 1987). Two strains of race 1 (XV 86-2 and XV 86-7) were used as inoculum. Pathogenicity of both strains was tested in plants of the susceptible cultivar Early Calwonder (ECW). Race was confirmed by the presence or absence of HR in pepper lines with genes *Bs1* and *Bs3* (Hibberd, Bassett and Stall. 1987).

The strains had been stored in 15% glycerol at -15°C. Inocula were prepared from late log-phase nutrient broth cultures derived from single colonies on nutrient agar plates. After centrifugation of cultures at 1,000 X g, the bacterial pellets were suspended in sterile tapwater and standardized photometrically to 0.3 A at 600 nm wavelength, which approximated at density of 3×10^8 cells/ml. These suspensions were serially diluted to approximately 10^3 cells/ml for inoculations. The final concentration was confirmed by replicated colony counts from 0.05 ml subsamples spread on nutrient agar plates. All inoculations were by infiltration of intercostal leaf tissues of fully expanded leaves.

Plant Culture

Capsicum annuum Early Calwonder, line 189-5 of PI 163189 and F_1 (189-5 × ECW) were used. The line 189-5 is a homozygous inbred selection resistant to races 1 and 3 and carries the gene *Bs1* for HR to race 2 of Xcv (Hibberd. 1985). Seeds of PI 163189 had been obtained from the USDA Atlantic Regional Plant Introduction Station, Georgia, USA.

Seedlings were transplanted to steamed sand: peat : eutrostox soil (2 : 1 : 1) in 10 cm diameter plastic pots. The plants were arranged in randomized rows of seven plants on benches in a glasshouse with a temperature range of 17 to 35°C. Plants were watered as required and treated four times during experiments with 23:4:18 N:P:K soluble fertilizer.

Bacterial Populations

The plants were inoculated with 6×10^3 cells/ml of strain XV 86-2 of 3 race 1. The inoculum was infiltrated into an area of 4 to 5 cm^2 on each of three leaves per plant. Leaves

were collected periodically after inoculation and bacterial populations in the inoculated areas were determined from one cm^2 samples. Samples were triturated in 0.5 ml of sterile tapwater, the suspension serially diluted ten-fold when appropriate in sterile tapwater, and 0.05 ml subsamples of the final dilution were spread on nutrient agar plates. Colonies of Xcv were counted after two to three days incubation at 30°C, and means were converted to log 10 values. There were three replicates and the experiment was repeated.

Quantitative Assessment of Disease

The number of lesions within a perimeter of 2 cm^2 imprinted with a cork-borer on the leaf was counted at each inoculation site while viewed with a dissecting microscope at a magnification of 2.5X. The diameters of five random lesions per site, or of all lesions where fewer than five existed, were measured with a graduated eyepiece in the microscope.

Inheritance of Quantitatively Assessed Resistance

A single plant of the homozygous selection, 189-5, was cross-pollinated with a single plant of ECW. A single F_1 plant was cross-pollinated with an additional plant of ECW to give backcross seeds. Populations of 270 backcross seedlings, 42 of 189-5 seedlings, 38 of the F_1 seedlings, and 77 of ECW seedlings were transplanted to pots and raised as described above. Populations of plants of the F_2 and backcross to 189-5 were not used. The first experimental aim was to evaluate major gene segregation in the backcross to the susceptible parent. Additive gene action was expected to occur (Hibberd, 1985) and could be evaluated from the four generations which were grown.

The three leaves preceding the first fork of the stem were each infiltrated with a suspension of approximately 2×10^3 cells/ml of both strains of race 1 (XV 86-2 and XV 86-7). Overlapping of areas infiltrated with the strains was avoided. These leaves were harvested 15 days later, sealed in plastic bags, and refrigerated (3°C). Over the next several days, the numbers of discrete lesions per 2 cm^2 of leaf and diameters of the lesions were determined as described above. Mean values for lesion numbers and diameters were obtained for both strains on each plant.

Statistical Treatment of Data

The quantitative data were evaluated by analysis of generation means weighted by their variances (Basford and De Lacy, 1979; Mather and Jinks, 1971). No prior assumptions on the relative importance of dominance is required in this analysis. The matrix specification of Fisher (1918) was used with parameters: m = general theoretical population mean at F_∞, a = value of additivity, and d = value of dominance deviation. The X^2 test of goodness of fit of means to the single gene model of three parameters could not be applied to three degrees of freedom.

Results and Discussion

Hypersensitive Resistance to Race 1 in Line 189-5

The bacterial cell populations of strain XV 86-2 of race 1 increased to 10^8 cells/cm^2 in leaves of the susceptible cultivar ECW (Figure 1). With the same inoculum level, cell populations in leaves of 189-5 and F_1 (189-5 × ECW) plateaued earlier and to levels lower than in leaves of ECW. The populations were approximately 10^5 cells/cm^2 of leaf of 189-5 at two to four days after inoculation, and 5×10^6 cells/cm^2 of leaf of the F_1 at four to six days after inoculation.

The curve for increase of bacterial cell populations in leaves of the heterozygote was intermediate to the curves of the two parents. The population increase continued for longer and

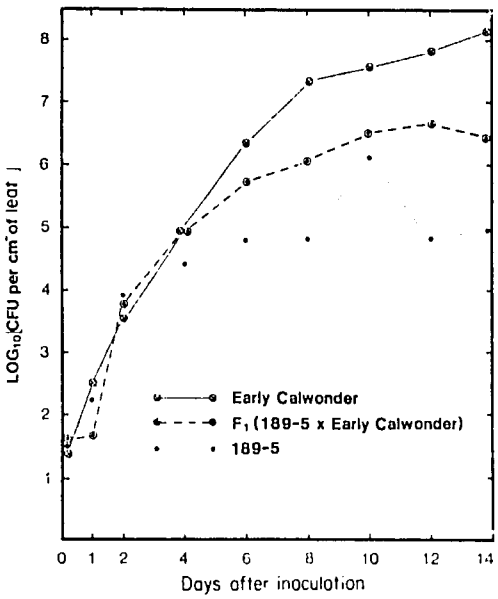

Figure 1.
Bacterial populations in leaves of Early Calwonder, 189-5, and F_1 (189-5 × Early Calwonder) after inoculation with strain XV86-2 of *Xanthomonas campestris* pv. *vesicatoria*.

reached higher levels in leaves of the F_1 than in the resistant parent 189-5, but was less than in the susceptible parent ECW. The intermediate growth curve of bacteria in the F_1 is taken to represent a gene action controlling resistance which is additive and not dominant or recessive.

The inoculum concentration (6×10^3 cells/ml) was too great to allow the counting of discrete lesions in leaves. Lesions in leaves of ECW were visible between five and six days after inoculation, and this time corresponded to about 10^6 cells/cm^2 of leaf (Figure 1). Very few lesions developed in leaves of 189-5, more in leaves of the F_1 (189-5 × ECW), and most in leaves of ECW. Lesions in leaves of ECW became confluent by about nine to ten days after incubation.

The curve for increase of bacterial cell populations in leaves of 189-5 are similar to those of previous studies (Hibberd, 1985; Hibberd, Stall and Bassett, 1987) which were used as partial evidence for quantitatively assessed resistance being a form of HR. The curve is also similar to those previously published for plants that contained the genes *Bs1* and *Bs3* for HR to races 2 and 1 of Xcv, respectively (Cook and Stall, 1968; Hibberd, Stall and Bassett, 1987). By analogy, the repeated tests of the bacterial growth in 189-5 and in the heterozygote indicate that the resistance is a form of HR.

Cell populations in leaves of one plant of 189-5 were unusually high, and equaled those of the F_1 (189-5 × ECW) (Figure 1). This plant was also atypical in that it had large numbers of oedematous lesions along large and small veins of the leaves. Oedematous tissue may reflect internal moisture stress induced by root pressure under conditions of ample soil moisture and high RH. Stress induced by excess free water may result in rupturing of cells (Chupp and Sherf, 1960). Enforced watersoaking of mesophyll inoculated with race 2 of Xcv defeats the hypersensitive resistance reaction of gene *Bs1* (Stall and Cook, 1979). By analogy, resistance in the atypical plant of 189-5 may have been temporarily defeated during periods of excess water in the mesophyll, and the cell population of bacteria increased as a result. The resistance of 189-5 to race 1 may therefore be modified by different environments to result in a range in disease severity.

Quantitative Assessment of Resistance

Differences occurred among the plant generations for numbers of lesions per inoculated area and mean diameter per lesion in leaves infiltrated with both strains of race 1 at low

concentrations of inoculum. The frequency distributions of plants in each generation based on categories of lesion number and lesion diameters are given in Tables 1 and 2. The distributions of plants inoculated with both strains of race 1 were equal in the generations. The slight difference in average lesion numbers between the two strains in the generations probably resulted from a small difference in inoculum concentrations. Also, generation means of lesion number and of lesion diameter were correlated for each strain, XV 86-2 and XV 86-7 (r^2 1.0 and r^2 1.0, respectively). Thus both strains were approximately equally aggressive in lesion growth in this experiment.

Table 1. Frequency distributions for lesion number in populations of pepper plants derived from the cross 189-5 (resistant) × Early Calwonder (susceptible) after leaf inoculation (approximately 1.5 × 10^3 cells/ml) with two strains of race 1 of *Xanthomonas campestris* pv. *vesicatoria*.

Plant populations	Strain Xcv	Upper class limits for number of lesions per 2 cm^2 of leaf Populations													Population[z] mean
		0	3	6	9	12	15	18	21	24	27	30	33	36	
189-5	XV 86-2		6	15	5	7	2	3	0	3	1				8.7 ± 0.98
	XV 86-7		13	12	3	6	3	1	2	2					7.2 ± 0.93
F_1 (189-5 × ECW)	XV 86-2			1	0	2	7	8	6	6	2	4			18.7 ± 0.94
	XV 86-7				2	7	8	6	5	5	3	0	1		16.7 ± 0.94
F_1 × ECW	XV 86-2		1	0	9	26	56	47	49	36	26	11	7		21.2 ± 0.35
	XV 86-7			4	20	46	60	65	37	24	10	1	1		18.6 ± 0.30
ECW	XV 86-2					5	9	17	7	17	12	8	2		23.5 ± 0.65
	XV 86-7				1	7	14	17	15	11	7	2	1		21.2 ± 0.59

[z] ± Standard, error of mean.

Table 2. Frequency distribution for lesion diameter in populations of pepper plants derived from the cross 189-5 (resistant) × Early Calwonder (susceptible) after leaf inoculation (approximately 1.5 × 10^3 cells/ml) with two strains of race 1 of *Xanthomonas campestris* pv. *vesicatoria*.

Plant populations	Strains Xcv	Upper class limits for lesion diameter (mean of five lesions: mm × 10)																	Population mean
		2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	>32	
189-5	XV 86-2	1	21	14	4	2													4.4 ± 0.28
	XV 86-7		20	17	2	3													4.3 ± 0.27
F_1 (189-5 × ECW)	XV 86-2			3	10	7	10	4	2										9.4 ± 0.46
	XV 86-7			6	7	6	12	5	1										9.4 ± 0.45
F_1 × ECW	XV 86-2			13	44	52	52	34	23	12	8	9	2	6	2	3	3	5	12.6 ± 0.39
	XV 86-7			14	46	66	57	24	21	14	6	1	7	3	2	1	1	5	11.9 ± 0.37
ECW	XV 86-2				1	12	14	14	14	6	8	2	3	0	1	1	1		14.5 ± 0.55
	XV 86-7				4	12	10	19	11	11	2	3	0	1	0	1	1		13.8 ± 0.52

[z] ± Standard error of mean.

Additive Gene Action

After inoculation with two strains of race 1 there was wide variation in both components of resistance in all of the populations of plants (Tables 1 and 2). Variation in both components was greatest in the backcross (F_1 × ECW) population. There was considerable overlap in frequency distributions between the different populations for both components of resistance. The frequency distributions were continuous and, in the F_1 and backcross, did not seem to fit into any segregation ratio or pattern. The distribution of lesion numbers in the F_1 and backcross populations were skewed toward those of the susceptible parent, ECW, which could mean that

this resistance component is recessively inherited. However, the distributions of lesion diameters, while continuous, were not skewed to either end of the distribution scale and were intermediate to those of the two parents. This could indicate an additive genetic effect.

The basic patterns of inheritance of the two components of resistance appeared to be quantitative, but different. To investigate this further, analysis was made of the weighted generation means of both components. The analysis was limited by there being only three degrees of freedom so that the X^2 goodness of fit test could not be applied to additivity and dominance of the single gene model (Basford and DeLacy, 1979). However, generation means for both components of resistance were consistent with the expected patterns: that is, dominance was incomplete for high lesion numbers and was negligible for lesion diameters (Table 3). Additivity was the major component of importance for lesion diameter. Thus, the population mean for lesion diameter of the F_1 was intermediate to parental values, and the population mean for lesion diameter of the backcross was intermediate to values of the F_1 and susceptible parent.

Table 3. Generation means analysis of numbers of lesions per 2 cm^2 of leaf and lesion diameter from 189-5 × Early Calwonder pepper progenies inoculated with strains XV 86-2 and XV 86-7 of race 1 of *Xanthomonas campestris* pv. *vesicatoria*.

		Component of resistance	
		Lesions per 2 cm^2 of leaf	Diameter per lesion (mm × 10)
Bacterial strain	Parameter[z]	Parameter[y] estimate	Parameter[y] estimate
XV 86-2	m	16.1 ± 0.56	9.6 ± 0.27
	a	7.4 ± 0.57	5.2 ± 0.27
	d	2.7 ± 0.99	0.1 ± 0.55
XV 86-7	m	14.0 ± 0.52	9.1 ± 0.26
	a	6.8 ± 0.52	4.8 ± 0.26
	d	2.6 ± 0.62	0.4 ± 0.53

[z]Parameters: m = estimated mean at F_∞, a = additivity, d = dominance deviation. [y]Estimated value ± standard error of estimate.

Relation Between Lesion Diameters and Numbers

Lesion number increased with lesion diameter among plants of all populations (Figure 2). However, the rate at which lesion numbers increased with diameter varied among the generations.

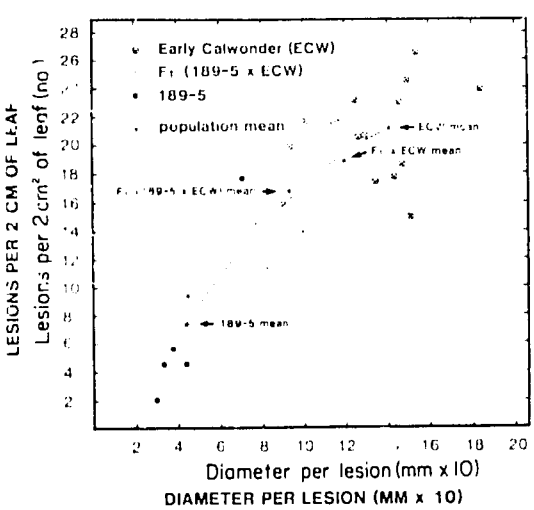

Figure 2.
Variation in lesion numbers related to lesion diameters in pepper generations inoculated with strain XV86-7 of race 1 of *Xanthomonas campestris* pv. *vesicatoria*.

For example, lesion numbers in plants of line 189-5 increased at the linear rate of 3.8 lesions for each 0.1 mm of lesion diameter, but the increase was only 1.4 lesions per 0.1 mm of lesion diameter among all plants of the 189-5, F_1, and ECW populations combined. Thus, a small increase in lesion diameter among plants which are resistant or partially resistant was associated with a relatively large increase in lesion number. In contrast, a small increase in lesion diameter among susceptible plants was associated with only a small increase in lesion numbers. The predictive value of lesion number alone declined with level of resistance, and lesion diameter appeared the more reliable of the two components.

Conclusions and Applications

Additive gene action controlled lesion diameter with both bacterial strains of race 1 in leaves of 189-5. Intermediate lesion diameters in leaves of F_1 plants were consistent with bacterial cell populations which also were intermediate to parental values. Resistance restricted cell population increase and concomitantly the rate of lesion expansion. The reduced rate of lesion expansion was sufficient to prevent most necrotic areas from becoming visible lesions in leaves of 189-5, but not in heterozygotes. Thus partial dominance occurred for high lesion numbers (Table 3). The maximum number of necrotic areas is controlled by the initial inoculum density (Turner and Novacky, 1974). Environmental effects may have induced higher bacterial cell populations in leaves of some plants of 189-5. Higher cell populations may have resulted in many more necrotic areas becoming visible lesions in these plants than in other plants of the same line.

Selecting the most resistant plants in each cycle of backcrossing would therefore require testing of inbred progenies. This finding is consistent with previous work in selecting resistant segregates from inbred progenies (Adamson and Sowell, 1983; Borchers, 1965). In the present study plants of intermediate disease severity were identified and used as parents for additional backcrossing. It may be possible to confirm the identity of heterozygotes by progeny testing of selected plants in single generation cycles of recurrent backcrossing (Hanson, 1959). The time needed for breeding resistant bell pepper would then be minimized.

Quantitative variability in components of resistance masked any ratio of segregation for resistance which may have occurred in the backcross population. Thus, it was not possible to confirm that additive gene action was controlled by a single gene of major effect. Segregation in inbred backcrosses may help resolve this point. Simple inheritance may also have been masked by choice of the recurrent parent. Cultivar ECW is in fact partially resistant to race 1 of Xcv (Hibberd, 1989). Segregation of minor genetic effects that control partial resistance may also have occurred in the backcross population. A more distinct segregation pattern may have resulted by using a recurrent parent more highly susceptible than ECW (Hibberd, 1985). However, such a choice would not assist in achieving the aims of practical plant breeding.

Additive gene action in 189-5 to strains of race 1 of Xcv, which has now been established in separate studies, conforms to practical experience in breeding resistant bell pepper. It may be that this form of generalized quantitative resistance to Xcv may occur in other plant introduction lines, as well as to other bacterial pathogens of crops.

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Symposium Discussion

Y. Haile: Have you attempted to transfer genes from sweet pepper to hot pepper to develop bacterial leafspot resistant varieties?
A.M. Hibberd: No. The genes are in hot peppers of USDA plant introduction lines. There is absolutely no reason why you could not continue to keep them in hot peppers if you want to. Similarly, sweet pepper lines with resistance genes — the result of breeding and selection could be used as parents for crossing into hot pepper.

B-S Kim: (1) Resistance may be lost during the backcross program. Could you tell us your strategy to hold a high level of resistance during any breeding program? (2) Do you have any interest in adopting anther or microspore culture techniques and dihybrid plants in pepper breeding?
A.M. Hibberd: (1) Recurrent parents may differ in their level of susceptibility, e.g. highly or very highly susceptible. Choose the best available. Inbreed once or twice each backcross, and then select. Evaluate plants stringently. In seedling selection, eliminate susceptibles or questionable plants, and field plant the remainder. Encourage the pathogen. (2) Bell pepper is an extreme phenotype. Disease resistance genes are mostly in unadapted, horticulturally unacceptable lines. Backcrossing with selection seems more appropriate. Once the genes are in bell peppers, then the methods you asked about may be appropriate.

229

25

Search for Bacterial Wilt-Resistant Tomato Varieties in Réunion

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Abstract

In the Island of Réunion, two kinds of tomatoes preferred are small elongated tomatoes (Roma type) and large round tomatoes (St. Pierre type). Bacterial wilt is the main limiting factor for tomato production in the hot season. Of the 121 entries tested for resistance to this disease, three were found satisfactory: MST 32-1, MST 21-23, both originally from AVRDC; and Caraïbo, developed by INRA, France. The search for bacterial wilt-resistant varieties, better adapted to the local market, is continuing.

Introduction

Réunion is a volcanic island of 2,520 km^2 with a population of 560,000 inhabitants. It is located 700 km to the east of Madagascar and 200 km to the southwest of Mauritius at a latitude of 21° South and a longitude of 55°30 East. It originated from two volcanoes, Piton des Neiges (3,070 m), now extinct, and Piton de la Fournaise (2,631 m), still active. Its relief is extremely uneven, which accounts for the small area of the total farmland: 65,323 ha in 1986 (Anon. 1987) which is less than 26% of the total area of the island. The island has two main seasons: a cool and relatively dry season from May to October (mean temperature of the coldest month between 20 and 22°C at sea level), and a hot season, with a cyclone rainfall pattern (mean temperature of the hottest month between 26°C and 28°C at sea level). The agriculture of the island is dominated by sugarcane, which covers 57% of the total farmed acreage (Anon. 1987). Vegetables account for less than 4% of the total cropped area (Anon. 1987), but that acreage is increasing each year. In 1986, Réunion produced 2,437 t of tomatoes on 523 ha, 274 t of hot pepper (*Capsicum frutescens*) on 54 ha and 45 t of sweet pepper (*Capsicum annuum*) on 11 ha (Anon. 1987).

Tomato production on the island is currently hampered by three main constraints: socioeconomic factors, marketing problems, and climate/disease problems.

Socioeconomic Factors

Tomato is seldom the main crop on a farm and very few farmers grow the crop with enough care, paying sufficient attention to pruning, staking and mulching. In most tomato plots, the crop is left simply to crawl on the ground. Recently, however, soil-less greenhouse cultivation has been practiced by some farmers in an attempt to produce high-quality fruits during the hot season.

Marketing Problems

The strongest demand is for small-sized elongated fruits of the Roma type, followed by large round tomatoes of the St. Pierre type. Other types of fruits, in particular small round ones,

cannot be sold on the local market, which greatly reduces the possibility of growing exotic varieties with resistance to bacterial wilt.

Climate/Disease Problems

French commercial varieties can be grown in the cool season, provided enough chemical protection is given against late blight (*Phytophthora infestans*). However, these varieties cannot be grown during the hot and wet season, mainly because of bacterial wilt, which can cause serious damage at low and medium elevations up to 700-800 m. Traditionally, some farmers try to avoid the problem by adopting long rotations of the tomato crop with sugarcane, but many do not practice this option. Since no control method is currently available, IRAT-Réunion initiated a program emphasizing resistance to bacterial wilt.

Research Objective

The objective of the IRAT-Réunion tomato improvement program is to develop and select fresh market varieties with high levels of resistance to bacterial wilt, which are suitable for cultivation in the hot and wet season when market prices for tomatoes are usually very high. Other desirable improvements are:

- acceptable fruit type;
  - small-sized tomatoes: elongated shape, medium size, uniform color with no greenshoulder and high dry matter content similar to Roma VF;
  - large-fruited varieties: round regular similar to St. Pierre shape;
- high yield, resistance to cracking;
- suitability for large-scale cultivation, without pruning, staking or mulching, especially for small-fruited varieties; and
- development of varieties with resistance to late blight (*Phytophthora infestans*) for cultivation during the cool period or at medium elevations.

Materials and Methods

Varieties

A total of 121 varieties and lines originating from commercial seed companies in the USA, Japan, and France, and from national and international research institutes in Australia, Burkina Faso, the Seychelles, Taiwan, the French West Indies, and the USA (Hawaii) were evaluated between 1980 and 1987. The materials were either introduced directly or indirectly after selection in the Seychelles (Grand Anse Experimental Station) or in Mauritius (Mauritius Sugar Industry Research Institute MSIRI). A list of all the varieties is available upon request from IRAT-Réunion.

Experimental Procedures

Originally the adaptability and variety trials were conducted at seven locations scattered throughout the island. Later only two locations, Ligne Paradis in St. Pierre (low elevation, 150 m) and Les Colimaçons in St. Leu (medium elevation, 800 m), were chosen. The Ligne Paradis location was used to screen for bacterial wilt resistance, while Colimaçons was used to evaluate the performance of varieties under medium elevation and the reaction to late blight.

Adaptability trials consisted of testing introduced lines together with a susceptible check (mostly cv Roma) regularly interspaced within the plots. These tests, which were not replicated, served as a preliminary screening for resistance to bacterial wilt and for fruit type (including resistance to cracking). Starting from 1985, the trials also included a bacterial wilt resistant check (MST 32-1). Varietal trials, with six to eight replications, were conducted to confirm bacterial wilt resistance and to evaluate yield potential.

The trials were usually conducted over two seasons: transplanting at the beginning of the hot season (October-November) with flowering and fruiting in the middle of the hot and wet season, and transplanting in the middle of the hot season (January-February), with flowering and fruiting at the end of the hot season/beginning of the cool season.

In both adaptability and varietal trials the plots consisted of two rows of 10 plants each, with a spacing of 1.5 m between rows and 0.5 m between plants. Disease resistance (percentage of wilted plants) was evaluated weekly. In the first years of testing, all the dead plants were recorded as wilted, including those destroyed by causes other than bacterial wilt (such as transplanting shock and fungal diseases).

Inoculum

St. Pierre had no bacterial wilt originally, so the plots were inoculated the first year by wounding the main root with a knife and pouring a dense bacterial suspension (about $7\text{-}10^8$ cfu/ml) around the plants.

Subsequently, the inoculum was allowed to become evenly distributed in the field by growing the susceptible cultivar Roma between plots. Since 1984, the experimental plots were inoculated by spraying a suspension of bacteria grown for 18-24 h in shaken liquid medium (yeast extract = 7 g; peptone = 7 g; distilled water = 1 l, pH = 7.2) on the soil, a day before transplanting. The suspension was approximately 10^9 bacteria per square meter and was applied with a herbicide spayer at 250 liters per hectare.

Results and Conclusions

The complete results of these trials have been reported (Auckenthaler and Marchand. 1982 a & b; Girard. 1986 a & b; Girard and Marchand. 1985 a & b; Marchand. 1983 a, b & c; Michellon. 1980, 1981 a & b, 1983 a & b) and are available upon request from IRAT-Réunion. The most significant results of the variety trials conducted between 1982 and 1986 are shown in Tables 1 and 2. The high incidence of wilted plants at the low altitude station is probably due to the fact that all dead plants were taken into account including those destroyed by causes other than bacterial wilt. The low proportion of marketable fruits is due to the fact that fruits were not prevented from touching the ground; and were attacked by rats and soilborne diseases (*Phytophthora parasitica*). A severe outbreak of late blight (*Phytophthora infestans*), favored by an unusual cool and wet period at the time of harvest, also resulted in heavily damaged fruits.

Only a few varieties can be recommended to farmers for growing during the hot and wet season: MST 32-1 and MST 21-23 for small-fruited tomatoes, and Caraïbo for large-fruited varieties. Their main characteristics are described in Table 3.

MST 32-1 was selected by MSIRI in Mauritius Island (Pillay et al. 1981) from AVRDC material (pedigree VC 9-1-2-3/Venus) and has been proposed to the Reunion farmers under the name Eureka. Its shortcoming is its susceptibility to late blight and the small fruit size which necessitates much labor at harvest, thus, reduces the market value. MST 21-23, also selected from AVRDC materials (pedigree VC 11-1-2-28/Saturn), was distributed to farmers under the name of Bourbonna. Fruit size is larger than that of MST 32-1, but the shape is irregular. It is less susceptible to late blight but not sufficiently resistant under high bacterial wilt disease conditions. Both lines showed a good ability to compete against weeds and to withstand adverse conditions such as frequent storms.

Caraïbo, obtained from Institut National de Recherche Agronomique (INRA), Guadeloupe, is large-fruited and a rather good level of resistance to late blight. However, its yields can be low at low elevations when fruit-set occurs during hot periods. Furthermore, fruits are often irregularly shaped.

Table 1. Summary of tomato variety trials in Réunion (1982-84).

Variety or line	Seed source	Fruit shape[z]	Fruit color[y]	Location: Ligne-Paradis (150 m)						Location: Les Colimaçons (800 m)			
				Planting date: 19/10/82			Planting date: 31/01/84			Planting date: 1/02/83			
				Wilted plants[x] (%)	Total yield (t/ha)	Average fruit wt. (g)	Wilted plants (%)	Total yield (t/ha)	Average fruit wt. (g)	Wilted plants[w] (%)	Total yield (t/ha)	Average fruit wt. (g)	Late blight rating[v]
Canner	AVRDC	O	U	15	14	34	24	20	33	0	17	35	3
Creeper	AVRDC	R	GS	18	9	41	39	16	42	3	18	42	2
Star	AVRDC	R	U	41	6	40	–	–	–	1	20	37	2
MST 32-1	MSIRI, Mauritius	O	U	28	11	32	26	24	33	0	16	37	3
MST 21-23	MSIRI, Mauritius	O to R	U	25	11	41	39	19	40	0	21	46	2
MST 21-34	MSIRI, Mauritius	R	U	29	7	52	20	19	40	–	–	–	–
MST 25-7	MSIRI, Mauritius	O to R	GS	21	7	40	20	16	37	0	21	46	4
Caraibo	IRAT, Martinique	R	U	25	5	80	19	19	61	0	24	91	2
Scorpio	Redland Horticultural Research Station, Australia	R	GS	36	2	71	–	–	–	0	25	93	1
Roma VF (susceptible check)	Vilmorin, France	E	U	98	0	–	100	–	–	49	11	44	2

[z]O = oblong; R = round; E = elongated. [y]U = uniform; GS = green shoulder. [x]Plants were artificially inoculated; rating was performed two months after planting. [w]Plants were grown in naturally infested soil; rating was performed two months after planting. [v]From 1 = resistant to 5 = susceptible.

Table 2. Lowland tomato varietal test (planted March 1986).

Variety or line	Seed source	Fruit shape[z]	Wilted plants[y] (%)	Total yield (t/ha)	Marketable yield (t/ha)	% of marketable fruits	Average fruit wt. (g)
Roma VF	Vilmorin, France (BW susceptible check)	E	97[x]	0.3	0.3	59	25
MST 21-23	MSIRI, Mauritius	O to R (not uniform)	16	17.7 bc	14.0 b	79	40
King Kong F_1	Known You Co., Taiwan	R	2	15.2 cd	8.3 c	55	95
CL 1131-00-4-3-8-1	AVRDC	R	1	25.6 a	19.6 a	77	30
PT 870	AVRDC	R	55	12.3 d	10.1 c	82	45
Caraibo	IRAT, Martinique	R (not uniform)	3	21.8 ab	15.3 b	70	81
C 330	Taiwan Seed Improvement & Propagation Station, Taiwan	R (soft fruit)	7	25.8 a	15.9 b	62	76
CL 1104-F7-00-9-1-4-3	AVRDC, Taiwan	R	5	19.6 bc	14.2 b	72	40

[z]E = elongated; O = oblong; R = round. [y]Plants were artificially inoculated; rating was performed two months after planting. [x]Values are means of 8 replicates. Means followed by the same letters are not significantly different by the Duncan's multiple range test (P = 0.05). Roma VF was not included in the analysis of variance.

Table 3. Characteristics of fresh-market varieties recommended for growth in the hot and wet season at low or medium elevation in Réunion.

Variety	Yield[z] (t/ha)	Fruit shape	Average fruit weight (g)	Growth habit	Resistance to disease	
					Bacterial wilt	Late blight[y]
MST 21-23	21	Round to oblong	40-45	Determinate	Medium	2
MST 32-1	24	Oblong	32-37	Determinate	Medium	3
Caraibo	24	Round	60-90	Determinate	High	2

[z]Maximum yield obtained during the hot season in IRAT experimental plots. [y]From 1 = resistant to 5 = susceptible.

Other varieties showing a good level of resistance to bacterial wilt were not released. These included Canner, not released because it has the same pedigree as MST 32-1 and shows similar traits and performance. Other varieties not released were Creeper, MST 25-7 and Scorpio because of green shoulder; CL 1131-00-4-3-8-1 and CL 1104-F7-00-9-1-4-3 because the fruits are round and too small; and King Kong because it was low-yielding under Réunion conditions of cultivation.

C 330 from the Taiwan Seed Improvement and Propagation Station, which is quite resistant to bacterial wilt and yields well, has not yet been endorsed because its fruits are too soft. This year, seeds of this variety were given to farmers to verify whether the variety can still be acceptable for commercial production. Presently, introduced germplasm is still being screened for bacterial wilt and acceptability for the local market.

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26

Environmental Influences on the Severity of Tomato Bacterial Wilt in the French West Indies: Interactions with Varietal Resistance

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Abstract

Guadeloupe (French West Indies -16°N), has year-round temperatures close to 30°C and a variety of soil types, both of which allow for observation and research into tomato bacterial wilt (*Pseudomonas solanacearum*). Ferralitic soils, andosols and vertisols originating from a volcanic substrate are conducive to infection. Calcic vertisols on the other hand are suppressive. Suppressiveness is associated with a high amount of smectic-type clays in calcic vertisols and is related to retraction of the smectic clay following drought. However, when calcic vertisols are cultivated and irrigated year-round, they become conducive. The influence of crop rotation on bacterial wilt is very apparent in Guadeloupe. Soils previously monocropped with sugarcane become heavily contaminated with *P. solanacearum* after two or three solanaceous crops, whereas on soils monocropped with banana, the first solanaceous crop may be severely attacked. Environmental influences are especially evident on tomato cultivars with an intermediate level of polygenic resistance (e.g. Carrette) or on resistant × susceptible F_1 hybrids. These plants are much more susceptible in July and August when the nights are warm (25°C) than in January and February when the nights are cool (18°C). The addition of organic matter to soil (in the form of forage sorghum green manure, soybean oilcake or sewage sludge) reduces bacterial wilt infection. However, when factors conducive to bacterial wilt infection are accumulated (ferrallitic soils, successive crops of solanaceous plants, low organic matter and warm nights), even some plants of the cultivars carrying the highest levels of polygenic resistance (e.g. Caraibo) succumb to bacterial wilt infection.

Introduction

In the French West Indies, where temperatures fluctuate from between 18° to 29°C in January to between 24° to 31°C in July, bacterial wilt is the most important disease of solanaceous crops such as tomato, eggplant and sweet pepper all year round. White potatoes, although normally not planted, are also severely attacked. On the other hand, tobacco and banana plantations remain disease-free, which indicates that pathotype 1A (Buddenhagen, et al. 1962) of *Pseudomonas solanacearum* E.F. Smith is predominant.

From 1967 to 1987 research on *P. solanacearum* was conducted at the Plant Pathology, Plant Breeding and Agronomy stations of 'INRA-Antilles-Guyane', the agronomic research center in Guadeloupe (French West Indies), which led to the release of bacterial wilt resistant tomato, eggplant and sweet pepper cultivars suitable for the West Indies. The resistance utilized by Kaan and Anais (Plant Breeding Station-INRA-Antilles-Guyane) for breeding large-fruited tomato

cultivars originated from CRA 66, which carries polygenic resistance similar to that of Venus and Saturn. This resistance was introduced into large-fruited cultivars in three different ways:

1. F_1 hybrids between susceptible large-fruited and resistant lines. These hybrids were used during the 1972-75 period, following the use of susceptible cultivars grafted onto CRA 66, or better onto CRA 257, a CRA 66-like line with the Mi gene.
2. Pure lines obtained by backcrossing, such as Carrette, which has probably retained only four resistance genes from the five suspected in CRA 66.
3. Lines obtained from complex crosses between bacterial wilt-resistant and heat-tolerant lines, such as Caraibo.

The availability of genotypes with different, and especially with intermediate levels of resistance was very useful for phytopathologic-agronomic investigations.

Seasonal Variations of the Aggressiveness of *P. solanacearum*

Under conditions of high and regular soil infestation, susceptible varieties throughout the year suffer 100% mortality. Cultivars with the highest level of resistance, like CRA 66, have 5% infected plants during the warm, most favorable season for disease (for example in July where temperatures range from 24°-31°C). Infected plants show internal necrotic symptoms that are different from those of susceptible plants. On the other hand, resistant × susceptible F_1 hybrids, such as 620.4 × Floradel show a considerable seasonal variation in the percentage of surviving plants, from 95% during the cool season (for example in January where temperatures range from 18°-28°C) to only 20% during the warm season. Since there is almost no variation of maximum day temperatures during the year (from 28° to 31°C), the night temperature is probably the most important contributing factor which influences the aggressiveness of the pathogen towards genotypes with an intermediate level of resistance.

Conducive or Suppressive Soils

Guadeloupe consists of two islands of very different geologic origin and linked by an isthmus. Basse Terre or Volcanic Guadeloupe is a recent volcanic island with volcanic rocks and ashes. It has high rainfall and most soils are acid, with more or less advanced ferrallitic evolution. On the same volcanic substrate, neutral, magnesic vertisols are differentiated along the western coast, under less than 1,000 mm annual rainfall. Martinique, St. Lucia, St. Vincent and Grenada are other West Indian islands with similar soil types. Grande Terre, the other island, is older, and the ancient flat volcanic substrate is covered by a thick layer of madreporic limestone. Because of drier conditions (linked to lower elevation) than those on volcanic Guadeloupe, calcic vertisols are differentiated. They are very rich in smectic-type clays, with a variable percentage of limestone gravel. Antigua and Barbados are similar to Grande Terre in this respect.

Growers who produce tomatoes under irrigation on calcic vertisols on Grande Terre, and in a small part of Martinique around the city of St. Anne, are using bacterial wilt susceptible cultivars like Floradel, or more recently F_1 hybrids such as Duke, because bacterial wilt is not a problem there. On the other hand, on Basse Terre, and over the larger part of Martinique, only bacterial wilt-resistant cultivars are able to survive.

This difference of disease occurrence was shown to be linked with soil and not with climate by a field experiment using soil exchange up to 60 cm depth (Beramis, Plant Pathology Station INRA-Antilles-Guyane, personal communication), and later in greenhouse pot experiments using the two different soils with artificial inoculation (Berniac and Beramis, 1973). The calcic vertisol remains suppressive to infection even when autoclaved for one hour at 120°C for three successive days (as distinct from Fusarium soil suppressiveness, which is destroyed by heat).

Different soil samples from Basse Terre and Grande Terre were amended with calcium or magnesium carbonate and evaluated for suppressiveness (Berniac and Beramis, 1973). It was

found that calcic sandy soils, neutral magnesic vertisol, or conducive soils amended with Ca or Mg were conducive. Suppressiveness could not, therefore, be attributed to neutral pH or Ca++ and Mg++ cations, and was thought to be associated with the presence of smectic clays.

The mechanism effective for elimination of *P. solanacearum* in smectic clays was elucidated. When suppressive soils were kept wet (pF 1.7-2.2) after inoculation, they became infective, allowing the bacteria to move and multiply. On the other hand, when these soils were dried (pF 4), the bacterial populations decreased rapidly (Prior et al. 1987). The pores of the smectic clay contract during drying, thus preventing the bacteria from moving and multiplying. These results indicated a danger of bacterial wilt appearance in calcic vertisols, if monocropped, under continuous irrigation. Following the installation of a collective irrigated area, which prompted the growers to monocrop tomato under continuous irrigation, this forecast was verified in Grande Terre.

Crop Rotation

When eggplant was first grown in Guadeloupe and Martinique for export to Europe, bacterial wilt susceptible cultivars such as Florida Market were used. When planted after sugarcane, severe losses from bacterial wilt appeared only at the second or third crop of eggplant . On the contrary, when planted after banana, the disease was often very severe on the very first crop. *P. solanacearum* race 1 is apparently able to survive on banana roots, even though not pathogenic on this host. The sugarcane effect can be simulated by growing forage sorghum for four to six months, cutting it five or six times, and by ploughing the whole of stems and leaves into the soil at the end of the crop as green manure. Cultivars with intermediate levels of resistance are better protected by this method than fully susceptible varieties. Vegetable gardening with cucurbits, crucifers, rootcrops, or bacterial wilt resistant solanaceous vegetables does not eliminate soil contamination by *P. solanacearum* (Messiaen, 1970; 1975).

Mineral and Organic Amendments

Lime or calcium carbonate amendments gave only a slight protection to susceptible × resistant F_1 hybrids, and none to susceptible cultivars. This was confirmed by pot experiments. On the other hand, organic amendments were effective in reducing bacterial wilt infection. The best protection was obtained either with low-nitrogen amendments, such as bagasse (sugarcane fibrous waste) which had an effect comparable to that of sorghum green manure, or with very high-nitrogen amendments, such as soybean oilcake (Rat, 1975, Plant Pathology Station INRA-Antilles Guyane, personal communication). In a similar way, a preplant application of 700 kg nitrogen/ha (from urea) can protect susceptible × resistant F_1 eggplant hybrids from bacterial wilt. This large amount of soluble nitrogen would be detrimental to a tomato crop. A similar, but longer lasting effect can be obtained by application of semidried sewage sludge (from 10 t before a crop up to 100 t/ha every third year). These field observations were later confirmed by greenhouse pot experiments (Prior et al. 1987). The mechanism of the sewage sludge effect has not yet been elucidated. Microbiological soil analysis does not demonstrate an important decrease of *P. solanacearum* soil populations, and bacteria can be isolated from xylem vessels of plants, which survive without external symptoms.

Conclusion

Highly susceptible tomato cultivars can be grown under West Indian conditions only if planted on calcic vertisols, with a nonirrigated fallow at least every second year, or on conducive soil amended with high amounts of sewage sludge. However, cultivars with intermediate levels of resistance can be grown with appropriate cultural practices (crop rotation, including grasses, or moderate organic amendment), especially during the cool season. Under conditions which

favor the diseases, such as planting in old vegetable garden soils, places where bananas were grown in highly conducive soils, or when night temperatures exceed 22°C, even cultivars with the highest level of resistance, such as Caraibo must be grown with some protection from previous green manure or organic amendment.

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Symposium Discussion

J.C. Girard: The use of 750 kg nitrogen per ha at one time is a large amount of nitrogen, which can result in pollution of the ground water.

C.M. Messiaen: In Guadeloupe or Martinique, water for drinking or irrigation is taken from the rivers at the forest level, well above the cultivated land. The problem would be serious for flat islands.

A. Sajjapongse: Smectic clay apparently traps *Pseudomonas* when dry; however, when it is wet again the clay mineral expands, hence could it release the bacteria?

C.M. Messiaen: When the smectic clay is wet again after having been dried, the bacteria have been killed during this period. This mechanism is effective even if drying lasts only 20 days. A nonirrigated fallow every second year during the dry season seems to be enough to prevent bacterial wilt problems on this type of soil.

S.K. Tikoo: In India there are reports of soil application of bleaching powder that help reduce the incidence of bacterial wilt in tomato. Do you have any experience with it?

C.M. Messiaen: The bleaching powder (calcium hypochlorite) was not tried for this use in the French West Indies.

239

27

Importance of Plant Resistance in the Control of Whiteflies and Whitefly-borne Viruses in Tomato and the Development of Screening Methods[1]

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Abstract

Two whitefly species may become the limiting factor in tomato production; the tobacco (sweet potato) whitefly *Bemisia tabaci* — primarily as vector of plant viruses in warm countries, and the greenhouse whitefly *Trialeurodes vaporariorum* which damages primarily the greenhouse tomatoes in temperate zones by sucking the plant sap and excreting honeydew. Over 70 virus diseases, of more than 30 different crops including tomatoes, are transmitted by whiteflies, of which *Bemisia tabaci* is the main virus vector. Prevention of infection is by vector control or by the use of cultivars resistant to the virus, to the vector, or to both. The use of resistant cultivars is considered the least expensive and most effective measure to reduce virus damage. Some wild Lycopersicon accessions are whitefly-resistant. The availability of rapid and reliable screening methods is a prerequisite for success in any breeding program. A continuous effort has been made to reduce the time required for laboratory tests without losing reliability. Preliminary investigations showed a high correlation between honeydew excretion by the whiteflies and the incidence of tomato yellow leafcurl virus (TYLCV) transmission. It is suggested that the screening methods, developed for the tomato/*B. tabaci*/TYLCV complex, might be useful for other whitefly-borne viruses, infecting different crops, for other whitefly species, and perhaps also for some other sucking insects which excrete honeydew.

Introduction

It has been postulated that, without insect pests, world food production would increase by about one-third (Van Emden, 1974). This tremendous level of pest damage occurs despite current control measures. Insects cause damage either directly by eating, grasping or sucking, or indirectly by transmitting virus diseases. Generally, direct damage is caused by large numbers of individuals, whereas indirect damage can occur through the action of a relatively low number. Usually, both types of damage caused by insects, the direct as well as the indirect damage, are highly correlated with the particular insect's population density, although the 'economic injury level' is usually much lower in the case of virus transmission. In the tropics and subtropics, whiteflies, and the viruses they transmit, may become one of the limiting factors for crop production (Anonymous, 1983; Duffus, 1987; Duffus and Flock, 1982).

Whiteflies are controlled chemically, biologically, and mechanically. However the use of these control measures is limited by climatic conditions, is inefficient, and uneconomic. Chemical control also causes environmental problems (Berlinger et al. 1988). Virus damage can be restricted by breeding plants which are resistant to the insect vector although they may be susceptible to the virus. Vector resistance in plants can usually be integrated with other control methods. Measures for the control of whitefly-transmitted viruses, should be based on the following:

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(1) The incidence of virus-infected plants is directly proportional to the density of the vector population, although economic damage is caused by a low vector density (Berlinger et al. 1988; Makkouk and Laterrot. 1983).
(2) The time necessary to control the vector must be shorter than the time needed for a viruliferous insect to inoculate a healthy plant with the virus, at least when primary infection is concerned.
(3) Plants can defend themselves against pest attack by repelling, killing or being unattractive to the whitefly vector (Painter. 1951).

Over 70 plant viruses are transmitted by whiteflies (Duffus. 1987; Muniyappa. 1980). Most of these, and all hitherto known whitefly-borne tomato viruses, are transmitted by *B. tabaci* (Duffus. 1987). A few are transmitted by *Trialeurodes vaporariorum* and *T. abutilonea* (Duffus. 1965). Although tomato is not a preferred host of *B. tabaci*, this whitefly is able to transmit efficiently various virus diseases to tomato, such as the tomato yellow leaf curl virus (TYLCV) tomato leaf curl, tomato yellow top, etc. which are caused either by the same virus, or by closely related strains of the virus (de Ponti et al. 1989; Makkouk and Laterrot. 1983).

TYLCV is transmitted solely by *B. tabaci*. About 4 h of inoculation feeding are sufficient to introduce the virus into a healthy tomato plant. Virus symptoms will appear after a three-week incubation time. Infected plants often stop growing and further fruit-set ceases (Cohen and Nitzany. 1966). The earlier the plant becomes infected, the greater is the yield loss. Thus, any delay in the plant's infection can be crucial in reducing the damage.

Whitefly-transmitted diseases such as the African cassava mosaic can be reduced significantly by using cultivars which are resistant or tolerant to *B. tabaci* (Bellotti and Kawano. 1980). Antixenosis to *B. tabaci*, was suggested as responsible for limited secondary spread of cowpea golden mosaic virus in cowpea, and lima bean golden mosaic virus in lima bean. Genotypes that showed field resistance to infection with the respective viruses supported fewer *B. tabaci* vectors than susceptible genotypes. The difference was greatest when whitefly populations were large (Vetten and Allen. 1983). Cotton leaf curl, which is a serious disease in some parts of Africa, is another example. Some cotton genotypes, although susceptible to the virus, are rarely infected in the field and are relatively free from whitefly infestation (Tarr. 1951, quoted in Jones. 1987).

Other examples of the importance of host-plant resistance to various virus vectors in the reduction of virus spread, and the mechanisms involved, are listed by Cohen (1982a, b), Jones (1987), Pathak (1970) and Thresh (1983).

Wild *Lycopersicon* spp. *L. hirsutum*, *L. hirsutum* f. *glabratum*, and *L. pennellii* have been used to introduce into tomato cultivars resistance to the greenhouse whitefly (Gentile et al. 1968; de Ponti et al. 1975), the tobacco whitefly (Berlinger and Dahan. 1987; Kisha. 1984) spider mites (Carter and Snyder. 1986; Gentile et al. 1969; Snyder and Carter. 1984), moth larvae (Juvik et al. 1982; Kennedy and Yamamoto. 1979; Tamim. 1986) and leafminer flies (Kelsheimer. 1963). The TYLCV infection rates of *L. pennellii* accessions, and of tomato × *L. pennellii* F_2 hybrids, were very low, compared to susceptible tomato and moderately susceptible *L. hirsutum* f. *glabratum* accessions (Berlinger and Dahan. 1987).

The success of any breeding program for insect resistance is highly dependent on the availability of quick and reliable test methods. Methods of evaluating plants for insect resistance are based either on the insects' reaction and behavior to the plant at the individual or population level, or on the plants' own features, such as the density of the leaf trichomes (Georgiev and Sotirova. 1978; Snyder and Carter. 1985) or the tackiness of the plant leaves, due to the tacky exudation of their glandular leaf trichomes (Dahan. 1985; Plage. 1975), provided that they contribute to the resistance.

For the evaluation of plant resistance to insects in plants, either a choice test is used, in which whitefly adults are allowed to choose between two or more given plants (Curry and Pimentel. 1971), or a non-choice test in which the whiteflies are confined on a plant and their survival, reproduction, duration of development, and so on are measured (Berlinger and de Ponti.

1981; de Ponti et al. 1975). Both testing methods are relevant, but they answer different although complementary questions. The choice test identifies resistance based primarily on antixenosis (nonpreference) (Painter. 1951; Kennedy. 1976), whereas the non-choice test primarily identifies resistance due to antibiosis (Painter. 1951; Kennedy. 1976). The properties of each test must be considered when drawing the conclusions.

Field tests, performed using commercial production practices, are indispensable to confirm the laboratory tests. They are most reliable and therefore should be incorporated into breeding programs as the final test. Results can be evaluated by scoring the damage caused to the plants, such as the amount of sooty mold, or the incidence of virus-infected plants. However, field tests are time-consuming and too expensive to be used as a routine method during a breeding program. Therefore attempts have been made to develop tests of shorter duration but equal reliability. Both choice and non-choice tests are generally used.

Choice experiments. These are used for screening resistance to whiteflies which cause direct damage. However, they are unsuitable in the case of virus vectors because of the flight, landing, and host selection behavior of whiteflies (Berlinger and Dahan. 1986). Whitefly adults usually alight at random, on host as well as on non-host plants. On non-host plants they may stay for a few minutes or for several hours before they leave. The appearance of whiteflies-in-transit might be very confusing when screening for resistance on this basis.

Non-choice experiments. From the point of view of population dynamics, the duration of development from egg to egg or from egg to adult is an extremely important factor. However, in the case of whiteflies the differences are too small to be measured precisely and comfortably (van Boxtel et al. 1978; Dahan and Berlinger. 1983, unpublished). On the other hand, differences in adult survival and oviposition are outstanding in their importance (Avidov and Harpaz. 1969).

Material and Methods

Resistance to the Greenhouse Whitefly

The resistant *L. hirsutum* f. *glabratum* and the susceptible *L. esculentum* cv. Allround were used and the following tests were performed.

Group A: Choice tests performed in a glasshouse under commercial growing conditions.

1. Rating the density of the whitefly population using a 0-9 scale on 18 plants of each tested accession grown separately in different compartments (12 m^2) of a glasshouse.
2. Counting the number of leaves infested by no, a few, an intermediate number, or many scales (big larvae and pupae) at a plant height between 0.5 and1.5 m. Ten to 20 leaves per plant were sampled.
3. Counting the number of eggs, larvae and pupae on ten leaf discs (14 mm in diameter), sampled at a height of 20, 60, 100, 180 cm and on the top leaves of eight plants.
4. Trapping whiteflies by sticky yellow traps to estimate the adult population levels (Berlinger. 1980). Six traps were installed in each glasshouse compartment.

Group B: Non-choice laboratory tests, under controlled conditions, using leaf cages:

1. Survival and oviposition rates: one or six one-day-old females were confined on a leaf by means of a clip-on leaf cage. The surviving females were counted every four days and transferred to a new leaf. The leaf was detached and the number of eggs was counted.
2. The duration of development, as well as the sex ratio among the progenies, was determined by confining a large number of females of unknown age on a leaf by means of a clip-on

leaf cage. The whiteflies were removed after 24 h, their eggs were counted and allowed to develop. The duration of development and the sex ratio was determined by daily counts of the progenies. The rate (%) of larval survival was calculated by the number of progeny per egg laid.

Resistance to *B. tabaci*, the Vector of TYLCV

L. hirsutum, *L. hirsutum* f. *glabratum* and *L. pennellii*, were used and the following tests were performed.

Field test. The two most resistant accessions of each group, found in previous studies (Dahan, 1985; Morag, 1986; Shevach-Urkin, 1983), were selected and subjected to a field test. Ten transplanted plants of each tested accession were grown under common commercial practices in the field in single rows of 5 m length with a distance of 2 m between the rows. The test was arranged in randomized block design, using six replications. The plants were scored weekly for virus infection.

Non-choice laboratory tests. As the first step, the same laboratory tests were used as for the above-mentioned greenhouse whitefly experiment in order to detect the two most resistant accessions of each species.

A 'sugar test' was performed for *L. pennellii* accessions in order to quantify 'leaf tackiness', determined as 'percent sucrose in an aqueous solution' (Dahan, 1985; Plage, 1975). Granulated sucrose was scattered over a known area of the leaf and the surplus was carefully shaken off. The sucrose which remained sticking on the leaf was washed off with a known quantity of water. The sucrose content of the water was then measured by means of a refractometer (Berlinger et al. 1984).

In order to unify the screening methods for detecting resistance to virus transmission in *Lycopersicon* accessions, an attempt was made to evaluate the ability of whiteflies to transmit TYLCV by quantifying the secreted honeydew as a measure for readiness of the whiteflies to feed on a certain plant and thus transmit the virus. Ten adult females were confined on a detached leaflet by means of a modified Munger-cell (10 mm in diameter and 3-4 mm in height). The honeydew was collected on a white filter-paper (Whatman No. 1) and sprayed with a solution of ninhydrin (200 mg ninhydrin in 100 ml n-butyl alcohol) by which the amino acids of the honeydew are stained blue. The area covered by the honeydew spots was measured by placing a transparent sheet of mm-paper over the filter paper.

Results and Discussion

Both whitefly species, the tobacco whitefly and the greenhouse whitefly, were found to be very similar in their reactions by the above mentioned methods. Furthermore, the methods used were generally in good accordance with each other.

Screening for Resistance to the Greenhouse Whitefly Causing Direct Damage

The most difficult problem encountered when adults were confined and their development on single tomato plants was determined, was the rapid growth of the young plants. To overcome this obstacle, large cages, 80 cm high, wrapped with cheesecloth and closed at the top by a transparent plastic cover (de Ponti et al. 1975) were used. This allowed the plants to be kept in the greenhouse for a period equivalent to 1.5 whitefly generations. Each cage was inoculated by 75 one-day-old male and female adults. After six weeks, the second generation of adults had appeared. The reproduction rate was determined by estimating (a) the number of adults (second generation), (b) the number of empty pupae (second generation), and (c) the number of eggs (third generation). Although the results obtained correlated well with the field tests, this method consumed too much time and space. Consequently the duration of the experiment

was reduced to a part of a whitefly generation using the pot plant test in the greenhouse at 22°C (de Ponti et al. 1975). The growing point of the plants at the second to third true leaf stage was removed. Each plant was covered with a transparent plastic cylinder, and inoculated with 15 one-day-old females. After 10 days the whiteflies were killed by Sulfotep fumigant. After 14 days the number of young larvae on the leaves was counted or estimated. The two most resistant plants of most accessions were subjected to a so-called second generation test carried out under the same conditions, where four to five leaf cages (diameter 2 cm), each containing one young female whitefly collected at the end of the previous test from plants of the same accession, were placed on the lower surface of the leaves. After 10 days the mortality of the females was determined and 14 days later the number of larvae per female was counted. However this test method failed. This was explained by the fact that there was no recognizable difference between the response of 1-5 day-old whiteflies on resistant and susceptible plants (Berlinger and de Ponti, unpublished).

In an attempt to further reduce the testing time, it was found that confining one-day-old whiteflies on the plants by means of clip-on cages, and investigating oviposition and adult survival during the following 11 days, was sufficient to evaluate the differences in resistance between susceptible and resistant plants.

Screening for Resistance to *B. tabaci*, the Vector of TYLCV

All the above mentioned methods, used for the greenhouse whitefly, were adequate as long as they were used to screen for resistance to whiteflies causing direct damage. Unfortunately, these methods were insufficient for detecting resistance to *B. tabaci* as the vector of TYLCV

All the tested accessions were found to be TYLCV susceptible. Even *L. pennellii* plants became infested with whiteflies and infected by TYLCV, when the sticky exudate had been artificially removed by wrapping the leaves carefully with cotton soaked in 95% ethanol.

Our search for more suitable testing methods was based on the concept that even virus-susceptible plants will not become infected if they are resistant enough to prevent whitefly feeding for a period long enough to allow virus transmission.

Field test. *L. hirsutum* f. *glabratum* plants became virus-infected almost as quickly as *L. esculentum*. Disease development in *L. hirsutum* accessions was delayed and one *L. pennellii* accession did not become infected at all by the end of the season (Table 1).

Table 1. Incidence of TYLCV (cumulative percentage) in wild type and cultivated tomato.

Time	*L. esculentum*	*L. hirsutum* f. *glabratum*		*L. hirsutum*		*L. pennellii*	
(weeks)[z]	Allround	LA 407	PI 34418	LA 771418	LA 1777	PI 365970	LA 716
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	50.0	14.2	5.0	0.0	0.0	0.0	0.0
4	100.0	47.6	35.7	0.0	0.0	0.0	0.0
5	100.0	57.1	78.5	0.0	0.0	0.0	0.0
6	100.0	92.8	89.3	4.0	0.0	0.0	0.0
7	100.0	92.8	89.3	4.0	0.0	0.0	0.0
8	100.0	100.0	89.3	45.0	46.6	5.0	0.0

[z]After transplanting.

It was found that percentage of adult survival after 24 h of forced contact in a non-choice experiment using leaf cages gave the best correlation with the field test (Table 2). Choice tests, counting whitefly adults per plant in a field test, or counting larvae on potted plants arranged at random on a bench in a greenhouse, were only in poor correlation with the incidence of virus-infected plants in the field.

Laboratory tests. Secondary plant metabolites (Kennedy and Yamamoto, 1979; Soost et al. 1967) proved to be toxic to the whiteflies, when exposed in their pure form in laboratory experiments. However their occurrence in various *L. hirsutum* f. *glabratum* accessions did not correlate with previously detected plant resistance (Shevach-Urkin, 1983).

When leaf tackiness was used as criterion to evaluate levels of plant resistance, only the most sticky plants of *L. pennellii* showed absolute resistance, i.e. 100% adult mortality (Dahan, 1985). The 'sugar test', to determine 'leaf tackiness', was a useful tool to detect resistance among hybrid progenies with *L. esculentum* cv. Allround (Dahan, 1985). In *L. hirsutum* f. *glabratum*, even the most sticky plants were not sufficiently resistant as measured by whitefly mortality after 24 h (Shevach-Urkin, 1983).

Based on the previously found correlation between the amount of honeydew and the number of TYLCV infected plants (Figure 1), we had suggested that feeding, honeydew secretion, and virus transmission should be highly correlated. Similar techniques, to evaluate the amount of feeding by measuring the amount of excreted faeces, have been used with other pests, such as spider mites (Gerson and Aronowitz, 1980), and lepidopterous larvae (Ben-Aziz et al. 1976). Honeydew secretion has been used in the case of aphids transmitting leafroll virus in potatoes (van der Heuvel, 1986), and in the case of the tobacco whitefly to estimate survival of nymphs after insecticide treatments (Melamed-Madjar et al. 1983). If the amount of honeydew produced can be correlated with the probability of virus transmission, then honeydew production can be a useful tool to estimate levels of plant resistance. This method, still under development, seems to be very promising (Figure 1).

Table 2. Correlation (R) between field tests and various laboratory tests.[z]

Parameters	Type of test[y]	*L. hirsutum* (n = 8)	*L. hirsutum* f. *glabratum* (n = 6)	*L. pennellii* (n = 6)
No. of whitefly adults/plant	Ch	R = 0.61 NS[x]	R = 0.61-0.75 NS	R = 1.0 < 1%
No. of larvae/plant (pot-test)	NCh	R = 0.08 NS	R = 0.61 NS	R = 0.57 < 5%
Adult survival (days)	NCh	R = 0.77 5%	- -	-
Adult survival (%) after 24 h	NCh	R = 0.84 1%	R = 0.81 1%	R = 0.96-1.0 1%

[y]Ch = choice; NCh = non choice [x]NS = not significant at 5%.

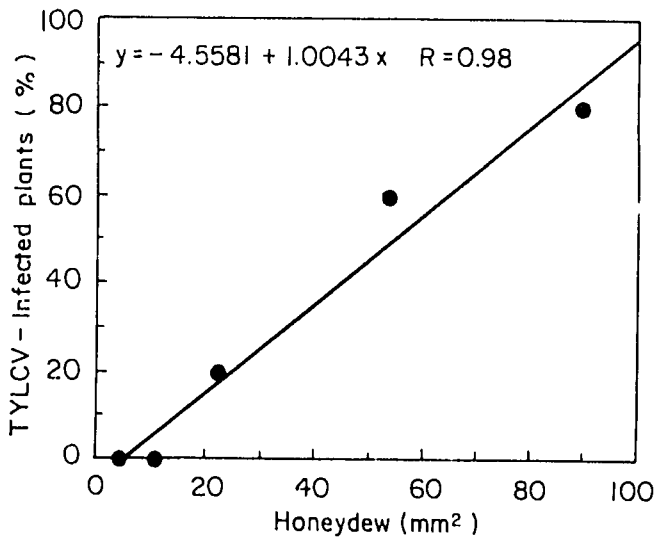

Figure 1.
Correlation between amount of honeydew produced and the incidence of TYLCV-infected plants.

Conclusion

Climatic conditions affect the behavior and development of the insects, as well as the morphology and physiology of the plants. While investigating the resistance of various wild *Lycopersicon* accessions to the tobacco whitefly, it was noticed (Berlinger et al. 1983; Kennedy et al. 1981; Snyder and Hyatt. 1984) that some accessions were resistant in summer but not in winter. In a laboratory test one *L. hirsutum* f. *glabratum* accession was found to be remarkably more susceptible when grown under lower light intensity, independent of day length. However in *L. pennellii* accessions only a combination of low light intensity and a short-day photoperiod resulted in susceptibility of some accessions. The transition from resistance to susceptibility and vice versa was expressed only in the newly developed leaves. Preliminary investigations showed that soil or water salinity negatively affect resistance in *L. pennellii*.

An increase in the use of nitrogen fertilizer in cotton resulted in an overall increase in attack by the tobacco whitefly. This was probably caused by an increase in insect fertility due to the higher N content of the leaves, as well as better protection because of a denser canopy of the plants (Harebaugh et al. 1983; Jackson et al. 1973). Spraying with DDT, sevin and parathion may cause a pest outbreak as a result of an increase in the nitrogen content of the leaves (Fowler. 1956; Ripper. 1964; Saad. 1975, cited by Weisser. 1980).

A previous virus infection may also change the outcome of a screening test because virus-infected plants may become less attractive to the whiteflies compared with healthy plants (Berlinger. 1985. unpublished; Rathi, cited in Nene. 1972).

The prerequisite of any breeding program is the availability of rapid, reliable, easy, and inexpensive methods to detect resistance. The main difficulties in developing such methods result from the fact that resistance is a dynamic feature. Both the plant and the insect pest react strongly to environmental changes and may readily adapt to new circumstances. The described insect-host plant relationships emphasize the necessity for optimizing and standardizing the environmental test conditions.

When screening for resistance to whiteflies causing direct damage, the study of population build-up parameters in laboratory tests, and the scoring of the number of eggs, larvae and pupal cases in field tests, are useful approaches. The survival of adults after four or 24 hours in laboratory tests, and the incidence of virus-infected plants in field tests are useful parameters to be measured in case of indirect damage via virus transmission.

It is hoped that screening methods, developed for the tomato/whitefly complex or the tomato/whitefly/virus complex, will become useful in the future for other whitefly-borne viruses, and perhaps also for other plant-sucking insects which exude honeydew.

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Symposium Discussion

I.D. Erinle: Is the yellow leaf curl virus you refer to the same as the one commonly referred to as leafcurl virus elsewhere?
M.J. Berlinger: These two virus diseases are either identical or very closely related. They may be strains of the same virus. Both are transmitted in a similar way by *Bemisia tabaci*.

J. Levy: (1) Which method do you recommend to control the vector *Bemisia tabaci*? (2) What methodology do you use to keep track of the vector population and at what stage do you start control?
M.J. Berlinger: (1) praying of pyrethroids is the most widely used chemical method. Planting under screen cover is the best mechanical method, as long as climatic conditions allow its use. Yellow plastic mulching, a behavioral control method, is effective during the first three weeks after planting. (2) In case of virus transmission, the use of yellow sticky traps is the best method for monitoring. Under our conditions we start control measures when more than 10 whiteflies/trap/week were trapped.

P. Rosset: You mentioned only *Bemisia tabaci* as a whitefly vector of virus diseases. Are there other whitefly species as vectors?
M.J. Berlinger: (a) *Trialeurodes vaporariorum* transmits beet pseudo-yellows in *Lactuca sativa*, *Beta vulgaris*, etc. [Duffus, J. E. 1965. Phytopathology 55:450-435]. (b) *T. abutilonea* reportedly transmits sweet potato yellow dwarf virus in Maryland [Hildebrand E.M. 1959. Plant Dis. Rptr. 43:712-714], and sweet potato mosaic in Georgia [Hildebrand E.M. 1960. Phytopathology. 50:751-756].

249

28

Virus Diseases of Tomato and Pepper in Queensland and Some Aspects of Their Control

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Abstract

In Queensland, a total of 11 viruses have been recorded from tomato and 5 of these have also been recorded on pepper.

By far the most widespread and important of these is potato virus Y (PVY), with recorded incidences of up to 100% in both crops. Control is difficult due to the abundance of alternate hosts and high vector populations, and genetic resistance is the most promising strategy. Three strains of PVY can be defined by their differential reaction on the various resistance sources available in pepper and several of these genotypes are resistant to all known PVY strains from Queensland. A source of resistance to PVY has been identified in *Lycopersicon hirsutum* PI 247087. The resistance is governed by a major recessive gene with probably some minor gene influences and it is effective against all Queensland isolates of PVY tested so far. Low heritability is hampering the incorporation of this resistance into a commercial tomato cultivar.

Cucumber mosaic, tomato mosaic and tomato yellow top viruses are at times also limiting factors in tomato production. Tomato mosaic virus is largely controlled by acid extraction of locally produced seed and trisodium phosphate treatment of imported seed. Recent isolated outbreaks have been virtually eliminated by crop hygiene and the use of trisodium phosphate as a disinfectant. Effective control measures are lacking for cucumber mosaic and tomato yellow top virus. The importance of alternative crop and weed hosts in the epidemiology of these two viruses is currently being investigated.

Introduction

Tomato (*Lycopersicon lycopersicum* Mill.) is the most important vegetable crop in Queensland, accounting for 32% of total value of the states vegetable production. The crop is almost exclusively grown for the fresh market and accounts for about 60% of the total value of Australian tomato production (Australian Bureau of Statistics, 1985/86). In Queensland, the production of peppers (*Capsicum annuum* L.) consists mainly of bell types and is a significant though much smaller industry, representing 2.5% of total value of the state's vegetable production. Diseases are an important constraint on production in both crops and at times viruses can cause serious damage. The locations of the major tomato and pepper production areas within Queensland are shown in Figure 1. This paper reports the range and relative importance of viruses recorded in tomato and pepper in Queensland, the variable success of breeding for resistance, and some aspects of epidemiology and control.

The Viruses and Their Importance

Viruses recorded in tomato and pepper, the range of crops they affect and abbreviations of their names used in the text are presented in Table 1.

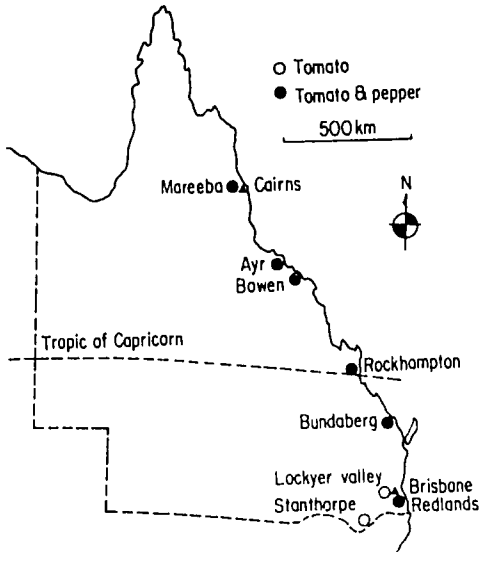

Figure 1.
The location of major tomato and pepper production areas in Queensland, Australia.

Table 1. Viruses recorded from tomato and pepper in Queensland.

Viruses and importance	Natural crop hosts
Economically important viruses	
Potato virus Y (PVY)	Tomato, pepper, tobacco, potato
Tomato yellow top virus (TYTV)	Tomato
Tomato mosaic virus (ToMV)	Tomato, pepper
Cucumber mosaic virus (CMV)	Tomato, pepper, spinach, cucumber and others
Tomato spotted wilt virus (TSWV)	Tomato, pepper, lettuce, peanut and others
Occasional records	
Alfalfa mosaic virus (AMV)	Many, including tomato, pepper, potato, celery and lettuce
Datura rhabdovirus (DRV)	Tomato
Australian tomato leafcurl virus (ATomLCV)	Tomato
Tobacco streak virus (TSV)	Tobacco, tomato
Tomato yellow vein virus (TYVV)	Tomato
Sunflower ringspot virus (SRSV)	Sunflower, soybean, tomato

Potato Virus Y

PVY is the most widespread and economically important virus in Queensland in both tomato and pepper. It occurs in all production areas and surveys have frequently revealed incidences of 50-100% in both crops (J.E. Thomas and D.M. Persley, 1987, unpublished).

The symptoms caused by PVY in tomato vary greatly depending on environmental conditions and virus isolates. High temperatures can cause plants to be totally symptomless or at most appear slightly chlorotic with the recently expanded young leaves recurved downwards and inwards to give a 'clawed' appearance. With lower temperatures plants may also show varying degrees of mottling and vein clearing and occasionally necrosis. 'Leaf-shrivelling' symptoms, consisting of patches of necrosis on the undersurface of the leaves, and the shrivelling of lower leaves was reported by Sturgess (1956) at mean temperatures less than 20°C. Nowadays, this latter syndrome is only occasionally seen in Queensland. Fruit symptoms do not occur, though fruit number and, to a lesser extent, fruit size are decreased. Yield losses of up to 50% can occur.

depending on time of infection and temperature conditions (Sturgess. 1956). A secondary form of loss is from sunburn of fruit, resulting from the poor leaf cover on severely affected plants.

Symptoms of PVY infection in pepper consist of mottling, dark green vein banding, leaf puckering and sometimes mottling and malformation of fruit. Yields can be substantially reduced particularly when early infection has occurred. High levels of PVY infection frequently occur in pepper crops planted late in the season or in situations where successive plantings have been made or crops ratooned.

Queensland isolates of PVY can differ significantly from each other in their host reactions (Heath et al. 1987; J.E. Thomas and D.M. Persley. 1987. unpublished). Using the traditional strain groupings, isolates from potato seem typical PVY°. An isolate resembling PVY^{n} has been recorded from tobacco. Many isolates, including most from tomato, tobacco and pepper, do not infect potato systemically and thus do not fit the traditional strain groupings. An alternative strain grouping has been proposed by Gooding and Tolin (1973), who differentiated PVY isolates into three groups according to their reaction on rootknot nematode (RKN) resistant and RKN susceptible tobacco cultivars. Representatives of all three groups are present in Queensland, but the majority of tomato and pepper isolates belong to the MsNr (i.e. mottle on susceptible cultivars, vein necrosis on resistant cultivars) or MsMr groups.

A third system of grouping isolates uses pepper cultivars for strain separation. Isolates from pepper, tomato and tobacco have been grouped into three strains designated 1, 2 and 3 (D.M. Persley. 1986. unpublished) using the pepper cultivars listed in Table 2. Particular emphasis is placed on the susceptibility or resistance of cultivars. For example, cultivar Yolo Y is resistant to strain 1, but susceptible to strains 2 and 3. Cultivars Florida VR-2 and Cordoba are resistant to strains 1 and 2, but susceptible to strain 3. Cultivars Delray Bell and Florida VR-4 are resistant to strains 1, 2 and 3. The cultivars Delray Bell and Florida VR-4 were selected by Cook (1984) for resistance to PVY, tobacco etch and pepper mottle viruses (PeMV). The reaction of these cultivars to strain 3 of PVY suggested that this strain resembled PeMV (Nelson et al. 1982). However, strain 3 differs from PeMV by not causing systemic necrosis in tabasco pepper (*C. frutescens* L.) (Nelson et al. 1982) and by the development of spur formations in SDS-gel diffusion serology using PeMV, but not PVY, antiserum (Greber and Persley. 1985. unpublished). When Queensland isolates from tomato and pepper were tested on the pepper differential cultivars of Gebre Selassie et al. (1985), strains 1, 2 and 3 from Queensland resembled the strains PVY-0, PVY-1 and PVY1-2 respectively, from France. All Queensland isolates tested induced a systemic mosaic on cultivar Bastidon in contrast to the systemic veinal necrosis reported for some isolates by Gebre Selassie et al. (1985).

The grouping of PVY isolates is not, however, necessarily consistent between the various systems. All isolates are serologically indistinguishable by SDS-gel diffusion serology (Purcifull

Table 2. Grouping of Queensland isolates of PVY according to reaction of pepper cultivars.

Cultivar	PVY strain[z]		
	1	2	3
Cordoba	R[z]	R	M
Citadel	R	R	N,M,S
Delray Bell	R	R	R
Florida VR-2	R	R	M
Florida VR-4	R	R	R
Yolo Y	R	M	M
Yolo Wonder	M	M	M
Bastidon	M	M	M
Serrano Vera Cruz	R	R	R
Anaheim TMR	LL,N,M,S	LL,N,M,S	LL,N,M,S
Tabasco	R	R	R

[z]R = resistant; S = susceptible, systemic mosaic; LL,N,S,St = local lesions, systemic vein necrosis, mosaic, severe stunting; M = mosaic, veinbanding; N = systemic vein necrosis; S = stunting; and LL = local lesions.

and Batchelor, 1977) and are readily detected by ELISA (Clark and Adams, 1977) using PVY antiserum (J.E. Thomas, 1987, unpublished).

Tomato Yellow Top Virus

TYTV is probably the second most important virus of tomatoes in Queensland. It has been recorded from all coastal areas of southeast Queensland from Brisbane to Rockhampton and in north Queensland around Mareeba, but not from the Bowen district. Outbreaks of this disease tend to be sporadic, but incidences are usually highest in autumn and early winter and can reach 50-100%.

TYTV is a luteovirus, persistently transmitted by the aphids *Myzus persicae* Sulzer and *Macrosiphum euphorbiae* Thomas and with a host range largely confined to the Solanaceae (Braithwaite and Blake, 1961; Thomas, 1984). The symptoms induced in tomato include downcurling and chlorosis of leaflet margins, rounding of leaflets, reduced leaf size and death of flower buds. Few fruits are obtained from plants infected before first fruit-set. Infection after fruit-set reduces fruit size.

Recent work has shown that TYTV is best considered a strain of potato leafroll virus (PLRV). Particles of TYTV were readily detected by immunosorbent electron microscopy using antiserum to PLRV (Thomas, 1981a) and PLRV and TYTV were serologically indistinguishable by agar gel double diffusion (Thomas, 1984). More recently, in tests with a panel of 10 monoclonal antibodies prepared to a Scottish isolate of PLRV (Massalski and Harrison, 1987), isolates of PLRV and TYTV from Australia were serologically indistinguishable (Massalski et al. 1986). However, TYTV produces few, if any, symptoms in potato (*Solanum tuberosum* L.) and PLRV produces only mild yellow top symptoms in tomato, and the two virus strains are probably epidemiologically distinct entities.

Other Economically Important Viruses

Other viruses frequently recorded from tomato and pepper, but generally of lower overall economic importance, include CMV, TSWV and ToMV. These viruses are known to occur worldwide and, while isolated severe outbreaks are recorded in Queensland, they generally pose a limited threat to tomato and pepper production. CMV causes 'fern-leaf' disease in tomato and regularly reaches significant levels in one location in the Lockyer Valley growing area. When young plants are also infected with the ubiquitous PVY, total fruit loss can occur (Sturgess, 1956). ToMV and TSWV are the only viruses to cause fruit symptoms in tomato, rendering them unmarketable. The former causing pale blotches or internal necrosis, the latter ringspots. In recent outbreaks of ToMV in the Lockyer Valley, Redland Bay and Bundaberg districts, infection levels of up to 80% in certain cultivars were noted. Dual infections of ToMV and PVY can cause total fruit loss (Sturgess, 1956). TSWV appears to be endemic in southeast Queensland, occurring most frequently at Stanthorpe and in the Lockyer Valley, with infection levels occasionally reaching 25%

Viruses Recorded Occasionally

AMV and TSV occur worldwide in many different host species but in Queensland these are recorded occasionally in tomato (AMV, TSV) and pepper (AMV) and are of no economic significance. Several other viruses also occur occasionally on tomato and have only recently been recognized. DRV is a subgroup II rhabdovirus (Thomas and Behncken, 1983; Thomas, 1985) which infects tomato, but not pepper. SRSV is a multicomponent isometric virus (Dale and Behncken, 1981) which has been recorded infrequently from sunflower, soybean and tomato. TYV disease occurs with low frequency in the Stanthorpe and Lockyer Valley districts. No disease specific bands have been detected by ds-RNA analysis and no virus particles have been

found. The causal agent is transmitted by grafting, but not sap inoculation, to a limited number of hosts in the Solanaceae including tomato, potato and eggplant (*Solanum melongena* L.). No vector has yet been found, and tests with the aphid *M. persicae*, the leafhopper *Orosius argentatus* Evans and the whitefly *Bemisia tabaci* Gennadius were unsuccessful (J.E. Thomas, 1985, unpublished). A leafcurl disease, caused by a geminivirus, is present in north Queensland, though of apparently of no economic importance (Thomas et al. 1986). By contrast, the virus is widespread and economically damaging to tomato crops in the Northern Territory (B.D. Conde, Department of Industries and Development, Darwin, NT, 1984, personal communication).

Epidemiology

Aphid Trapping

Most of the tomato and pepper production areas in Queensland have subtropical or tropical climates with hot, wet summers and mild, dry winters. This often allows vector populations to increase rapidly to high levels. As aphids are the vectors of the most economically damaging viruses, we commenced aphid trapping in 1987, using yellow pan traps, in two vegetable growing localities in the Lockyer Valley (J.E. Thomas and D.M. Persley, 1988, unpublished). The aims were twofold: firstly to identify any peaks of vector activity, and secondly to determine the major species present. We have noted that identical crops planted as little as two weeks apart in the same area can have vastly different levels of virus infection, possibly indicating concentrated periods of high vector activity. Preliminary data from these trapping experiments are presented in Figure 2.

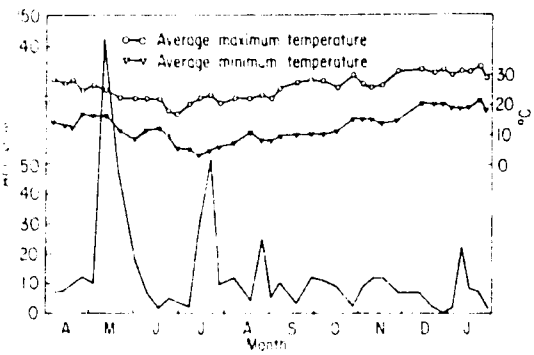

Figure 2.
Total aphid catches at a site in the Lockyer Valley, Queensland between April 1987 and January 1988, using a yellow pan trap (solid line). A daily average was calculated for each collection period (usually about one week.)

At least 24 different aphid species have so far been identified. Although the data is still very incomplete, some interesting results and trends are becoming apparent. A major peak in aphid numbers occurred in autumn (May) and consisted primarily of *Lipaphis erysimi* Kaltenbach and *M. persicae*. A second peak occurred in July (winter) and consisted primarily of *L. erysimi*, but with moderate numbers also of *Dysaphis* sp., *M. persicae* was almost totally absent during this peak. Aphid numbers have since fluctuated from low to moderate from July through to January. *L. erysimi* remained the dominant species trapped until early November when *M. persicae* reappeared in high numbers and became the dominant species.

Significant numbers of a wide range of aphid species are present throughout the year in the Lockyer Valley providing ample opportunity for the transmission of such vector nonspecific viruses as PVY, CMV and AMV. On the other hand, *M. persicae* is the only recorded vector of TYTV that has been trapped and it shows marked variation in population levels throughout the year.

Weed and Alternative Hosts

A reliable source of inoculum, in addition to an active vector population, is required if regula epiphytotics are to occur. Weed and alternative crop hosts play an important role as viru reservoirs in Queensland.

The known natural hosts of PVY in Queensland are restricted to the Solanaceae. They includ the crops tomato, pepper, tobacco and potato and s en weed species of which the more importan are *Nicandra physalodes* L. *Physalis* spp. and *Solanum americanum* Mill.. The latter specie are ideal hosts for both PVY and aphids. Tomatoes are one of the dominant crops in the mair production areas. Farmers use sequential plantings over an extended production period of many months and thus older crops provide a constant source of inoculum for nearby newly plantec crops. Susceptible weed hosts and/or volunteer crop plants are present all year round to adc to the inoculum reservoir.

Bowen is one of the largest tomato producing areas and crops are grown under irrigation from March through to October during the dry winter season. During surveys in 1984, crops grown in isolation and with very low weed populations in the dry surrounding areas had only 2-4% PVY. However, crops growing a. the same time in the more intensively cultivated areas of Bowen had infection levels of 70-100%. High levels of PVY infection in peppers at Bowen are unusual, despite the common use of fully susceptible cultivars and high inoculum levels in tomato crops growing nearby (V.N. Meurant, D.M. Persley and J.E. Thomas. 1987. unpublished).

In contrast to PVY, CMV has an extensive host range (775 species in 85 families; Douine et al. 1979) and has been recorded from 32 species in Queensland. CMV regularly occurs at significant levels of infection in tomato crops in the fairly isolated Flagstone Creek area of the Lockyer Valley, though not elsewhere in the district. As tomatoes are grown here only during spring and summer, this would suggest a source of CMV, peculiar to this area of the Lockyer Valley, in which the virus survives between tomato crops. However, in three separate surveys comprising samples of nearly 900 plants from 65 different species, no such reservoir was found (J.E. Thomas and M.L. Davidson. 1987. unpublished). These surveys included species such as *Capsella bursa-pastoris* (L.) Medic. and *Stellaria media* (L.) Vill. known elsewhere (Tomlinson et al. 1970) as important weed hosts in which CMV is seedborne.

The host range of TYTV is restricted largely, but not entirely, to the Solanaceae. Potato, which is infected,but without symptoms, is the only other known crop host. Susceptible weed hosts include *C. bursa-pastoris*, *N. physalodes* and *Datura stramonium* L. Peppers are not susceptible (Thomas. 1984). High levels of infection (near 100%) can occur in tomato plantings in the Redland Bay district, even when no nearby crops tomato and potato are present. Susceptible weeds growing near the infected crop are themselves often uninfected. The lack of obvious local sources of infection implies that a more distant and as yet unidentified source of infection must exist.

Control

Due to the high vector levels and large amounts of inoculum present throughout the year, control of PVY by weed and aphid control has a limited chance of success in intensively cultivated areas. Tomato and pepper crops are regularly sprayed with conventional aphicides (pirimicarb, methamidophos) which can control colonizing aphids, but have little effect on virus transmission by incoming vectors. It is well known that these aphicides can even increase the level of infection of nonpersistent viruses by causing aphids to be less settled (Raccah. 1986). Genetic resistance was seen to be the best prospect for control of PVY in tomato and peppers.

Resistance to PVY in Tomato

Several sources of resistance to PVY have been identified in *Lycopersicon* species. *Lycopersicon hirsutum* Humb. and Bonpl. PI 247087 was immune to PVY, while *L. peruvianum*

(L.) Mill. PI 128643 and PI 128660 segregated for resistance (Thomas, 1981b; Thomas and McGrath, 1988). *Lycopersicon hirsutum* PI 247087 was chosen for further study as it was immune to a wide range of PVY isolates in field and glasshouse trials. The inheritance of resistance to PVY was studied in a cross between PI 247087 and a susceptible cultivar of *L. lycopersicum* (Thomas and McGrath, 1988). The segregation data obtained for PVY-inoculated parent lines, F_1, F_2 and backcross generations are summarized in Table 3. These results were obtained by using enzyme linked immunosorbant assay (ELISA), as infected plants were often symptomless.

These data are consistent with the hypothesis that resistance to PVY in PI 247087 is conferred by a single recessive gene. The results summarized in Table 3 were obtained three to six weeks after inoculation. However, when plants were rescreened later, it was found that some individual plants of F_1 × PI 247087 and F_2 (but not the PI 247087 parent) previously rated as resistant were in fact infected. The change in numbers of susceptible plants in the F_2 was not sufficient, though, to invalidate the hypothesis for a 3:1 segregation ratio.

During the backcrossing program to incorporate this resistance into *L. lycopersicum*, progressively fewer resistant plants than expected were found (J.E. Thomas and D.J. McGrath, 1987, unpublished). Additionally, many of these 'resistant' plants were shown to be infected at later screenings, indicating that their resistance was being expressed merely as a reduced rate of virus multiplication. After the fifth backcross generation, only fully susceptible plants or plants with the reduced rate of virus multiplication were detected. When these plants were selected, selfed and grown in a field trial, they reacted identically to fully susceptible *L. lycopersicum* cultivars to PVY infection. It appears that the effect of the PVY-resistance gene from PI 247087 is affected by the highly susceptible genetic background of *L. lycopersicum* resulting in poor heritability of resistance.

Table 3. The reaction of parents and segregating generations of the cross *L. lycopersicum* × *L. hirsutum* PI 247087 to inoculation with PVY.

	Susceptible	Resistant	Total	Proposed Ratio S:R	X^2 probability
L. lycopersicum	65[z]	0	65	1:0	> 0.95
L. hirsutum PI 247087	0	79	79	0:1	> 0.95
F_1	2	0	2	1:0	> 0.95
F_1 × *L. lycopersicum*	189	0	189	1:0	> 0.95
F_1 × *L. hirsutum* PI 247087[y]	26	54	80	1:1 (?)	> 0.01
F_2	342	111	453	3:1	0.50-0.75

[z]Numbers of plants. [y]All results were obtained by ELISA, except for F_1 × *L. hirsutum* PI 247087 for which electron microscopy (negatively stained leafdips) was used.

Resistance to PVY in Pepper

Resistance to PVY is an important selection criterion for cultivars used in southern Queensland. The bell cultivars Yolo Y and Maor were resistant to PVY until 1981 when strains 2 and 3 were detected. These strains overcame the genetic resistance effective against strain 1 and are now endemic in southern Queensland (D.M. Persley, 1986, unpublished).

Most cultivars originate from commercial breeding programs conducted outside Australia. The bell cultivar now grown most extensively, Bell Tower, is resistant to strain 1 and partially resistant to strain 2. Effective control of strain 3 presents a challenge because there are few resistant cultivars. Two cultivars with resistance to this strain are Delray Bell and the related Florida VR-4 which were bred for multiple virus resistance (Cook, 1984). These cultivars yield poorly in our environment and are highly susceptible to bacterial spot disease caused by *Xanthomonas campestris* pv. *vesicatoria*.

The aim of the breeding program at the Redlands Research Station in southern Queensland is to develop adapted bell pepper cultivars with adequate resistance to bacterial spot and the

PVY complex (A.M. Hibberd, D. Gillespie, G. Nahrung, D.M. Persley, 1988). A sweet pepper highly resistant to PVY strain 1 and partially resistant to bacterial spot was recently released (Hibberd et al. 1988).

A very small-fruited 'piquin' type chili, accession 1534, is highly resistant to PVY strains 1, 2 and 3 (D.M. Persley and A.M. Hibberd, 1987, unpublished). Crosses of this line with bell type cultivars are now at the second backcross stage with virus resistant segregates being identified. There do not appear to be deleterious linkages between fruit size and virus resistance in these generations.

Inheritance of resistance to strains of PVY in Queensland has not been investigated in pepper.

Control of ToMV in Tomato and Pepper

ToMV is spread mainly by plant-to-plant contact and on hands and tools during crop production. Alternate hosts play a negligible role in Queensland and the major sources of infection are seed, infected trash from old crops, and contaminated trellises.

Control of ToMV in Queensland is easily achieved by using 'clean' seed and careful crop management and so no attempt has been made to incorporate the various ToMV resistance genes (Broadbent, 1976) into our commercial cultivars. The majority of seed used is produced by a growers' organization (Committee of Direction of Fruit Marketing) with assistance from the Queensland Department of Primary Industries. Seed crops are regularly inspected prior to harvest and the seed is acid-extracted (Broadbent, 1965) which is very effective in eliminating external ToMV contamination. Quarantine regulations require that hybrid and other seedlots which are imported from overseas are treated, prior to release, with 10% trisodium phosphate for one hour. This method is similarly effective in eliminating externally borne ToMV (Broadbent, 1965).

The treatment of trellis posts and wires before reuse may be necessary if ToMV was present in a previous crop. Similarly, destruction of trash from infected plants of old crops is also necessary. We have noted high levels of ToMV infection in *S. americanum* and volunteer tomatoes on land where a badly infected crop had previously been grown.

Several important pepper cultivars are resistant to the common strains of tobacco and tomato mosaic viruses in Queensland. A distinct tobamovirus, capsicum mosaic virus, which systemically infected all cultivars tested, occurs in glasshouse grown crops in New South Wales (Pares, 1985), but has so far not been recorded in Queensland.

Conclusion

Tomato and pepper are naturally infected with a wide range of viruses in Queensland, though fortunately only a few are of economic importance. All commonly grown commercial tomato cultivars are still susceptible to the major viruses (PVY, ToMV, TYTV). Overall, PVY is the most damaging virus and genetic resistance remains the best strategy for its control in both crops. PVY is generally adequately controlled in pepper using resistance sources available in commercial cultivars, although cultivars resistant to strains 2 and 3 are limited and these strains are now predominant in south Queensland.

Considerable variation has been demonstrated within the potyvirus complex infecting peppers in various countries. It is important that this variation be monitored, particularly in relation to strain virulence and aggressiveness. One means of assisting these efforts would be the provision of a standard set of pepper cultivars for international use, which would, ideally, be maintained and distributed by one institution. A set of international reference cultivars should allow some standardization of strain nomenclature.

Attempts to incorporate resistance to PVY into tomato have so far been unsuccessful. The reasons for this failure are not known, but aberrant segregation ratios appear to occur commonly in interspecific crosses within *Lycopersicon* (Thomas and McGrath, 1988). Johnson (1984) has

stated that the effect of resistance genes can be reduced or even completely suppressed when backcrossed into susceptible genotypes. Our approach is now to re-examine earlier backcross generations, attempt to identify resistant plants, and stabilize the resistance in that generation. Should this fail, consideration may be given to aphid control using synthetic pyrethroids and mineral oil sprays.

The control of ToMV in tomatoes seems assured as long as seed supplies from apparently healthy plants are acid-extracted or treated with trisodium phosphate. There appears to be no need, as yet, to incorporate resistance genes into commercial tomato cultivars.

The effective control of CMV and TYTV will probably remain elusive until the major sources of infection are identified. Aphid trapping studies may indicate periods of low vector activity when crops can be planted to avoid infection. Unfortunately there are few sources of resistance to CMV and TYTV (AVRDC, 1987; Mink et al. 1981), and with CMV the limited area of occurrence means that an expensive breeding program cannot be justified to the industry as a whole.

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Symposium Discussion

C. Duranton: You mentioned 3 strains of PVY, do other strains also occur? Do you have an interpretation about the different genes which control this resistance towards PVY, respectively in VR-2 and Delray Bell? Thank you.
J.E. Thomas: At present we can only distinguish three PVY strains on pepper. We have not yet conducted any genetic studies with PVY resistance sources in pepper.

C.M. Messiaen: In Queensland, do you have only shoestring and fernleaf symptoms on tomatoes caused by CMV, or also necrotic symptoms on stems and fruits? In the Mediterranean areas these symptoms are caused by a satellite RNA of CMV also called CARNA-5.
J.E. Thomas: In Queensland, I have noted only fernleaf and shoestring symptoms in tomato with CMV infection, and I have not seen necrosis typical of CARNA-5. Dual infection of tomato with alfalfa mosaic virus and CMV has been noted to cause necrotic symptoms in Queensland.

J.W. Scott: What is the concentration of HCl used to control TMV on tomato seed and what is the duration of the treatment?
J.E. Thomas: We use a concentration of 3% HCl in H_2O for 3 hours, followed by a rinse in water.

R.L. Villareal: What other techniques are used to clean seeds in addition to 3% HCl to control ToMV?
J.E. Thomas: Other methods are: (1) 10% trisodium phosphate in water for 30 minutes at room temperature, followed by a water rinse, (2) dry heat, 70°C for 48 hours.

260

29

A Quick Diagnostic Test for Tomato Yellow Leaf Curl Virus

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Abstract

The tomato yellow leaf curl virus (TYLCV) is a geminivirus with a circular single-stranded DNA genome of about 2800 nucleotides. The viral genome was cloned and sequenced and a quick DNA hybridization test using chromogenic probes was developed to detect the presence of the virus in both plants and insects. Tissues are squashed onto a nylon membrane. No prior treatment of the biological material is necessary. Squashes are hybridized with a sulfonated virus-specific DNA probe and hybrids are challenged with mouse antibodies against sulfonated DNA. Detection is with alkaline phosphatase conjugated antimouse immunoglobulin which transforms a colorless substrate into a colored product. The color reaction indicates the presence of viral nucleic acids. The entire detection procedure can be carried out at ambient temperatures and results can be obtained the same day the tissues are sampled. The DNA of TYLCV can be detected well before disease symptoms appear by hybridization of cloned probes from infected plant tissues (leaves, roots, stems, flowers and fruits) squashed onto the nylon membrane. Viral DNA can also be detected in squashes of individual whiteflies. Use of this method should make the user completely independent of laboratory facilities. Squash-blotting provides a tool for rapid large-scale diagnosis of infected plants and insect carriers. Squash-blots may have many other potential applications for virus detection, for example in quality control procedures used by seedling companies, and as a rapid screening tool in breeding programs for disease resistance.

Introduction

Tomato production in the Middle East is limited by a disease caused by the tomato yellow leaf curl virus (TYLCV), which is transmitted by the tobacco whitefly (*Bemisia tabaci* Genn.), but which is not transmitted mechanically (Cohen and Harpaz, 1964; Cohen and Nitzany, 1966). The disease is acute during summer and autumn. It is believed that wild plants near tomato fields (e.g. *Cynanchum acutum* L.) are the natural hosts of the virus and serve as reservoirs (Cohen et al. 1986). Symptoms similar to those characteristic of this disease have also been described in North and Central Africa and Southeast Asia (Mak. ·k and Laterrot, 1983; Green et al. 1987). The disease seems to be spreading to regions where it was not previously reported (Brown et al. 1986).

Prevention of the disease has been attempted by controlling the whitefly population, usually by spraying insecticides two to three times a week when the whitefly population is at its peak. The diagnosis of TYLCV has relied for a long time on symptom expression and transmission

to test plants (Cohen and Nitzany, 1966). In the future, integrated TYLCV management will rely on rapid and accurate detection of infected plants and insect carriers.

In a recent study (Czosnek et al. 1988a) the virus was isolated from infected tomato plants (*Lycopersicon esculentum* Mill.). The virus has a twinned particle morphology (20 x 30 nm in size) and a covalently closed circular single-stranded DNA genome, characteristic of the gemini viruses (Stanley, 1985; Lazarowitz, 1987). The TYLCV genome was subsequently cloned and sequenced (Navot et al. 1989). The gene encoding the coat protein was subcloned and introduced into the Ti plasmid of Agrobacterium tumefaciens. Ti-mediated tomato transformation experiments are in progress. The expression of the TYLCV coat protein in transgenic tomato may provide resistance to the yellow leaf curl disease. Radioactive cloned probes could detect TYLCV nucleic acids in lysates (Czosnek et al. 1988b) and in squashes of infected plants and viruliferous whiteflies (Navot et al. 1989). This is achieved without any pretreatment of squashes because in the infected tissues most of the TYLCV DNA is present in a single-stranded form (Navot et al. 1989). However because of the use of radioisotopes these assays have to be performed in specially equipped laboratories. To overcome these obstacles, a nonradioactive color test useful for field diagnosis has been developed.

Materials and Methods

Plants and Insects

Squashes were prepared from field-infected *L. esculentum* cv. M82 plants, or from plants inoculated in the greenhouse by viruliferous whiteflies (*B. tabaci*). Leaves and flowers were squashed onto the nylon membrane using a hard object such as a glass rod or pen. Longitudinal and cross sections (from the apex to the crown) of stems were pressed onto the membrane. Fruits were cut open and imprinted. The specificity of TYLCV detection was tested using leaf squashes from tomato plants infected with either the cucumber mosaic virus (CMV) or the potato virus Y (PVY). Blots of insects prepared from either female whiteflies kept on TYLCV-infected jimsonweed (*Datura stramonium* L.) plants for an acquisition period of 18 hours (Cohen and Nitzany, 1966), or from insects collected in the field. Whiteflies were frozen at -20°C and squashed individually onto the membrane.

TYLCV-Specific DNA Probe

TYLCV was isolated as previously described (Czosnek et al. 1988a). The double-stranded TYLCV replicating form was cloned as previously described (Navot et al. 1989). A full length TYLCV genomic clone, homologous to DNA 1 of cassava latent virus, was used as probe.

Hybridization with Sulfonated Cloned TYLCV DNA and Color Detection of Virus DNA

The chromogenic test follows the following steps:

1. The tissues to be tested (plant and insect) are squashed onto a nylon membrane Hybond-N (Amersham International);
2. The samples are hybridized with a TYLCV-specific DNA probe tagged by inserting an antigenic sulfone group into cytosine moieties of the denatured DNA probe (Sverdlov et al. 1974), using the Chemiprobe Kit (version 4.1, October 1987) from Orgenics Ltd., Yavne, Israel;
3. Incubation for one hour with a mouse monoclonal antibody against sulfonated DNA which binds to the virus DNA-sulfonated probe hybrid;

4. Two seven-minute washes with 0.5 M NaCl and 0.3% Brij 35 T;
5. Incubation for two hours with goat antimouse immunoglobulin antibody conjugated to alkaline phosphatase which recognizes the complex and transforms the colorless substrate into a colored product. The color reaction indicates the presence of viral nucleic acids;
6. Three ten-minute washes with the Brij solution, incubation with the chromogenic substrates Nitro Blue Tetrazolium (NBT) and 5-Bromo-4-chloro-3-indolyl phosphate (BCIP) for one to five minutes at 37°C until hybrids are visualized.

The complete assay, hybridization and color detection is carried out at ambient temperatures.

Results and Discussion

A strong color signal was obtained within a few hours with TYLCV-infected plant tissues, but never with tissues from healthy plants. Squashes from tomato plants infected with CMV or PVY did not hybridize with the TYLCV probe (Figure 1). Viral nucleic acids could be detected in all tissues tested, including roots, stems, leaves, flowers and fruits of a TYLCV-infected plant with fully developed symptoms (Figure 2). The chromogenic probe could detect TYLCV in individual whitefly carriers. Whiteflies which had fed on healthy plants produced no color signal.

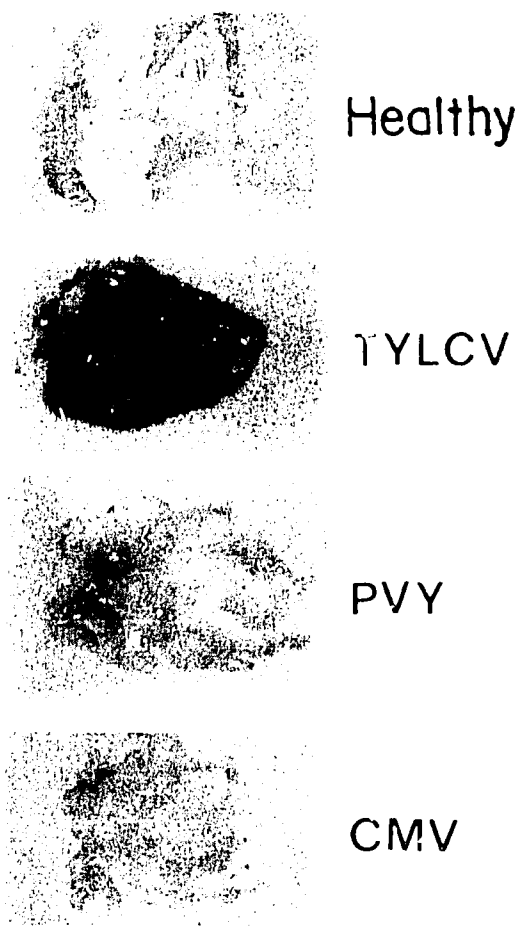

Figure 1. Chromogenic detection of TYLCV nucleic acids in a leaf from a TYLCV-infected tomato.

Figure 2. Chromogenic detection of TYLCV DNA in TYLCV-infected tomato plant tissues. (S = stem; R = root; Fl = flower; Fr = fruit.)

The results of the field test (Figure 3) indicated that for most of the tested plants, the four stem squashes gave an homogeneous answer, either positive for TYLCV (e.g. plants A1, B2, J3) or negative (e.g. plants A4, J4, C5). Some of them gave mixed results (e.g. plants B1, F4, K5), indicating that diagnosis should rely on more than one sample per plant. A few symptomless plants were found to be TYLCV positive. Healthy plants grown in an insect-proof greenhouse always tested negatively for TYLCV.

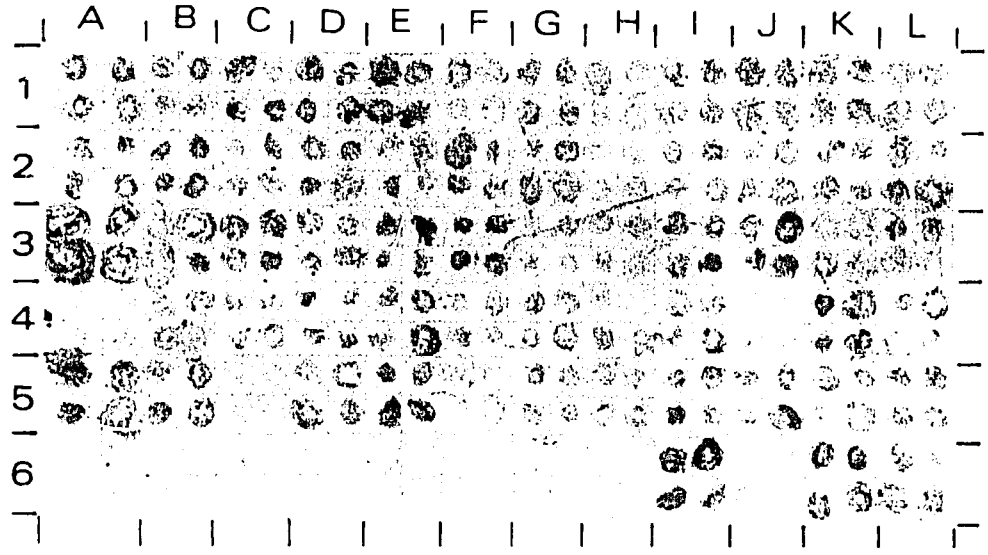

Figure 3. Field detection of TYLCV.

Plant virus diagnostics rely heavily on ELISA tests. In regions where other gemini viruses (e.g. tomato golden mosaic virus) infect tomato plants, the use of ELISA may be misleading since whitefly-transmitted gemini viruses are antigenically related (Roberts et al. 1984; Thomas et al. 1986). DNA sequencing data suggests that the coat protein of many whitefly-transmitted gemini viruses have related amino acid sequences (Donson et al. 1987; Hamilton et al. 1984; Howarth et al. 1985; Stanley and Gay. 1983), so antiserum prepared against TYLCV may detect other members of the whitefly-transmitted gemini virus family.

The use of DNA probes for diagnostic purposes is more versatile because probes can be made from any region of the viral genome. High specificity can be achieved by choosing a unique DNA sequence as probe. The gene encoding the coat protein is conserved among the whitefly-transmitted gemini viruses but differs from that of the leafhopper-transmitted gemini viruses (Lazarowitz. 1987). The gene encoding the putative replicase is more conserved than that encoding the coat protein (Howarth and Goodman. 1986). For unambiguous TYLCV diagnosis, an intergenic DNA fragment of about 200 nucleotides is suitable; this region is unique to each one of the gemini viruses, the remaining virus genome having various degrees of homology (Lazarowitz. 1987).

The chromogenic test has many features which make it convenient for large-scale field diagnostics:

- all time-consuming sample preparation steps have been eliminated (e.g. purification of DNA, preparation of clarified plant saps). A small piece of tissue is sufficient for analysis, and an entire field can be sampled in a short time.

- the test is independent of laboratory facilities, as it can be performed at ambient temperature and does not rely on radioactive materials.
- the complete procedure from sampling to visualization and scoring, can be performed within one day. Sensitivity of detection is comparable to that provided by autoradiography.
- blots of squashed samples (plants and insects) can be stored for many months at ambient temperature before testing. They can be mailed from one country to another for sampling and analysis (Navot et al. 1989).
- the method is adequate for large-scale epidemiological studies.

It should be feasible to predict TYLCV epidemics by sampling whiteflies or plants at regular intervals at the beginning of the tomato growing season, and to test them for the presence of the virus. An increase in the number of virus-carrying insects or plants may be taken as the signal for starting or intensifying the spraying of insecticides.

The test procedures fit the prerequisites of simplicity and rapidity which a kit for TYLCV diagnosis would need. Commercial development of a TYLCV detection kit will depend on the willingness of firms to carry on this work.

Acknowledgments

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Symposium Discussion

I.D. Erinle: How do you control the TYLCV vector in the field?
H. Czosnek: The insecticide Senprotathrin ('Smash') is effective against whiteflies when sprayed two to four times a week during the whitefly population peak.

J. Hallard: 1. Your experiments have shown that the TYLCV was identified on seeds by using the squash technique. Do you have any evidence that the TYLCV could be seedborne and seedtransmitted? 2. Do you know of any biological control measure against *Bemisia tabaci*, like the one against *Trialeurodes* sp., the greenhouse whitefly in Western Europe?
H. Czosnek: 1. TYLCV can be detected in fresh seeds. We do not know whether the virus is in the seed itself or in the tissues surrounding the seed. It is generally admitted that TYLCV is not seed-transmitted, but this may be due to rapid decay of the virus during storage. We have not tried to grow plants from fresh seeds of TYLCV infected tomato. 2. No successful biological control against *B. tabaci* has been reported.

W. Loh: Please give some more details on the 'squash-blotting'. Can squash blots be reprobed with other probes?
H. Czosnek: Tissues are squashed on a dry nylon membrane (Hybond-N, Amersham International). This is sufficient to make nucleic acids available to hybridization because TYLCV is a single-stranded DNA geminivirus (the DNA is probably denuded during the squash). The material is permanently fixed on the membrane and can be kept for months until the test is performed.

B. Rowell: Do you expect that your DNA probe for TYLCV will also be able to detect the tomato leaf curl virus infecting tomato in South and Southeast Asia?
H. Czosnek: A full length clone of TYLCV reacts with squashes made from leaf curl infected tomato from Taiwan and Thailand. However hybridization signals are usually weaker than those obtained from TYLCV infected tomato plants from Israel which may indicate that these viruses are closely related but not entirely identical.

T.A. Thomas: Have you got any resistant or tolerant germplasm of tomato for leaf curl virus?
H. Czosnek: Contact Dr. Shlomo Cohen, Department of Virology, Agricultural Research Organization, Bet-Dagan, Israel for more information.

-267

Integrated Pest Management

268

30

Biological, Chemical and Physiological Approaches to Control Gray Mold Disease on Tomato and Pepper

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Abstract

Gray mold disease of tomato or pepper serves as a model demonstrating various possibilities of controlling foliar diseases. Because of resistance to common fungicides in the population of *Botrytis cinerea*, alternative control methods need to be developed. Application of antagonistic *Trichoderma* spp. to leaves of pepper or tomato resulted in decrease of disease severity. Ethylene increased susceptibility of the host tissue and led to development of necrosis. Inhibitors of ethylene production or action reduced disease incidence significantly. Film-forming polymers applied on the leaves of tomato and pepper resulted in a significant decrease in infection, necrosis and disease severity. The integration of film-forming materials with protectant fungicides is suggested as a way of improving control of this fungus.

Introduction

Botrytis cinerea Pers. is an extremely widespread fungus, with a wide host range, able to infect many different tissues (Palti, 1981). It is the cause of blossom and petal blight and gray mold of fleshy organs (fruits) before and after harvest. Ghost spot is a disease which is known in tomato fruits and which is caused by latent infections with the fungus which occur during flowering (Verhoeff, 1970; 1974). The pathogen develops mostly on soft, immature, fleshy, senescent or necrotic tissues (Baker, 1949). To become aggressively parasitic, *B. cinerea* requires high humidity or free moisture and temperatures near 18°C (Baker, 1949). In Israel, it is a common pathogen of tomato and pepper as well as other crops. During winter, when plants are grown under plastic and high humidity prevails during most hours of the day, the fungus is particularly serious.

Gray mold cannot be effectively controlled by common fungicides because of resistance of the pathogen to these fungicides (Katan, 1982). Therefore new fungicides have to be constantly sought and alternative control methods need to be developed.

It is known that epicuticular waxes can protect plant parts from pathogens. Although Martin (1964) concluded that epicuticular waxes were not important in resistance to plant pathogens, most reports indicate that the outer layer of the host can affect its susceptibility to disease (Blakeman and Sztejnberg, 1973; Koluttukudy, 1985; Skoropad and Tewari, 1977). The use of film-forming polymers in order to establish a physical, chemical, or electrostatic barrier to penetration by pathogenic fungi is a promising treatment against disease. Several film-forming antitranspirants have been used successfully to control plant diseases, including *B. cinerea* of tomatoes (Chastanger and Ogawa, 1979), apple scab (Shaffer and White, 1985), and septoria leaf blotch of wheat (Ziv, 1983; Ziv and Hagiladi, 1984; Gale and Poljakoff-Mayber, 1962).

Biological control is a measure for potential use in combination with the conventional chemical control methods (Blakeman and Fokkema, 1982). The surface of aerial plant parts provides a habitat for epiphytic saprophytic microorganisms, many of which are capable of influencing the growth of pathogens and of reducing the incidence of foliar diseases (Blakeman and Fokkema,

1982). Biological control of foliar diseases, including *B. cinerea*, has already been reported by several workers (Windels and Lindow, 1985). *Trichoderma* spp. is a popular antagonist which has been found to be a successful biocontrol agent of *B. cinerea* (Dubos and Bulit, 1981; Tronsmo and Raa, 1977; Wood, 1950).

During normal plant growth the amount of ethylene produced is usually relatively low, but slight peaks in production occur, mainly at germination, and during leaf abscission when the plant is mature (Lieberman, 1979). Diseases cause an increase in ethylene production (Bradford and Yang, 1980; Goodman et al. 1986). Ethylene in the storage atmosphere was found to stimulate decay (El-Kazzaz et al. 1983). Maintaining ethylene concentration in the storage atmosphere at $<0.1\ \mu l\ l^{-1}$ increased the susceptibility of tomatoes to infection by *B. cinerea*, whereas higher concentrations resulted in less infection (Geeson et al. 1986).

The possibility of reducing infection of *B. cinerea* with a new fungicide, with inhibitors of ethylene production or activity, with biological control agents such as *Trichoderma* spp., and with the use of film-forming polymers is investigated.

Materials and Methods

Botrytis cinerea Pers. was isolated from naturally infected tomato (*Lycopersicon esculentum* Mill.) plants and maintained on potato dextrose agar (PDA) (Difco). Test plants were *Capsicum annuum* L. cv. Maor and *Lycopersicon esculentum* cv. VF 198. Plants or detached leaves were inoculated with *B. cinerea* in one of the following ways:

1. detached leaves: a disk from the growing margin of a PDA culture of the fungus was placed in the middle of the leaf and pressed onto it. The area of necrotic tissue of the leaf around the mycelium was measured.
2. whole plants: a conidial suspension (10^5 conidia ml) from two-week-old cultures, supplemented with 0.1 M glucose, was sprayed on the canopy. Disease severity was recorded according to a scale of 0-5, where 0 = healthy leaf (or plant) and 5 = completely destroyed leaf (or plant).

Treatments

Humidity. Inoculated mature leaves were either enclosed in plastic bags or placed in a dew chamber at 98% relative humidity and incubated in an illuminated growth chamber at 20° ± 2 C. For low relative humidity (70%) conditions, plants were placed directly in the growth chamber without plastic cover or dew chamber.

Film-forming polymers. The following substances were sprayed on two-month-old-plants, prior to inoculation of all leaves with mycelial plugs of *B. cinerea*, at a concentration of 3% with an atomizer until runoff: Wilt Pruf (Wilt Pruf Products, Inc., Greenwich, CT 06830-0280, USA); Vapor Gard (Miller Chemicals Corporation and Fertilizers, Box 333, Hanover, PA 17331, USA); Colfix-Fungicide sticker, polyvinyl emulsion (Javin Yaffe, Tel Aviv, Israel); Safe Pack (Safe Pack Products, Penn Walt Corporation, Philadelphia, PA, USA); Folicote (Crystal Soap and Chemical Co., Inc., Lansdale, PA, USA) and Biofilm (Colloidal Products, USA).

Fungicides. The factory mixed fungicide, isopropyl N (2,4-diethoxyphenyl) carbamate (NPC = diethofencarb) and carbendazim (MBC) 50 wp (Sumitomo Chemical Co., Osaka, Japan), was sprayed on two-month-old-plants at a concentration of 0.2% until runoff prior to inoculation of all leaves with mycelial plugs of *B. cinerea*.

Fungal antagonists. Fourteen *Trichoderma* isolates were collected from diseased plants and maintained on PDA. Conidial suspensions at concentrations of 10^7 ml were sprayed on the

mature, detached (12 per wolate) leaves before infection with a conidial suspension of *B. cinerea*.

Ethylene inhibitors. L-methionine (Sigma Chemical Co., St. Louis Mo., USA) at 5×10^{-3} and 5×10^{-2} M, aminooxyacetic acid (AOA, Sigma) at 5×10^{-3} M, and silver thiosulfate (STS, prepared from silver nitrate and sodium thiosulfate, 1:8 mol/mol) at 5 x 10 -3 M, were sprayed on autoclaved leaves or plants immediately before their inoculation with conidia of *B. cinerea*. Autoclaved detached leaves were placed in 32 ml bottles (six leaves per bottle) plugged with cotton wool stoppers. On the eighth day the cotton wool was replaced with a rubber stopper and ethylene was measured a day later with a gas chromatograph.

All experiments were conducted two or three times. A completely randomized design was used. Each treatment with detached leaves consisted of 12 replicates whereas 5 replicates were used for two-month old plants. Plants were grown in a growth chamber, before they were subjected to the different treatments.

Results and Discussion

At one week after infection by *B. cinerea* there were no visible signs of disease on the tomato plants which had been grown under 70% RH before infection, whereas those grown under 98% RH were diseased (index 0.57). It seems that predisposition of host plants to *B. cinerea* depends upon the growth conditions. High humidity during the growth season, which is the situation which prevails when plants are grown under plastic in the Israeli winter, increases the susceptibility of the host to the disease. This may be due to immobility of calcium ions to the attacked tissue. Growth of crops under high humidity conditions causes a drastic inhibition of calcium translocation into the canopy (Armstrong and Kirkby, 1972; Clarkson, 1984). Calcium deficiency may render the plant more susceptible to infection by pathogens (Stall et al. 1965). From our research with other crops (Elad and Volpin, 1988), application of Ca^{++} at 2-3 mM ($CaNO_3$) can reduce gray mold damage. Similar results were reported by Seall et al. 1965 investigating the effect of calcium-phosphorous balance on susceptibility of tomato to gray mold.

The fungicide mixture NPC + MBC sprayed at a rate of 0.1% until runoff on leaves of tomato and pepper significantly reduced necrosis incited by the mycelium plugs by 67% (Table 1). Since *B. cinerea* has already developed resistance to benzimidazoles and dicarboximides, it is likely that resistance to the new fungicide mixture will also develop in the future in the fungus population (Elad et al. 1988). Alternative control methods therefore have to be developed, in order to reduce the danger of the appearance of resistant strains.

Several film-forming polymers, with the exception of Folicote, a natural wax formulation, showed potential for control of *B. cinerea* on pepper and tomato (Table 2). However, none of the polymers was more efficient than the fungicide NPC + MBC (Table 2). Polymers may provide better protection when combined with protectant fungicides.

Table 1. Control of gray mold[z] with isopropyl N-(3,4-diethoxyphenyl) carbamate (NPC) + carbendazim (MBC)

Treatment	Disease index[y]			
	Tomato		Pepper	
	10[x]	16	10	16
No Fungicide	1.00 a[w]	2.50 a	2.50 a	3.00 a
NPC + MBC (0.1%)	0.00 b	0.25 b	0.25 b	0.25 b

[z]Plants were inoculated with suspensions of 10^5 conidia/ml, supplemented with 0.1 M glucose. [y]Evaluated on a scale of 0-5, where 0 = healthy plants and 5 = completely destroyed plants. [x]Days after inoculation. [w]Figures followed by different letters within columns are significantly different (P = 0.05) according to Duncan's multiple range test.

Five isolates of *Trichoderma* spp. isolates (502, y, 180H, 28, 309) were capable of reducing the development of necrosis on detached leaves (Table 3). However, a difference in activity on the two hosts was observed, possibly because of the effect on the fungal antagonist by the different natural microflora and nutrients present on tomato and pepper leaf surfaces.

Silver thiosulfate, STS an inhibitor of ethylene activity, significantly decreased gray mold on tomato and pepper by 56% and 63%, respectively.

Aminooxyacetic acid (AOA), an inhibitor of ethylene production reduced disease severity by 89% and 45%, on tomato and pepper, respectively (Table 4). However when methionine, a precursor of ethylene, was sprayed on pepper leaves at a concentration of 5×10^{-2} M, the necrotic area caused by mycelium infection increased by 137% (Figure 1).

Table 2. The effect of film forming polymers on gray mold[z] of tomato and pepper.

Treatment[y]	Infected leaf area (cm^2)					
	Tomato			Pepper		
	4[x]	6	8	4	6	8
Untreated control	1.8 a[w]	3.3 a	3.9 a	1.0 bc	3.5 a	5.4 a
Folicote	2.0 a	2.5 ab	2.9 ab	2.0 a	2.4 ab	2.8 b
Safe Pack	0.1 bc	0.7 cd	1.0 c	0.4 cd	0.8 cd	0.8 de
Wilt Pruf	0.7 b	1.6 bc	1.6 cd	0.8 bcd	1.9 bc	2.4 b
Vapor Gard	0.6 bc	0.8 cd	1.0 c	1.7 bc	2.0 bc	–
Colfix	0.5 bc	1.5 bc	1.8 cd	0.5 cd	0.8 cd	1.1 cde
Biofilm	0.3 bc	0.5 cd	0.8 c	0.3 cd	0.9 cd	1.4 e
NPC + MBC (fungicide)	0	0 c	0 d	0 c	0 d	0 d

[z]Leaves were inoculated with mycelial plugs of *Botrytis cinerea* after application of the polymers or the fungicide. [y]Polymers were applied at a concentration of 3%. The fungicide was applied at a concentration of 0.1% by spray until runoff. [w]Figures followed by different letters within columns are significantly different (P = 0.05) according to Duncan's multiple range test. [x]Days after inoculation.

Table 3. The effect of conidial suspensions of *Trichoderma* spp. on the development of gray mold[z] on detached tomato and pepper leaves.

Host	Control	*Trichoderma* isolate													
		502	192	35	Y	180H	80	28	132	33	309	94H	315	164	RCT
Tomato	30	20*	30	30	30	30	30	20*	30	28	18*	30	40	30	23
Pepper	50	23	40	40	20*	20*	37	33	37	43	28	25	33	40	40

[z]Presented as necrotic area (cm^2), 6 days after inoculation with mycelium plugs of *Botrytis cinerea*. *Significant reduction of disease as compared with non-treated control (P = 0.05).

Table 4. The effect of AOA and STS on severity of gray mold disease.

Treatment	Disease severity[z]			
	Tomato		Pepper	
	10[y]	16	10	16
AOA	1.25 b[x]	0.25 c	2.0 a	2.2 a
STS	0.50 ab	1.00 b	0.5 b	1.5 b
Control	1.00 a	2.25 a	2.5 a	4.0 a

[z]Estimated on a scale of 0-5, where 0 = healthy plants and 5 = completely destroyed plants. [y]Plants were infected with conidial suspensions of *Botrytis cinerea*, supplemented with glucose. [x]Figures followed by different letters within columns are significantly different (P = 0.05) according to Duncan's multiple range test.

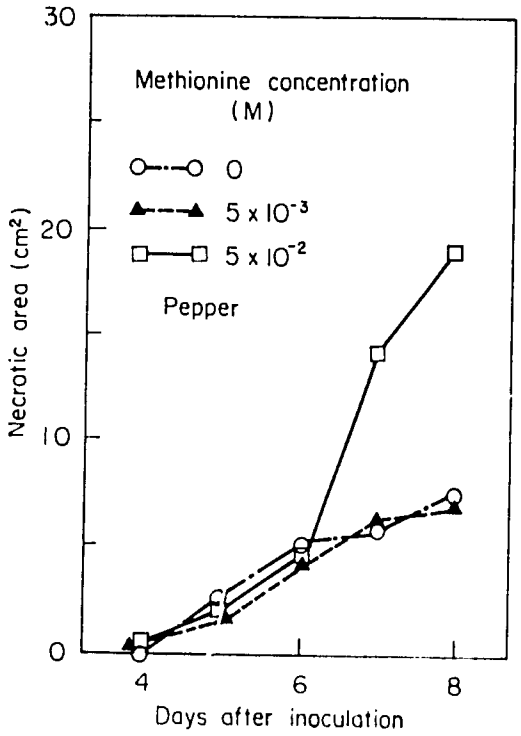

Figure 1.
The effect of methionine spray on leaves of pepper at concentrations of 0 (○), 5 × 10^{-3} M (△) and 5 × 10^{-2} M (□) on the development of necrosis caused by mycelium infection with *Botrytis cinerea*.

Ethylene is the first known endogenous plant growth regulator. Studies with a number of plant species suggest that increased ethylene synthesis and tissue senescence are reactions to both biotic and abiotic stresses (Lieberman, 1979). Ethylene production is increased in pepper infected by *Xanthomonas vesicatoria* (Ben David et al. 1986). Pepper is very sensitive to changes in ethylene and it responds to stress by leaf defoliation, probably due to an increase in ethylene production. Since ethylene production is induced by infection by *B. cinerea* (Elad, 1988), and ethylene in turn induces susceptibility of the host tissue to degradation by the pathogen, it is likely that inhibitors of ethylene production or activity will reduce gray mold severity. Indeed, STS and AOA reduced disease level in both tomato and pepper plants.

Further studies are needed in order to develop a practically feasible and effective integrated control method for gray mold, using a proper combination of biological, chemical and physiological agents.

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Symposium Discussion

J.C. Cheng: Can you describe the technology in the application of *Trichoderma* spp. in the field, the formula, package, and quantity applied? Is this biological agent available commercially? Is this biological control widely accepted in your country?

Y. Elad: A suspension of *Trichoderma* spp. at concentration of 10^8 conidia/ml is sprayed at a volume of 100 liters per 1000 m^3. The *Trichoderma* preparation is produced by a commercial company in Israel. There is a trend towards the use of biological products with pathogens for which chemical control is not possible or not effective. The use of *Trichoderma* preparations for the control of soilborne or foliar pathogens is becoming increasingly popular.

-275

31

Practical Application of Pest Management on Tomatoes in Florida

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Abstract

An integrated pest management program has been developed and implemented on Florida fresh-market tomatoes. The joint extension-research program focuses on insects but includes diseases, nematodes and weeds. The program is based upon twice weekly sampling of fields to estimate pest density and severity. Pesticidal sprays are recommended if action thresholds are equalled or exceeded. Plant parts for sampling are specified and vary depending upon the pest and crop phenology. Insecticides are selected for recommendations based upon their efficacy against the target pest(s) and their toxicity to biological control agents, particularly parasites of *Liriomyza* spp. leafminers. Since the initiation of the program in 1976, the crop area scouted by professional scouts has increased from none to an estimated 40% of the hectarage grown, although not all is scouted using the techniques and thresholds developed in this program. Most crop area is scouted by private pest management companies although some larger growers employ their own scouts. Of the growers, utilizing professional scouts, 62.5% estimated monetary savings in excess of scouting costs of about US$50 per hectare. Despite these increased returns, most growers ranked early detection and identification of pests and improved levels of pest control as their highest priorities in using scouts.

Introduction

During the winter vegetable season of 1976-77, an outbreak of *Liriomyza* spp. leafminers across the state's tomato growing areas threatened Florida's fresh market tomato crop. An estimated 90% defoliation occurred in the absence of leafminer control (Schuster, 1978). Subsequent investigations indicated that all insecticides registered for leafminer control on tomato in 1977 were ineffective (Schuster et al. 1982). This failure of control, combined with the unavailability of new insecticides for leafminer control, increased interest in an integrated pest management (IPM) program that had been initiated on tomatoes in Dade County in 1976-77 by Pohronezny and Waddill (1978). The success of that program combined with the continued interest of producers in IPM prompted expansion of the program to other counties in the autumn of 1978. Although the joint extension-research program focuses on insects, it also includes diseases, nematodes and weeds.

Leafminers are considered to be secondary pests; that is, they are normally kept under control by hymenopterous parasites but can be elevated to pest status when the parasites are killed by insecticides applied for control of primary pests. Thus, the goal of the IPM program is to integrate biological and chemical control through the application of selective insecticides or insecticide combinations based upon pest and, where possible, parasite densities.

Materials and Methods

Scouting Procedures

Background information is collected for each field. This information covers the number of years in production, previous crop(s), slope, irrigation method, soil fumigation history, fertilizer type and amount, row and plant spacing, and cultivar(s). The perimeter of each field is measured and the field partitioned into 1 ha grids. Six contiguous plants are sampled twice weekly in each grid. The sample site within each grid is changed every sampling date and is chosen without bias. The sampling procedures are similar to those outlined by Pohronezny et al. (1980) and Schuster et al. (1980) although changes have been made as research results have warranted. The number and identity of flying insects are observed as the scout approaches the selected sample site. The densities of leafminer larvae (living and dead), aphids and insect eggs are estimated on the whole plant (up to two true leaves present), the terminal three leaflets (trifoliolate) of the third fully expanded leaf from the top of the main stem (three true leaves to bloom) or the terminal trifoliate of the seventh leaf from the top of any branch (postbloom). Whole plants are examined for true bugs and lepidopterous larvae with the exception of the tomato pinworm (*Keiferia lycopersicella* Walsingham). Searching for lepidopterous larvae is focused in the vicinity of foliar feeding. Tomato pinworm densities are assessed by counting the numbers of larvae on the foliage of whole plants (0 to 7 true leaves present) or on one leaf selected from the lower canopy of each plant (Pena, 1983). After fruit-set, 10 fruits are examined from each sampling site for damage by lepidopterous larvae, stinkbugs and disease. Thrips densities are assessed by gently exhaling on each of 10 flowers selected from the six-plant sampling sites and counting the number of thrips thus disturbed.

The severity of foliar diseases is estimated using the Horsfall-Barratt rating system (Horsfall and Barratt, 1945). The extent to which plants are affected by soil and vascular pathogens (wilt), viruses, physiological disorders, nutrient deficiencies, etc. is reported as a percentage of plants affected. Where the condition of the plants warrants, soil samples are collected for the determination of total soluble salts and pH. Subjective observations of the extent of "weediness" are made when warranted. Physical conditions, including temperature, wind, relative humidity, rainfall, etc., are also noted.

Scouting efficiency for sampling leafminer larvae has been increased through the development of a visual rating system for total leafminers (Table 1) (Schuster and Beck, 1983) and a presence-absence system for reporting living and dead larvae (Table 2) (Schuster, D.J. and Beck, H.W. 1984, unpublished data).

To assess whether leafminer larvae are alive or dead, the leaflet is excised, held up to the sun and the backlit larvae are observed with a hand lens for coloration and mouth hook movement. Living larvae are generally light yellow. The mouth hooks of living larvae are generally moving in a back and forth motion; however, this feeding activity may cease when larvae are disturbed though it usually resumes after a few moments. Living larvae that are about to molt also cease feeding activity. Nevertheless, mouth hook movement has generally been a good indicator of

Table 1. Visual rating system for *Liriomyza* sp. damage to tomato foliage.

Rating	Estimated no. ofleafminers/3 terminal leaflets
1	0
2	1
3	2
4	3
5	6
6	12
7	18
8	24

Source: Schuster and Beck, 1983.

Table 2. Relationship between the proportion of infested tomato leaf samples[z] and the number of leafminer larvae present.

Ave. proportion	Mean density	Density range
0.15	0.2	0.10-0.30
0.25	0.4	0.25-0.55
0.35	0.6	0.40-0.80
0.40	0.7	0.45-0.95
0.45	0.8	0.55-1.00
0.50	1.0	0.60-1.20
0.55	1.2	0.60-1.60
0.60	1.4	0.80-2.00
0.65	1.6	0.80-2.20

[z]Each sample consisted of the terminal 3 leaflets of the 7th leaf from the top of a main stem, lateral or sub-lateral of a tomato plant.

larvae that ultimately survive to pupation under laboratory conditions (Price, J.F. Asst. Prof., Univ. Florida, personal communication). Using these criteria may overestimate the number of living larvae by underestimating the number of larvae parasitized by larval-pupal parasites. These parasites oviposit in the leafminer larvae but do not kill the larvae until after it has pupated. The parasite larvae then pupates within the leafminer puparium. Darkened larvae with no visible movement of mouth hooks are considered to be dead. Dead larvae are examined for evidence of parasitization by larval parasites. These parasites paralyze the leafminer larvae and oviposit either inside (endoparasites) or adjacent to (exoparasites) the leafminer larvae. Parasite development, including pupation, is completed inside the leaflet. The presence of larval parasites cannot be determined with a hand lens until larvae become apparent, about three to four days following oviposition. A larval parasite can then be categorized as endoparasitic or exoparasitic based upon location of the parasite larva or pupa. If there is no evidence of parasitization, dead larvae are further categorized as having been killed by either insecticides or adult parasite females in the absence of oviposition (Patel. 1987). This judgment is dependent upon the previous insecticide and parasitism history of the tomato field. Since leafminer larvae recently parasitized by larval parasites cannot be detected readily for several days, their numbers would be included in one of the two above categories and would thus be underestimated.

The grower is provided with a summary of the scouting results. Since spraying pesticides on demand has not been effective for management of diseases such as late blight (Jones. 1978) growers are encouraged to apply fungicides preventively; however, scouting information may be used to advise changes in spray programs including alternative pesticides or spray schedules. Unlike diseases, insects lend themselves well to spraying on demand. Insecticide recommendations are made when established action thresholds are equalled or exceeded and, in the case of leafminers, when parasite activity is minimal. Insecticides or insecticide combinations are selected for recommendations based upon their toxicity to the target pest and their toxicity to parasites, primarily those attacking leafminers.

Action Thresholds

The thresholds utilized are largely those reported by Pohronezny and Waddill (1978), Schuster et al. (1980) and Pohronezny et al. (1986) and are summarized in Table 3. Changes were made in thresholds as data and experience warranted. For instance, the threshold for leafminer larvae was initially one per plant or trifoliolate leaf; however, this was reduced to 0.7 larva per plant as insecticide efficacy declined. After fruit-set, one lepidoptera egg was made equivalent to one larva since some lepidopterous larvae, particularly *Heliothis* spp., feed preferentially on fruit (Snodderly and Lambdin. 1982). The threshold for tomato pinworm larvae was initially one larva per top three leaves (Wolfenbarger et al. 1975) but was later expanded to one larva per

top four leaves in order to sample lower on the plant. Pena (1983) found that the lower canopy rather than the top three leaves was the preferred site for sampling larvae. Consequently, the sampling site was changed and the threshold of 0.7 larva per lower leaf (Pena. 1975) was adopted.

Insecticide Recommendations

Insecticides commonly recommended and utilized on fresh market tomatoes in Florida are listed in Table 4. There are three leafminer parasite species which predominate in Florida tomatoes

Table 3. Action thresholds utilized for management of insect pests on Florida fresh-market tomatoes.

Pest	Crop phenology	Threshold
Armyworms, fruitworms	Pre-bloom	1 larva/6 plants
	Post-bloom	1 egg or larva/field
Tomato pinworms	0-7 true leaves	0.7 larva/plant
	>7 true leaves	0.7 larva/lower leaf
Leafminers	0-2 true leaves	0.7 larva/plant
	>2 true leaves	0.7 larva/3 terminal leaflets
Thrips	Post-bloom	>5/flower
Stinkbugs	Post-bloom	Presence
Aphids	Season long	>3-4/plant
Loopers	Season long	1 larva/6 plants

Source: Pohronezny and Waddill 1978; Schuster et al 1980; Pohronezny et al 1986

Table 4. Insecticides commonly utilized in Florida fresh-market tomato production.

Insecticide common name	Target pests	Toxicity to leafminer parasites[z]	
		D. intermedius	*C. punctiventris*
Methomyl	aphids armyworms loopers stinkbugs tomato fruitworms tomato pinworms	+ + +	+ + +
Endosulfan	aphids armyworms stinkbugs tomato pinworms	+ +	+ + +
Bacillus thuringiensis	armyworms loopers	+	+
Permethrin	armyworms loopers stinkbugs tomato fruitworms tomato pinworms	+ + +	+ + +
Fenvalerate	armyworms loopers stinkbugs tomato fruitworms tomato pinworms	+ +	+ +
Methamidophos	aphids armyworms (southern) leafminers stinkbugs thrips	+ + + (adults) + + (larvae, pupae)	+ + + (adults) + + (larvae, pupae)

Source: Schuster, D J. 1987, unpublished data. [z]Relative toxicity ranges from low (+) to high (+ + +) for adults, larvae and pupae. Where no lifestage is specified, all are similarly affected.

(Schuster and Price. 1985). Two of these, *Diglyphus intermedius* (Girault) and *Chrysonotomyia punctiventris* (Crawford), are larval parasites with the former being an exoparasite and the latter being an endoparasite. The third major parasite species is *Opius dissitus* Muesebeck, which is a larval-pupal parasite. The results of laboratory evaluations of the toxicities of the insecticides to the adults, larvae and pupae of the above larval parasites is included in Table 4. Where labels and grower acceptance permit, insecticides are selected for recommendations based upon the densities of the target pest(s) and the lifestage(s) of the larval parasite(s) present.

Prior to the implementation of the present program, methomyl was the insecticide of choice for control of many of the primary pests attacking tomatoes in Florida. The negative impact of methomyl on leafminer parasites with resulting increases in leafminer populations was first documented by Oatman and Kennedy in 1976 and has since been confirmed by several researchers including Johnson et al. (1980) and Trumble and Toscano (1983). Applying methomyl only on demand might be expected to reduce this negative impact; however, reduced numbers of emerging leafminer parasites have been observed even after a single application of methomyl (Schuster and Price. 1985). Since endosulfan has been shown to be less detrimental to leafminer parasites in field tests (Poe et al. 1978; Schuster and Price. 1985), it is recommended as an alternative for control of armyworm larvae, primarily the southern armyworm (*Spodoptera eridania* Cramer), and stinkbugs. The combination of endosulfan with *Bacillus thuringiensis* var. *kurstaki* Berliner has been shown to be more effective in reducing the number of fruit damaged by tomato pinworm larvae than endosulfan alone (Schuster et al. 1981). *Bacillus thuringiensis* is recommended as an alternative to methomyl, particularly to growers wishing to apply an insecticide for preventive control of lepidopterous larvae after fruit-set.

The pyrethroids permethrin and fenvalerate were initially recommended for control of leafminers in addition to those pests listed in Table 3. However, these insecticides have not demonstrated efficacy toward leafminers in small plot research and are not currently recommended for leafminer control. Fenvalerate (formulated as Pydrin^R) is recommended over permethrin due to its lower toxicity to parasites (Table 3; Waddill. 1978). However, due to the tendency for fenvalerate to cause chlorotic spotting of young foliage, particularly at higher rates, the insecticide has not been widely accepted by growers. A purified isomer of fenvalerate (esfenvalerate, Asana^R) is not phytotoxic to tomato and may be more acceptable to growers.

Methamidophos is the only insecticide registered in Florida currently being recommended for leafminer control in the program. When applied weekly, this insecticide reduced leafminer parasitization (Poe et al. 1978); however, when applied once, methamidophos resulted in reductions in leafminer adults emerging from treated foliage without reductions in emergent parasite adults (Schuster et al. 1979). Unfortunately, methamidophos has not provided leafminer control in recent small plot research and a substitute will be required. Two new insecticides, cyromazine and abamectin, have been proven effective against leafminers in field and laboratory studies on tomato (Schuster and Everett. 1983). The former has demonstrated low toxicity and the latter moderate toxicity to all lifestages of both *D. intermedius* and *C. punctiventris* (Schuster, D.J. 1987. unpublished data). Thus, when these insecticides become available for commercial use, they should fit well into the program.

Results and Discussion

The success of the program with regard to the conservation of parasites of leafminers was determined during the 1977-78 season in Dade County (Pohronezny et al. 1986). Foliar samples containing leafminer larvae were collected in tomato fields under IPM and conventional management. The samples were held in cartons for adult leafminer and leafminer parasite emergence. In those fields receiving 10 or more applications of broad spectrum insecticides, leafminer parasitization ranged from 3 to 31% and averaged 16%. This is contrasted to the fields receiving less than 10 applications where parasitization ranged from 24 to 53% and averaged 44%. The control of lepidopterous larvae was equivalent under both management programs.

Thus, the IPM program was successful in maintaining control of primary pests while conserving biological control of the secondary pests, leafminers, by reducing the use of broad spectrum insecticides.

The program has also been evaluated under different cultural situations. The procedures and thresholds were found applicable under different fertilization levels (Csizinszky and Schuster. 1982) and different row spacings (Stanley et al. 1988).

A survey of tomato growers in peninsular Florida was sponsored by the University of Florida and the USDA Cooperative Extension Service. It was designed by Drs. V.H. Waddill, R.T. McSorley, K. Pohronezny, J.F. Price, D.J. Schuster and W.R. Summerhill and was conducted by county extension specialists. The survey covered about 70% of the planted tomato hectarage in four selected counties.

The survey was completed in 1986 and has indicated that the amount of crop area scouted by professional scouts has increased from essentially none to an estimated 40% of the hectares produced in the four county area. Professional scouts are defined as those employed by firms incorporated specifically to provide scouting services, or those employed directly on grower payrolls and whose primary job is scouting. Not all scouted areas are scouted by firms using techniques and thresholds developed in this program. Nevertheless, the majority of growers utilizing professional scouts use scouting data in at least 67% of their insect management decisions. Some 85% of these growers considered beneficial insects when choosing an insecticide and 53% used information on parasite abundance in making application decisions. Although 62.5% of growers using professional scouts reported an estimated net monetary saving of US$50 per hectare, most ranked early and accurate detection and identification of pests and improved levels of pest control ahead of increased net returns as the top benefits of IPM.

Thus, the program has been successful in promoting the philosophy and practice of pest management on tomatoes in Florida. Continued refinements in the present program and the incorporation of new control technology as it becomes available will ensure the continued growth and success of IPM in Florida tomatoes.

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Symposium Discussion

P. Rosset: (1) Have you ever found that weed control makes armyworm problems worse? (2) What kind of data or experiments were used to estimate action thresholds?

D.J. Schuster: (1) *Spodoptera exigua* larvae infesting *Amaranthus* have been observed to move to tomato following weed control. Where weeds are likely to compete with tomato for nutrients, sunlight, etc., management should be initiated before they can serve as reservoirs of pests. Where weeds are not likely to compete with tomato, or serve as refugia for pests, they may be beneficial as trap hosts or as sources of beneficial organisms. (2) Some action thresholds were derived wholly or partially from the literature (for example that of the tomato pinworm) while others are based more on what we don't know than what we know and are, therefore very conservative (for example that of pentatomil and culture bugs).

N.S. Talekar: (1) How do you test insecticides against leafminer larvae? (2) Are leafminer-parasites egg, larval or pupal parasites?

D.J. Schuster: (1) To avoid confusion that can sometimes occur in field trials, we use laboratory bioassays to supplement field trials. Tomato leaflets containing either leafminer or leafminer parasite larvae are treated with insecticides usually by leafdip, and subsequent mortality and/or other effects noted. (2) There are two groups of hymenopterous parasites that attack *Liriomyza*

leafminer; larval and larval-pupal. Larva parasites attack and kill leafminer larvae at the time of oviposition. Parasite larval and pupal development is completed within the leafminer. Larval-pupal parasites do not kill leafminer larvae at the time of oviposition. Parasite larvae begin their development within leafminer larvae but complete their larval and pupal development after leafminer larvae exit the leaf, form the puporia and pupate.

- 283 -

32

Tomato Pest Management in the Midwestern United States

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Abstract

The cost of tomato production has been lowered without an increase in insect damage through programs instituted in Indiana and surrounding states. Emphasis on scouting for insect presence and thereafter judicious insecticide use, in terms of both choice and timing, has reduced the number of insecticide applications per growing season from an average of 9.5 to ca. 4.5. Key pests involved are Colorado potato beetle *Leptinotarsa decemlineata* (Say), variegated cutworm *Peridroma saucia* (Hübner), tomato fruitworm *Heliothis zea* (Boddie), and cabbage looper *Trichoplusia ni* (Hübner). Under conventional programs, growers often experience secondary insect problems with green peach aphid and two-spotted spider mite, induced by pesticide applications for primary pests. Growers utilizing modified programs seldom have problems with these pests. Program specifics include heat unit scouting for Colorado potato beetle, scouting for variegated cutworm with an emphasis on treatment of early instars, and trapping of moths and scouting for larvae of tomato fruitworm with emphasis on maturity of nearby maize fields. It is suggested that less emphasis be placed on the routine use of the insecticides carbaryl and methomyl, and more on the early use of *Bacillus thuringiensis* and methamidophos. Estimates on insecticide dollars saved range from $13 to $25 per hectare. The primary obstacles to greater implementation are grower uncertainty and a lack of trained scouts and effective pest management companies.

Introduction

For many decades, several states in the midwestern United States have been growing and processing tomatoes. Indiana, Ohio, and Michigan have been the top producers among these midwestern states. In 1918, a maximum of 39,400 ha were planted in Indiana, dropping to a minimum of 2,300 ha in 1981. In 1986, 2,750 ha were planted: average field size was about 20 ha with an average yield of 48,200 kg/ha. Yields have also ranged widely. In 1987 average yield was 52,400 kg/ha. In 1923 the average yield was only 6,500 kg/ha. By way of comparison, in 1985 California produced 63,000 kg/ha on 88,000 ha. Ohio in 1986 grew 6,700 ha with average yields of 51,520 kg/ha.

Per capita consumption of processed tomato products, with the exception of tomato juice, continues to rise in the US. About 60% of the product processed in Indiana is wholepack and diced tomatoes, juice and juice products; the remainder is tomato sauce and paste, catsup, pizza sauce, and miscellaneous products. While the midwest share of US production is only about 15%, tomatoes continues to be an attractive alternative crop to maize, soybean, or other grains. Cost of production is approximately $650 per ha. Some 75% of the midwest acreage is machine harvested.

Principle foliage and fruit fungal diseases are early blight, caused by *Alternaria solani* (Ell. and Mart.) Jones and Grout, Septoria leafspot, caused by *Septoria lycopersici* Speg., and anthracnose, caused by *Colletotrichum* spp. Two bacterial diseases, bacterial spot and bacterial

speck, are frequent problems as well. Spraying to prevent these diseases is undertaken frequently, often weekly depending upon weather conditions, to prevent foliage loss and fruit infection. Spraying usually begins in mid June to early July with between 5 and 15 applications being made.

Current production practices for growing processing tomatoes show few significant relationships between weed management programs and insect or disease infestations. While weeds are a substantial problem if managed improperly, we largely rely on preplant herbicide programs which have little bearing on later arthropod or disease incidence. It is recommended that ground to be planted to tomato be plowed in autumn or spring.

In the last few years with the increasing popularity of double cropping, minimum-till or no-till grain crops and 'set-aside' acreage, increased damage from stinkbug (Hemiptera: Pentatomidae) in both tomato and maize has been observed, presumably because the pest can find shelter during inclement weather. Stinkbug has also been a problem in processing tomato in California (Hoffman et al. 1987).

Primary insect pests in the midwest are Colorado potato beetle (CPB) *Leptinotarsa decemlineata* (Say), variegated cutworm (VCW) *Peridroma saucia* (Hübner), tomato fruitworm (TFW) *Heliothis zea* (Boddie), and cabbage looper (CBL) *Trichoplusia ni* (Hübner). In addition on direct-seeded, as opposed to transplanted, tomatoes there are several flea beetles of the genus *Epitrix* which can cause severe damage to newly emerged plants. Also of concern at times, particularly when allowed to become numerous because of unwise insecticide practices, are green peach aphid *Myzus persicae* (Sulzer), vegetable leafminer *Liriomyza sativae* Blanchard, and twospotted spider mite *Tetranychus urticae* Koch.

Control of insects begins in direct-seeded fields shortly after plant emergence while plants are still in the cotyledon or one-leaf stage. On larger transplanted tomatoes, flea beetles are seldom numerous enough to cause problems.

CPB adults appear in late April to early May. After a preoviposition period of two to four weeks depending on temperature (May 1981), eggs appear, followed shortly by larvae. We have found that the 60 to 70 heat units (HU) (t = 11°C) for egg development (Walgenbach and Wyman, 1984) is sufficiently accurate to predict first generation larvae even though sampling for first stage larvae is nearly impossible and not cost effective. For the two years we collected data, the 370-377 HU generation time (Walgenbach and Wyman, 1984) sufficiently accurately predicted adult peak populations.

VCW occurs sporadically but often causes damage in midwest crops. The first adults appear in mid April to early May in fields and in pheromone traps, but are not attracted to light traps in this generation. Larval duration may be 50 to 60 days under these cool spring conditions. Eggs and adults appear at about 700 HU (t = 7°C) intervals thereafter (Simonet et al. 1981).

CBL is of little concern as a foliage feeder, however late in the season when populations are high pupation commonly occurs on fruit, creating a grading problem for processing plants.

TFW has two generations in the midwest. In Indiana the first migrating adults appear in late May to mid June depending on latitude, and the second in late July through mid August, just about the time fruit is being set and ripened. These second generation larvae pose a substantial threat to ripening fruit. In research plots up to 5% damaged fruit is sometimes seen; in growers' fields there is seldom more than 1% to 2% damage and usually substantially less. The stage of development of maize fields in the vicinity of tomato fields seems to influence greatly the amount of damage. When maize has matured early, silks are dry and unattractive, and greater potential for fruit damage in tomatoes occurs. If the maize is still green and attractive, however, it is a preferred host for oviposition and tomato damage is substantially less in such years.

Aphids and spider mites tend not to be a problem except when several early applications of insecticides are applied. While this is only supported by causal observation, a program in which four or possibly three applications of insecticides (in tomatoes, often carbaryl) are made before July seems to assure growers of green peach aphid and two-spotted spider mite problems later in the season. Early parathion applications also promote later green peach aphid problems. Also, early applications of methomyl seem to result in mid to late season leafminer (Agromyzidae).

Recommended Programs

Currently we recommend that tomatoes be planted in ground which has not grown tomatoes for two years previously, and that the ground be plowed in the autumn or early spring. We recommend that the field be at least 500 m and preferably 1000 m from any field which contained tomato or potato the previous year. We are confident that these restrictions have reduced CPB problems due to the inability of overwintering adults to travel long distances prior to feeding (Lashomb and Ng, 1984; Wright, 1984; Ferro, 1985).

Early season insect numbers are likely to be low, but we recommend fields be scouted soon after crop establishment, especially if the crop has been direct seeded. Flea beetle feeding can be severe on cotyledon and one- to two-leaf direct seeded plants, but overseeding and a great deal of within-row compensation for lost plants makes losses to flea beetle negligible if observed and treated early. Control with a single insecticide application (usually carbaryl) is commonly obtained, but, as mentioned earlier, is to be avoided if at all possible.

In June, in addition to routine field observations, growers are urged to scout fields at key target dates (TD) based on accumulated HU as measured at regional recording weather centers. The first of these is usually for VCW oviposition and larval appearance. Because of a difficulty in accurately timing the appearance of the first moths and eggs (mid-April), HU accumulations for timing the occurrence of the June moth flight and oviposition are not as useful as pheromone trapping of adults. Upon capture of moths in pheromone traps, however, scouting is recommended thereafter for presence of larvae.

Timeliness in locating larvae is important as we feel it is necessary to apply insecticides before larvae reach the fifth instar if adequate control is to be obtained. We have observed that VCW feeding in tomato and potato is much more difficult to control in late instars than when feeding in beans or alfalfa. This is also the case with VCW feeding in mint (Berry et al. 1980; Yu et al. 1979). Head capsule guides have been distributed for an accurate instar identification (Figure 1). Moreover, while it has been shown that ca. 95% of foliage consumption occurs from instar five to pupation (Berry and Shields, 1980; Buntin and Pedigo, 1985; Shields et al. 1985) foliage consumption to the point of reducing yields by leaf feeding caterpillars is seldom a problem due to tomato's compensatory growth (Aung and Kelly, 1966; Wilcox et al. 1966). For the next generation, however, which begins in August when fruit is maturing, care must be taken that fruit feeding does not occur. For that period we have been suggesting an action threshold of one to two fourth instars per foot of row. While carbaryl and methomyl are most likely to be used by growers, neither is a material of our choice because of the secondary pest induction likely from their use. If larvae are small (instars 1 through 3) *Bacillus thuringiensis* is preferred. If larvae are older or excessively numerous, methamidophos is recommended.

Because of the build up potential for CPB it is particularly important to obtain adequate control of overwintering adults and their larvae. We recommend treatment at a threshold of one overwintering adult per or two larvae per plant. Upon first generation emergence we recommend treatment when three summer adults per plant are found, or five larvae per plant. While we continue to obtain satisfactory control of this insect with carbaryl and there is little or no evidence of resistance, we prefer to see growers use methamidophos as it does not seem to contribute to later season aphid and mite problems and is extremely effective on all of the lepidopterous pests of tomato which may be present at this time. However, should the egg parasitoid *Edovum puttleri* Grissell become established (Lashomb et al. 1987), methamidophos would be a problem because of its high toxicity to this beneficial parasite (Obrycki et al. 1986).

In early to mid-August as the fruit matures, moths of TFW begin to appear. Pheromone traps have proven much more successful in identifying the first few days of moth flight than did light traps (Figure 2). About this same time a moth flight of variegated cutworm and possibly cabbage looper is occurring. Because of the high investment already made up to this point, because fruit is in the field, and because of time constraints on the part of the growers there is little willingness to gamble on pest management at this stage. About a week after the moth flights, most growers begin a regular program of insecticide applications. Carbaryl and methomyl can

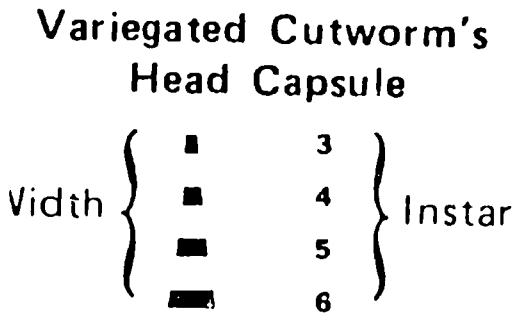

Figure 1. Head capsule guide distributed to growers for determining age (size) of variegated cutworm.

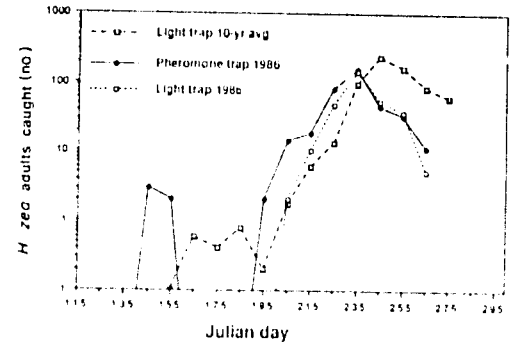

Figure 2. Comparison of weekly light trap and pheromone trap catches of tomato fruitworm moths. (Note the earlier catch in pheromone trap.)

now be used without consideration of pest induction. Growers would prefer to use pyrethroids to achieve somewhat higher mortality but, as temperatures at this time are often in the 22°C (min) to 38°C (max) range, growers are reluctant to use them for fear of reduced insecticidal activity (Grafius, 1986; Sparks et al. 1982; Sparks et al. 1973; Harris and Konoshita, 1977).

There is no question that pest surveillance, use of action thresholds, and judicious choice of insecticides can in some years reduce insecticide use and improve the profitability of growing processing tomatoes. In a survey of grower practices of 1986, those using conventional calendar insecticide applications made an average of 9.5 applications (n = 10 growers). Of those incorporating one or more components of our recommendations for tomato pest management, the number of applications made was 4.5 (n = 8 growers). Only one of the eight growers (four applications of insecticide) felt he had suffered excessive insect damage as a result of the reduced insecticide application. Estimates on dollars saved ranged from $13 to $25 per ha. This figure will differ considerably from grower to grower and from year to year. In contrast to historical weekly applications of fungicide, many growers now follow a practice of biweekly applications (Stevenson, 1977) reducing application costs by half. Where previously they often included insecticide in the spray tank whether or not it was needed, today they are more likely to consider pest occurrence possibilities, pest density, and related environmental conditions.

When growers who did not adopt new approaches were questioned about their decision, the most frequent response was that the uncertainty and stress associated with the new approach were still too high. A secondary reason was that they did not have time themselves to scout fields or check traps, and neither were there trained scouts available nor a pest management company in their area.

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Symposium Discussion

I.D. Erinle: You indicated that synthetic pyrethroids are not very effective at temperatures of 30°C and above. Does this apply to a wide range of pyrethroids or permethrin which you used in the study.

A.C. York: This applies to pyrethroids in general and is widely published in US journals.

N.S. Talekar: We found one *L. hirsutum* accession resistant to tomato fruitworm. This is the same accession found to be resistant to other lepidopterous pests at the North Carolina State University. Did you try it for Colorado potato beetle?

A.C. York: No, we have not evaluated this accession for CPB resistance. My understanding is that it is being developed for fresh market not processing use.

R.L. Villareal: Please comment on the price difference between the processing tomatoes of California and the midwest.

A.C. York: Much of the difference in the price the grower receives is due to the ultimate use of the product. Tomatoes destined to be packed as peeled whole tomatoes are worth more than those to be used as ketchup, pizza sauce, etc. This year in Indiana there will be a $12 per ton differential: $85 and $73 per ton.

33

Evaluation and Validation of a Tomato and Bean Polycultural Cropping System as a Component of IPM for Tomatoes in Nicaragua

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Abstract

The use of a tomato and bean polyculture as a prophylactic component of an integrated pest management (IPM) program for tomatoes in Nicaragua was evaluated. The polyculture overyielded significantly, with a land equivalent ratio (LER) of 1.72 ($P < 0.03$). Beans as a companion crop did not affect the yield of tomatoes in the polyculture (relative yield, or RY = 0.97), while the intercrop bean yield was 75% of the monocultural production (RY = 0.75). The use of the polyculture greatly reduced the incidence of three principal tomato pests: the *Heliothis* spp. [Lepidoptera: Noctuidae] fruitworm complex ($P < 0.015$); the Spodoptera spp. [Noctuidae] armyworm complex ($P < 0.10$); and *Liriomyza sativae* Blanchard [Diptera: Agromyzidae], the vegetable leafminer ($P < 0.005$). A large-scale validation trial, conducted in 1984 in the Department of Managua showed a similar pattern of strongly reduced incidence of fruitworms and armyworms (> 90% reduction in damage). There was no effect of intercropping on tomato diseases. An economic analysis showed that the polyculture was between 1.1 and 2.2 times more profitable than the tomato monoculture depending on the wholesale market price of tomatoes. Overall, the results of this evaluation and validation in terms of yields, pest incidence, and profitability indicate that tomato and bean intercropping should be strongly considered as part of tomato IPM in the tropics.

Introduction

The purpose of this study was to evaluate the potential of a tomato and bean polyculture as a prophylactic component of an integrated management program for tomato pests in Nicaragua. A related objective was to evaluate the yielding properties of this cropping system.

As reported by Rosset et al. (1984) this cropping system has excellent yielding potential, and a review of the literature suggests that it might also diminish pest populations. In particular, other studies have shown that the attack of several tomato pests may be reduced, including *Manduca* spp. (Lepidoptera: Sphingidae: Vandermeer et al.), *Spodoptera sunia* Guenée (Noctuidae; Rosset et al. 1985) and possibly aphids (Rosset at al. 1984). Preliminary, nonquantified observations in Nicaragua by this author also suggest that attack by the cotton whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), on tomatoes may be reduced by the presence of beans.

A major focus of research involving polycultures has been the effect of plant community diversity on the populations of herbivorous insects. Recent reviews have cited many basic ecological studies showing decreased herbivore abundance with increased plant diversity (Altieri et al. 1977; Andow. 1983; Atsatt and O'Dowd. 1976; Cromartie. 1981; Dempster and Coaker. 1974; Kareiva. 1983; Litsinger and Moody. 1976; Norton. 1975; Perrin. 1977; Perrin and Phillips. 1978; Risch et al. 1983; Stanton. 1983; Way. 1977). A number of basic mechanisms

leading to lower herbivore populations emerge from this literature. They can be grouped into three general categories as follows:

Attraction: A wide variety of factors can reduce the attractiveness of the crop in a polyculture, including greater percent ground cover, physical barriers, high diversity of chemical cues, presence of diversionary hosts, complex crop architecture, etc.

Tenure time: In the case of highly mobile pests, the length of time that they remain in the crop may be reduced by such factors as contact with non-hosts, chemical repellents, increased shade, etc.

Mortality: A higher natural enemy abundance may lead to greater mortality in a polyculture.

Despite this abundance of promising basic scientific work, however, there are few examples where intercropping has actually gone from basic research to practical application as **an explicit pest management strategy** (for a theoretical discussion of how this might be done see Vandermeer, 1984, and Vandermeer and Andow, 1986). The major examples reported in the literature are based on strip cropping which differs significantly from the type of intercropping reported here (Swezey and Daxl, 1983; Stern, 1969).

Chemical control of tomato pests in Nicaragua is difficult because the source of two of the key pests, the *Heliothis* spp. complex (Lepidoptera: Noctuidae), and the *Spodoptera* spp. complex (Noctuidae) is the cotton producing zone of the Pacific, where they have acquired powerful resistance to most insecticides in use (Vaughn and Leon, 1977). A third pest, the vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae) is widely known as a secondary outbreak pest provoked by excessive insecticide use (Oatman and Kennedy, 1976). Within this context, therefore, it is imperative to develop non-chemical alternatives such as polycultures to reduce reliance on insecticides of doubtful effectiveness.

The *Heliothis* complex in Nicaragua is made up of two species, *H. zea* Boddie and *H. virescens* Fabricius, with the former being predominant. They are considered major pests of cotton, tobacco and tomatoes. They attack corn too, but are not considered of major economic importance on that crop. They are present throughout the year, with major population peaks in May-June and September-January (Comité de Control Integrado, 1979). They do not oviposit on tomatoes until flowers are present, at which time single eggs are deposited on terminal leaflets near flowers or fruit. After eclosion, they move directly to fruit if available, or to flowers. They bore deeply into the fruit, where they are difficult to reach with insecticides. The larvae leave deep watery cavities in the fruit that are contaminated with feces and cast skins. Such fruit usually rot and fall to the ground. When the fruits are small, each larva may damage several of them (IPM Manual Group, 1982). Wolfenbarger et al. (1971, 1973) reported that *H. zea* in Nicaragua was 44 times more resistant to methyl parathion than in Texas, and 23 times more resistant to endrin than in Mississippi.

The *Spodoptera* complex on tomatoes in Nicaragua consists of *S. exigua* Hbn., the beet armyworm, *S. sunia* and *S. latifascia* Walk. They are pests of cotton, beans and tomatoes. Peak adult populations, as estimated from light trap data, are in January-March (Hellpap, 1985). They are highly resistant to insecticides and are known as secondary outbreak pests in cotton, with an explosive potential for population growth (Vaughn and Leon, 1977). Eggs are deposited on the leaves in masses, and the newly hatched larvae feed on foliage. They soon move to the fruit where they excavate shallow holes that characteristically scar over (IPM Manual Group, 1985). In Nicaragua, they feed at night, and spend the hot daytime hours sheltered in litter on the ground. As a result of this habit, they more frequently damage those fruit in contact with the ground than those higher up on the plant.

Liriomyza sativae can attack tomatoes at any point during the growing cycle, although damage is most common between the seedling and the flowering stage. The larvae make characteristic serpentine mines in the leaves, and can only be controlled with insecticides that have some translaminar action. In California, it is resistant to all available insecticides except Monitor[R] (IPM Manual Group, 1985). There is some confusion in the literature as to whether or not *L.*

sativae actually affects tomato yields. Lindquist (1974) in Ohio and Rosset et al. (1983) in Nicaragua found no relationship between leafminer populations and yield, while Wolfenbarger and Wolfenbarger (1966) found a possible relationship. It seems that only when the density of leaf mines is so high that severe defoliation occurs does the leafminer depress yields (IPM Manual Group, 1985; Schuster et al. 1980). Tomatoes can tolerate significant defoliation, and in fact indeterminate varieties are often pruned because excess foliage depresses yields (IPM Manual Group, 1985).

In this study, damage on tomatoes caused by *Heliothis*, *Spodoptera* and *L. sativae* was monitored in polycultures and monocultures, to see if the damage was indeed reduced by intercropping.

Some workers have suggested that polycultures may also reduce disease spread, by decreasing the proportion of susceptible hosts in a field. On the other hand a polyculture may improve the microclimate (temperature, humidity) for microbial pathogens, and lead to greater problems (van der Plank, 1963, and Zadoks and Schein, 1979, for reviews). A secondary feature of this study was therefore to monitor pathogen attack.

Materials and Methods

Study Site

This experiment was conducted at the Sébaco Valley Regional Experiment Station, near San Isidro, Matagalpa, Nicaragua during the 1982-83 dry season. The experimental field had been previously cultivated with rice, and therefore had a high density of the weed purple nutsedge, *Cyperus rotundus* L. (Cyperaceae), known locally as *coyolillo*. Table 1 shows an analysis of soil samples taken from the field shortly before planting.

Table 1. Soil characteristics at the Sébaco Valley Regional Experiment Station, near San Isidro, Matagalpa, Nicaragua (1982).

	Texture: loam
	Sand: 46%
	Silt: 34%
	Clay: 20%
	pH: 6.8
	Organic carbon: 0.99%
	Organic matter: 1.71%
	Total nitrogen: 0.11%
	Al: 1.6 me/100 g
	P: 27 μ g/ml
Exchangeable ions, me/100 g:	Ca, 19.50; Mg, 6.84; Na, 0.31; K, 2.25; H, 5.
Cation exchange capacity:	Total = 33.90; NH_4OAc = 30.5
Base saturation:	Total = 85%; NH_4OAc = 95%

Agronomic Practices

Separate monocultures and polycultures of beans and tomatoes were direct-seeded during the dry season on 14 January, 1983. A determinate tomato cultivar, UC-82, was used, which is the standard processing variety utilized in the Sébaco Valley. The bean cultivar used was Revolución 79, a red bean variety common in Nicaragua. The crops were planted on raised beds that were 1.2 m wide and 0.4 m apart, which is the normal commercial practice for large-scale irrigated production of both beans and tomatoes in Nicaragua. Ten tomato seeds or two bean seeds were planted in shallow holes (1-2 cm in depth), and the tomatoes were later thinned to one plant per hole. Two hundred and sixty kg/ha of 12-30-10 NPK fertilizer was applied

in bands adjacent to the tomato rows at the time of planting, and two additional broadcast applications of 130 kg/ha each of urea (46% N) were made at 38 and 62 days after planting (d.a.p.). No fertilizer was applied to the bean rows at any time.

The plots were weeded by hand at 10, 19 (block 1 only), 39, and 67 (tomatoes only) d.a.p. Earth was hilled around the tomato plants at 39 d.a.p. The experiment was irrigated by sprinkler approximately once every eight days. The insecticide Lannate[R] (against *Diabrotica* sp. attacking the seedlings of both crops) and the fungicide Benlate[R] (against *Phythium*) were applied at 12 d.a.p. No other pesticide applications were made during the course of the experiment, so as not to interfere with insect and pathogen populations.

Experimental Design

The size of each experimental plot was 10 m × 6 beds (9.6 m), with an unplanted but weeded border between plots of 1 m or 1 bed (1.4 m). The experimental design consisted of five randomized blocks with the following three treatments:

Tomato monoculture. The planting consisted of two rows of tomatoes on the center of each bed, with 0.4 m between them and 0.3 m between each row and the edge of the bed. The plants were thinned along the rows to one every 0.25 m (50,000 plants/ha).

Bean monoculture. The planting consisted of four rows of beans on each bed, with 0.4 m between the center rows, and 0.3 m between each center row and the adjacent outside row, planted on the edge of the bed. The bean seeds were planted in holes that were spaced 0.1 m apart along the rows (two seeds per hole, ≤ 250,000 plants/ha).

Polyculture. The planting consisted of two center rows of tomatoes and two edge rows of beans on each bed, planted at the same within row densities as the respective monocultures (50,000 plants/ha of tomatoes and ≤ 125,000 plants/ha of beans). The tomato rows were 0.4 m apart, with 0.3 m between each tomato row and its neighboring bean row.

Data Collected

The beans were harvested at 80 d.a.p. In each plot, dry weights adjusted to 15% humidity were taken for the two center beds plus the interior halves of the next two beds. Data were not taken from a 1 m border at the end of each row to eliminate edge effects.

All tomatoes were harvested at 88 d.a.p., and the weight and number of commercial fruits from the four center beds of each plot were recorded, once again leaving a 1 m border at the end of each row. A random sample of 100 rejected, or noncommercial, fruits was taken from the tomatoes harvested from each plot, and was graded according to categories of damage (Table 2).

Table 2. Percent unmarketable yield by category of damage, in polyculture (P) and monoculture (M).[z]

Block	Late blight P/M	Bacterial spot P/M	Virus P/M	Insect damage P/M	Total P/M
I	3.2/6.1	11.1/11.6	10.1/16.51	5.3/6.1	29.7/40.4
II	0.9/2.6	8.3/7.9	7.4/14.3	9.3/6.9	26.0/31.7
III	2.5/1.2	5.3/4.3	5.7/5.9	8.8/7.4	22.3/18.8
IV	1.1/2.6	5.1/7.5	3.4/6.1	7.1/7.9	16.8/24.2
V	1.2/0.9	3.9/3.8	4.8/3.8	7.9/7.0	17.9/15.5
Mean	1.8/2.7	6.7/7.0	6.3/9.3	7.7/7.1	22.5/26.1

[z]The difference in means is not statistically significant

Pest insects and plant diseases were sampled weekly on the tomato plants. For insect sampling, four sampling stations were randomly chosen and marked with plastic flagging in each plot. Each station consisted of five adjacent plants along a row, for a total of 20 plants per plot. The only insect pests that appeared in analyzable numbers were *L. sativae*, *Heliothis* spp., and *Spodoptera* spp. The cotton whitefly, *B. tabaci*, was observed attacking the beans in low numbers, but none were recorded in the tomato sampling. Bean pests were not sampled. The following data were collected for the plants sampled in each plot:

- The number of *L. sativae* mines containing living larvae on all of the leaflets of the fourth fully expanded compound leaf from the top of the plant (modified from Rosset et al. 1983 and Pohronezny et al. 1980).
- The number of fruits damaged by the larvae of *Heliothis* spp. and *Spodoptera* spp., respectively. The damage caused by each was distinguished using pictures and descriptions in an IPM manual from California, U.S.A. (the most recent edition of this is IPM Manual Group, 1985).

Disease sampling was carried out weekly and consisted of determining the percentage of tomato plants affected by wilt diseases in the four central beds of each plot (leaving a 1 m border). Samples sent to the Plant Pathology Laboratory of the Ministry of Agriculture (MIDINRA) in Managua indicated that all of the affected plants were infected with *Fusarium* wilt. The total number of fruit per plant and the percentage affected by fungal and bacterial pathogens was determined in a random sample of 10 plants per plot on weekly basis beginning at 61 d.a.p. All affected fruit had bacterial spot, *Xanthomonas campestris* pv. *vesicatoria*, except at harvest when late blight, *Phytophthora infestans*, appeared.

At 53 d.a.p., eight bean plants were chosen at random from each plot and the number of root nodules was counted on each plant.

Results

Table 3 gives the relative and absolute yields for each crop for each block and for the entire experiment, along with Land Equivalent Ratios, or LERS. The LER is defined as,

$$LER = P1/M1 + P2/M2, \qquad (1)$$

where P1 and P2 are the yields of crops 1 and 2 in polyculture, and M1 and M2 are the yields in monoculture (Vandermeer, 1981; Sanchez, 1976; Soria et al. 1975). A 2 × 5 treatments

Table 3 Absolute and relative yields (kg/ha) of polycultures and monocultures, and land equivalent ratios (LERs).

Block	Monoculture		Polyculture		Relative yields (RY) in Polyculture		
	Tomato yield[Z]	Bean yield[Y]	Tomato yield	Bean yield	Tomato RY	Bean RY	LER
I	5,426	717	6,445	662	1.19	0.92	2.11
II	6,566	347	7,253	223	1.10	0.64	1.75
III	11,628	779	8,372	336	0.72	0.43	1.15
IV	10,022	594	12 430	728	1.24	1.22	2.46
V	11,633	1,080	7,077	567	0.61	0.53	1.14
Mean ± std. Deviation	9,055 ± 2,897	703 ± 268	8,315 ± 2,403	503 ± 216	0.97[X]	0.75[W]	1.72[V]

[Z]Marketable yield. [Y]15% moisture content. [X]Tomato RY is not significantly different from 1. [W]Bean RY is not significantly different from 1 or from 0.5. [V]LER is significantly greater than 1 ($P < 0.05$), Schultz's LER Test (Schultz).

× blocks) ANOVA of tomato yields showed no significant difference in means between polyculture and monoculture. A similar ANOVA for beans also showed no difference with regard to two null hypotheses, that polycultural yields equal monocultural, or that polycultural equal 50% of monocultural (because bean density in polyculture was 50% of that in monoculture).

The null hypothesis that the LER = 1 was evaluated using a transformation developed by Schultz (ms.). In each block a transformed monocultural yield (TMY) was calculated,

$$TMY = Tm + k\,(Bm), \qquad (2)$$

where Tm and Bm are the respective monocultural yields of tomatoes and beans, and k is a constant,

$$k = Tm/Bm, \qquad (3)$$

where Tm and Bm represent means for the entire experiment on this occasion. Similarly, a transformed polycultural yield (TPY) was calculated for each block,

$$TPY = Tp + kBp, \qquad (4)$$

where Tp and Bp are the polycultural yields and k is the same constant. With the values calculated in this way, the null hypothesis can be rewritten as,

$$TPY = TMY/2, \qquad (5)$$

where TPY and TPY are the means of the block values, which is equivalent to LER = 1.

Any paired comparisons test (randomized block ANOVA, Wilcoxin's Test, etc.) can then be used to reject the null hypothesis. In this case the Signs Test (Siegel, 1979) was used, and the hypothesis was rejected ($P < 0.03$). Thus the LER was significantly greater than 1, and the polyculture overyielded.

Table 2 presents the percentages of noncommercial fruits rejected by category of damage. The damage encountered was graded as due to late blight (*Phytophthora infestans*), bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), virus (not identified), or fruitworms (*Heliothis* spp. and *Spodoptera* spp.). The unidentified virus had symptoms that included stunted plants with a broom-like profusion of branches, and an excessive number of small fruit that never enlarged or ripened. None of the differences between polycultures and monocultures for these categories of damage were significant.

Figures 1, 2 and 3 show the population dynamics of the three tomato pests that appeared in analyzable numbers. Differences in mean numbers over the course of the season were tested using repeated measures, randomized block ANOVA, (treatments × blocks × sampling dates), eliminating those sampling dates with zero values (Brecht and Woodward, 1984). *L. sativae* attacked early, in much greater numbers in the monoculture than in the polyculture ($P < 0.005$, Figure 1). The number of fruits damaged by *Heliothis* was significantly greater in the monocultures ($P < 0.015$, Figure 2). The same tendency was observed for *Spodoptera*, but was not significant due to the high variance ($0.05 > P < 0.10$, Figure 3). Although not explicitly sampled for, a number of *Spodoptera* egg masses were encountered on tomatoes during the sampling of leafminers. A total of 10 were found in monocultures, and two in polycultures. This difference is highly significant according to the Mann-Whitney U Test ($P > 0.001$) (Siegel, 1979).

Bacterial spot peaked early in fruit formation, declining as harvest approached (Figure 4). There was no difference between polyculture and monoculture. The relatively constant number of fruit per plant over the time period sampled, combined with the declining percentage damaged by bacterial spot, indicates two things. First, most affected fruits must have fallen to the ground before harvest, and second, the plants must have been producing a compensatory number of new fruit. What is unclear is whether this was in fact compensation, in which case yield would

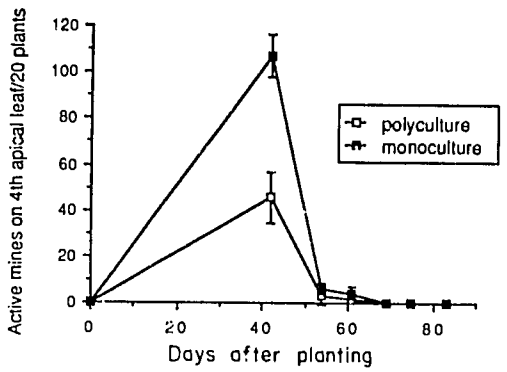

Figure 1. Population dynamics of *Liriomyza sativae* on tomatoes as estimated by the number of active mines on the fourth fully expanded compound leaf from the top of the plant (± standard deviation, $P < 0.005$).

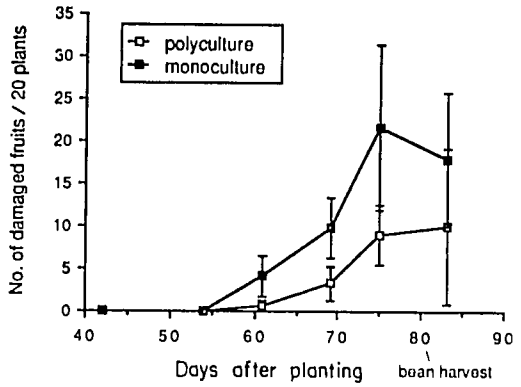

Figure 2. Population dynamics of *Heliothis* spp. on tomatoes as estimated by the number of damaged fruits per 20 plants (± standard deviation, $P < 0.015$).

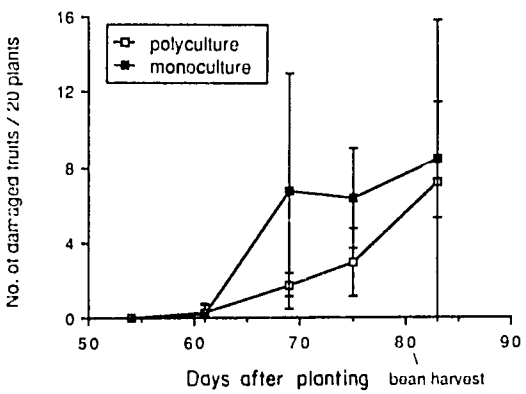

Figure 3. Population dynamics of *Spodoptera* spp. on tomatoes as estimated by the number of damaged fruit per 20 plants (± standard deviation, $P < 0.10$).

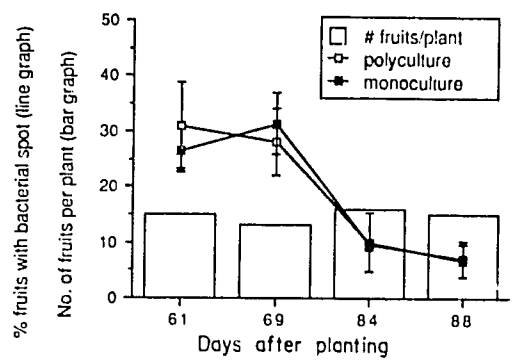

Figure 4. Percent tomato fruit infected with bacterial spot, and number of fruits per tomato plant (± standard deviation). Note that the x-axis is not linear.

not be depressed, or if these new fruits would have been produced anyway, in which case yield would have been drastically reduced.

Fusarium wilt affected a large proportion of tomato plants in both monocultures and polycultures. Figure 5 shows the epidemiology during the season. There were no significant differences observed.

Figure 6 shows plant survival during the season. No significant differences were noted.

Overall root nodule numbers on beans were extremely low in all blocks and treatments (Table 4). There was no significant difference between polyculture and monoculture, and there was no correlation between nodule numbers and final bean yield.

Discussion

Plant Protection

The greater than 50% reduction in *Heliothis* damage in the polyculture suggests that the polyculture might effectively be used as a prophylactic control measure for this pest, reducing overall populations and thus also the need to spray (Vandermeer and Andow, 1986).

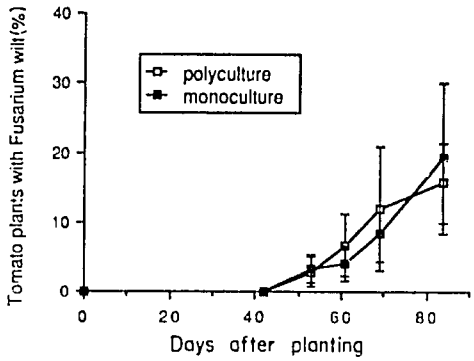

Figure 5. Percent tomato plants with symptoms of Fusarium wilt (± standard deviation).

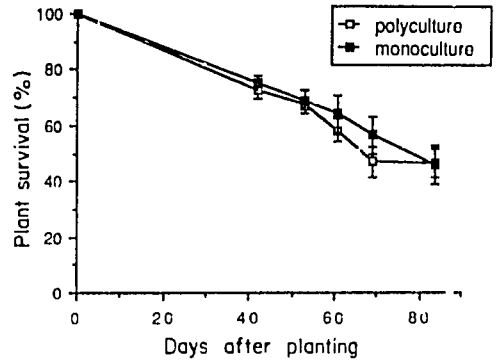

Figure 6. Percent survivorship of tomato plants (± standard deviation).

Table 4. Mean number of root nodules per bean plant.[z]

Block	Polyculture	Monoculture
I	3.88	6.63
II	10.13	5.75
III	5.88	9.63
IV	5.13	3.13
V	2.75	3.38
Mean	5.55	5.70

[z]The difference in means is not statistically significant.

Although this experiment was not designed to examine mechanisms reducing attack, it seems likely that reduced oviposition was the key factor. The natural enemy fauna at the Experiment Station is depauperate, presumably due to excessive pesticide use, and few predaceous insects were observed during this experiment. Also *Heliothis* larvae are not likely to move great distances, and *Heliothis* is not known as a bean pest in Nicaragua. Therefore it seems unlikely that reduced tenure time on tomatoes was a major factor. The bean rows were in physical contact with the tomatoes, forming a sort of impenetrable wall. Since *Heliothis* oviposits on leaflets near flowers, and since there are few or no flowers on the uppermost (youngest) branches that extend above the beans, it may be that the beans blocked access to oviposition sites. Eggs were not sampled for, and only one was encountered by chance, so this hypothesis cannot be explicitly tested.

It is possible that *L. sativae* was affected by a similar mechanism, although it is questionable whether the reduction in attack by this pest affected yield (see earlier discussion). A related species, *L. bryoniae*, that attacks greenhouse tomatoes in England, oviposits on young lateral foliage in preference to apical foliage (Ledieu and Helyer, 1985). In this experiment casual, nonquantified observation of *L. sativae* in tomato monoculture revealed a similar pattern of hovering near lateral foliage. Thus, it may be that preferred oviposition sites were blocked in the polyculture. To the extent that *L. sativae* is a real pest, the polyculture appears to be a highly effective prophylactic technique. Whether or not it affects yield, however, farmers direct considerable amounts of insecticide toward it, in both Nicaragua and in the United States, and it is difficult to convince them not to (personal interviews; Schuster et al. 1980; Oatman and Kennedy, 1976). Thus a reduction in density may lead to reduced spraying and associated benefits.

Although the differences between polyculture and monoculture were not significant for *Spodoptera*, the trend toward reduced attack in the polyculture encourages future investigation. To the extent that the pattern may be real, the greater number of egg masses in the monoculture also points to an oviposition mechanism. Since all three *Spodoptera* species are bean pests, it

may be that the beans act as a diversionary host or trap crop (Rosset et al. 1985). The greater percent ground cover in the polycultures may also have been a factor in reducing attraction of adults of any of these species (Cromartie, 1981).

Although no advantage was noted for the polyculture in terms of tomato disease reduction, the fact that there were no differences means that control strategies would not have to be modified with the use of this cropping system.

Yielding Properties

The LER of 1.72 means that the polyculture had a total yield of tomatoes and beans 72% greater per unit area than the separate monocultures. The fact that the relative yield of tomatoes was not significantly different from 1 (RY = 0.97) suggests that it is possible to plant beans within a tomato field without negatively affecting tomato yield. At the same time 75% of a monocultural bean yield was obtained from the polyculture (RY = 0.75). These relative yields are impressive in light of the expectation that the increased overall density in the polyculture should reduce yields through competitive interactions (assuming that the recommended monocultural densities are optimal). However, relative yields and LERs represent the sums of various interactions, some negative and some positive. The beans certainly compete with the tomatoes for certain resources such as light, water, space and nutrients, and this must be negative for the tomatoes (Vandermeer, 1981). Yet there are other possible interactions with positive effects. Vandermeer's "Environmental Modification Principle" postulates that these positive effects may outweigh the negative ones, leading to overyielding (Vandermeer, 1984). For example, although not quantified it appeared during this experiment that the bean rows protected the tomatoes from the desiccating and damaging effects of the wind (for example, Radke and Hagstrom, 1976). Shade from the beans must also reduce the soil temperature, which often limits tomato production in the tropics (Villareal, 1982). Plant protection effects may also contribute in this way to overyielding.

In this regard, there were no significant differences between polycultures and monocultures in terms of the percent fruit rejected because of disease or insect damage (Table 2, Figure 4). However, many fruits damaged by insects dropped from the plants a considerable time before harvest, and thus are not taken into account by a harvest-time analysis. The greater intensity of attack in monocultures by *Heliothis* and *Spodoptera* may thus have contributed to the relatively strong polyculture performance. The polyculture was also an effective control measure for *L. sativae*, although, since defoliation did not occur, it is unlikely that this affected yield.

The RY of 0.97 for tomatoes is considerably lower than the 1.62 reported from Costa Rica (Rosset et al. 1984). First of all it should be noted that the planting design was different. Another potential line of explanation lies with the tomato cultivars used. UC-82, used in this experiment, is a determinate variety, while Tropic, an indeterminate variety, was used in the Costa Rican experiment. Another difference is that the rate of nodulation of the beans (Table 4) was much lower than in the Costa Rican experiments (casual observation). If it were possible for the beans in some way to supply nitrogen to the tomatoes, or if the beans compete less for available nitrogen when they nodulate well, this could explain the difference in LERs (Boucher et al. ms.). This could be tested for in an experiment with different levels of nitrogen fertilizer, with and without inoculation with *Rhizobium*.

It must also be noted that the mean tomato yields in Costa Rica were lower than in Nicaragua; it appears that the polyculture may in some ways protect tomatoes from particularly adverse conditions. Absolute tomato yields in both polyculture and monoculture were low, although higher than in Costa Rica. The 9,055 kg/ha in the monoculture are equivalent to 560 baskets/manzana (local measurement, 1 manzana = 0.7025 ha), and the National Development Bank bases its crop budgets for irrigated processing tomatoes on an expected yield of 800 baskets/manzana (BND, 1983a). As discussed earlier, this low yield may have been due to early attack by bacterial spot. The heavy *Fusarium* wilt attack and the high plant mortality also undoubtedly suppressed overall yields considerably. Another possible explanation for the low yields is that no pesticides

were applied during the major part of the growing season, which was done so that the effects of pest attack could be studied without interference. Nevertheless, if no fruits had been rejected for disease or insect damage, the yields would only have risen to 12,000-13,000 kg/ha (projected from the figures in Table 2).

Finally it is possible that available potassium was insufficient for optimal tomato production. Mg is antagonistic to potassium, and the ratio of Mg to K was 6.84/2.25, indicating that it may have been limiting (Corey, 1973; von Uexkull, 1979).

Economic Analysis

Preharvest and harvest costs were estimated for the polyculture and the monoculture, based on the inputs and the labor required, and their costs from the National Development Bank's estimated crop budgets (BND, 1983a; 1983b). Assuming a bean price of US$390/45.45 kg, the minimum price guaranteed to producers by the National Basic Grains Corporation (ENABAS), relative value totals (RVT) (Schultz et al. 1982) were determined for different tomato prices. The RVT was calculated here as the ratio of net profit in the polyculture to net profit in the tomato monoculture (because this cropping system is directed at tomato producers, and because in general tomatoes are the more valuable crop). A range of tomato prices was used, from the US$20/11.36 kg that the National Development Bank bases its budgets on (BND, 1983a) to US$80/11.36 kg, the highest wholesale price recorded during 1982 (unpublished CIERA figures).

The polyculture overyielded economically (RVT > 1) at all price combinations (Figure 7). The RVT = 2.19 at a tomato price of US$20/11.36 kg means that the polyculture was 119% more profitable than a tomato monoculture, at that price. The RVT falls from that high value to 1.09 at the highest tomato price, US$80/11.36 kg. However it is unlikely that a producer would actually realize this price for the entire harvest, due to problems with transportation and resultant spoilage. At no price, the monoculture is more profitable than the polyculture. From an economic perspective the polyculture is an effective buffer for the farmer against fluctuations in the price of tomatoes (and in the yield of tomatoes).

Validation

The on-farm validation was conducted in January 1984 under an agreement with the members of the Luciano Vilchez Agricultural Cooperative, located at kilometer 13 of the Old León Highway in the Department of Managua, Nicaragua.

An approximately 4-ha field was divided roughly in two, with half transplanted with tomato seedlings only (determinate processing variety "Roma"), in rows 1 m apart with 1 m between plants. The other half consisted of alternate rows of tomatoes and beans (direct seeded on the same date that the tomatoes were transplanted), and the rows varied between 1 m and 0.5 m apart, with the result that the average tomato density in the polyculture was lower than in the monoculture.

Insect sampling was carried out on a regular basis during the season. The only pests that attacked after transplant in analyzable numbers were the *Spodoptera* and *Heliothis* complexes. The percent fruit damaged by each was recorded in three to six 5 m sections of row randomly chosen in each treatment. No statistical analysis was performed on the data, beyond calculating standard errors and graphing the results (Figures 8 and 9). At the peak of *Heliothis* damage (45 days after transplant, d.a.t.) there was a 14.4-times greater percentage of damaged fruits in the monoculture than in the polyculture (7.2%:0.5%; Figure 8). Peak *Spodoptera* damage was also recorded at 45 d.a.t., and there was a 12.5-fold increase in the monoculture over the polyculture (6.25%:0.5%; Figure 9). In both cases, the percentage of fruits damaged dropped considerably before harvest, as damaged fruits presumably fell to the ground.

The results of this validation thus confirm and support the conclusion of the small-plot experiment that the polyculture cropping system strongly reduces fruitworm and armyworm damage.

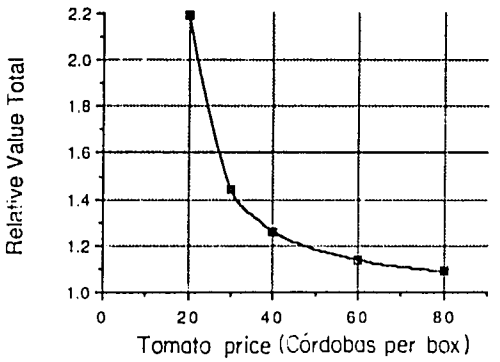

Figure 7. Relative value total (RVT) of the polyculture at different tomato prices.

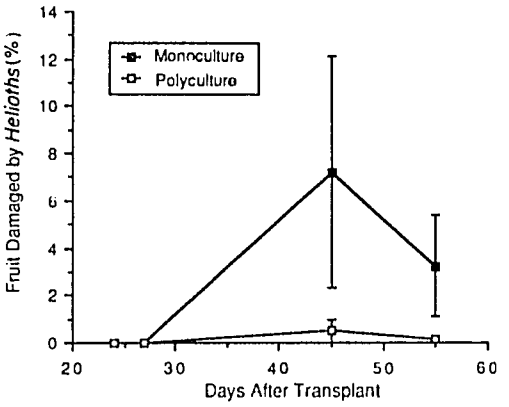

Figure 8. Damage by *Heliothis* spp. on tomatoes in monoculture and polyculture large-scale validation plots (± standard error).

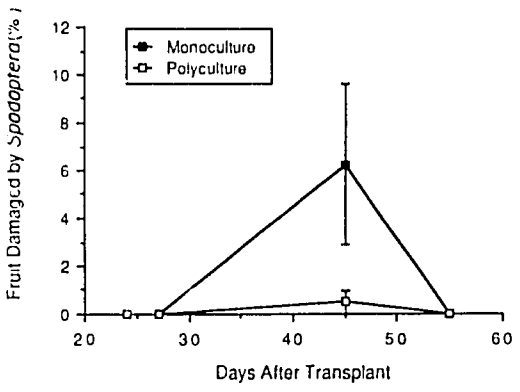

Figure 9.
Damage by *Spodoptera* spp. on tomatoes in monoculture and polyculture large-scale validation plots (± standard error).

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Symposium Discussion

A.L.H. Dibyantoro: I have been working extensively on *Spodoptera* and *Heliothis* both on pepper and tomato. (1) Do you have any experience with IGRs (insect growth regulators) such as triflubenzuron or chlorfluazuron which control these pests? (2) Is there a possibility of setting up a similar type of program as yours in Southeast Asia, particularly in Indonesia?

P. Rosset: (1) No, I do not have such experience, but I would be very interested in seeing your results. (2) You would have to speak to US-AID or other funding agencies about that possibility.

Propamocarb-HCl, a Fungicide Suitable for Integrated Pest Management

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Abstract

Propamocarb-HCl the active ingredient of Previcur (R) N (registered trademark of Schering AG, Federal Republic of Germany) is a fungicide that controls *Pythium* spp., *Aphanomyces* spp., *Pseudoperonospora* spp., *Phytophthora* spp. and *Peronospora* spp. in numerous crops such as tomatoes, peppers, cucumbers, etc. It is also safe for the crop and does not exert an adverse influence on symbiotically living mycorrhizal fungi. On the basis of these properties, the compound is particularly suitable for use in an integrated pest management system.

Introduction

In an integrated pest management system, the choice of an appropriate pesticide to control pests and diseases, not only depends on its performance against the target organism and safety to the crop but also upon its specific properties, particularly the effect on beneficial organisms.

Propamocarb-HCl (Previcur N, Propyl 3-(dimethylamino) propylcarbamatehydrochloride), a fungicide developed by Schering AG, Federal Republic of Germany, controls *Pythium* spp., *Aphanomyces* spp., *Phytophthora* spp. and other oomycete fungi in numerous crops (Pieroh et al. 1978; Cohen. 1979; Colbaugh. 1987). This paper presents trial data which demonstrates the activity of propamocarb against *Pythium* spp. in tomato and pepper and *Phytophthora capsici* in pepper, its crop safety, as well as the safety of this fungicide to vesicular arbuscular (VA)-mycorrhiza.

Materials and Methods

The activity of propamocarb-HCl against *Pythium ultimum* in a seedling nursery of pepper (*Capsicum annuum* cv. Yolo Wonder) and tomato (*Lycopersicon esculentum* cv. Grosse Liese) was checked in an air-heated glasshouse at an average temperature of 27°C. Each plot consisted of one tray containing eight small containers (three replications/treatment). The soil used was a mixture of 50% peat and 50% washed river sand, which was steamed at 64°C for 30 minutes before sowing. Except for the untreated control, all plots were covered with 1 cm of soil containing *Pythium ultimum* (mycelium and spores) after fungicide treatment.

Propamocarb-HCl (72.2% SL) as well as etridiazole (24% WP) were applied as a drench with a concentration of 0.2% a.i. and 0.05% a.i., respectively (1 liter solution/plot).

Field evaluation of propamocarb for the control of *Phytophthora capsici* in pepper (*Capsicum annuum* cv. Export) was carried out in Romania. Pepper was sown in an open field and treated with propamocarb-HCl at a concentration of 0.25% (drench with 4 liters solution/m^2) at the time of sowing. For comparison, captafol (80% WP) was used (0.15% concentration). Four replications of each treatment were used. Plots were assessed 21 days after sowing.

Under practical conditions (trials conducted by farmers), propamocarb-HCl was used as a seedbed drench in pepper against *Phytophthora capsici* in the Republic of Korea. The fungicide was applied twice (four weeks after sowing and four weeks before transplanting) at 0.1% concentration (2 liters solution/m^2) and compared to foliar treatments with captafol (975 g a.i./ha) four weeks after sowing and mancozeb (2,475 g a.i./ha) four weeks before transplanting in Ansong and with thiophanate-methyl (910 g a.i./ha) and chlorothalonil (2,475 g a.i./ha) in Haman. Plant growth and yields were evaluated at harvest.

Greenhouse-pot tests to investigate the impact of propamocarb-HCl on VA-mycorrhiza on cucumber and maize were carried out by Dehne (1986).

Results

Trials in the greenhouse with artificial inoculation clearly showed that a seedbed drench with propamocarb-HCl resulted not only in a high percentage of surviving plants, indicating a high efficacy on *Pythium ultimum*, but also in improved plant growth, expressed by enhanced height and fresh weight of tomato and pepper seedlings (Tables 1 and 2).

Table 1. The performance of propamocarb-HCl used as a seedbed drench on *Pythium ultimum* in tomato seedlings (artificial inoculation).

Treatment	Surviving plants[z]	Plant height[z]	Plant fresh weight[z]
Inoculated control	100	100	100
Noninoculated control	122	100	103
Propamocarb-HCl	125	158	152
Etridiazole	120	125	112

[z]In % to the inoculated control.

Table 2. The performance of propamocarb-HCl used as a seedbed drench on *Phythium ultimum* in pepper seedlings (artificial inoculation).

Treatment	Surviving plants[z]	Plant height[z]	Plant weight[z]
Inoculated control	100	100	100
Non-inoculated control	131	100	95
Propamocarb-HCl	151	118	105
Etridiazole	132	106	106

[z]In % to the inoculated control.

Trials in the open field confirmed that propamocarb-HCl is also active on *Phytophthora capsici*, another important pathogen in pepper (Table 3). Applied as a drench at sowing, it reduced infestation to 5%, compared to 18% in the standard treatment with captafol, and 40.5% in the untreated control. Trials in the Republic of Korea (Table 4) showed that, following repeated treatment with propamocarb-HCl, plants grew more vigorously and increased yields compared to those treated with the conventional standard treatment.

Tests carried out by Dr. Dehne at the University of Hannover, Federal Republic of Germany showed evidence that propamocarb-HCl did not have any significant adverse effect on the beneficial VA-mycorrhiza in the roots of cucumber and maize plants in contrast to the other fungicides tested, i.e. captan, benomyl and metalaxyl (Table 5).

Table 3. The performance of propamocarb-HCl used as a seedbed drench on *Phytophthora capsici* in peppers.

Treatment	Dose rate (% concentration)	Diseased plants (%)	% control
Untreated control	–	40.5	–
Propamocarb-HCl	0.25	5.0	88
Captafol	0.15	18.0	54

Table 4. Effect of 2 applications of propamocarb-HCl on growth and yield of red pepper at two locations in the Rep. of Korea.

Location/ Treatment	Plant height (cm)	Leaves/ plant (no.)	Fruits/ plant (no.)	Yield (kg/ha)
Ansong				
Propamocarb-HCl	14.3	8.4	20.4	257
Standard[z]	14.1	7.8	15.6	220
Haman				
Propamocarb-HCl	35.4	19.4	22.3	296
Standard[y]	32.5	14.6	18.6	231

[z]Captafol and mancozeb. [y]Thiophanate-methyl and chlorothalonil.

Table 5. Effect of fungicides on the development of VA-mycorrhiza on cucumber and maize after a single drench application.

Treatment	Root infestation with VA-mycorrhiza (%) of infested roots	
	Cucumber	Maize
Untreated control	41.3	60.7
Propamocarb-HCl	39.0	56.2
Captan	12.7*	15.5*
Benomyl	3.5*	7.3*
Metalaxyl	22.9*	26.5*

Source: Dehne 1986. *Significantly different from the untreated control (P = 0.05).

Discussion

These investigations showed that propamocarb-HCl effectively controlled important pathogens such as *Pythium ultimum* in tomato and pepper and *Phytophthora capsici* in pepper. In addition, applied according to the instructions for use, treatments with propamocarb frequently led to an improved plant vigor and increased yields.

Although propamocarb-HCl belongs to the group of fungicidally active carbamates, the mode of action has not yet been clarified, the very narrow activity spectrum, the high systemic properties and the often observed low activity of propamocarb *in vitro* in contrast to its excellent activity *in vivo* may indicate differences to other compounds in this group such as mancozeb or maneb.

The narrow activity spectrum increases the safety of propamocarb-HCl against nontarget organisms. In particular, in an integrated pest management system, the choice of an appropriate pesticide should not only depend exclusively on its performance against the target organism, but also on its specificity, particularly its safety to beneficial organisms.

Propamocarb-HCl does not interfere with the development of the symbiotic-living VA-mycorrhiza, , which occur on most crop plants and in most soil types and sites (Winter, 1951; Dehne, 1981). Their usefulness to crop plants, resulting in improved nutrient uptake and increased resistance to stress factors and pathogens has been demonstrated (Dehne, 1982, 1987; Hall,

1987; Schönbeck. 1986). Hence, if fungicide treatments against soil-borne pathogens are necessary, care should be taken to ensure that they control only the target organisms and not injure the beneficial VA-mycorrhiza.

The demonstrated efficacy against important pathogens, crop safety and safety of propamocarb-HCl against beneficial VA-mycorrhiza, combined with the great flexibility in application, including drip irrigation (which should be used in preference to large-scale treatments for ecological and economical reasons), leads to the conclusion that propamocarb-HCl is an appropriate compound for the control of soil-borne pathogens within an integrated pest management system.

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Symposium Discussion

I.D. Erinle: How does propamocarb compare with metalaxyl?

T. Wilde: According to the investigations by Dehne (1986), metalaxyl treatment (as a drench) causes a decrease of the development of VA-mycorrhiza in the roots of cucumber and maize. In contrast, propamocarb did not show an adverse effect on this beneficial organism.

Cultural Management

308

35

Water Management of Tomatoes in the Tropics

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Abstract

Tomato is a universally grown crop because it is a recognized source of vitamins and minerals. It can also be used as a fresh vegetable, or can be processed and stored for later consumption. Thus tomatoes can raise the diet quality of many developing countries. Nearly 50 million tonnes of tomatoes are grown yearly in the world on over two million hectares of land, but less than 20% of the yield comes from the tropics. Adverse climatic conditions and soil characteristics are primarily responsible for the low productivity of tomatoes. Excessive rainfall often restricts access to the field, impedes soil aeration, leaches nutrients from the root zone, enhances weed growth and diseases, and reduces the efficacy of fertilizers and pesticides. Constant high temperature and humidity conditions and the sensitivity of tomatoes to water stress and poor soil aeration also inhibit the development and growth of tomatoes. In this paper, we will review the fundamentals of water management and irrigation. We will discuss water and nutrient management techniques which can be used under tropical conditions, and we will review and describe recent developments in some systems and procedures which can be adapted to tropical conditions to improve the productivity of tomatoes and other vegetable crops.

Introduction

Tomato (*Lycopersicon esculentum* Mill.) is the most widely grown vegetable crop in the world, mostly because it improves the income of the growers, expands export potential, improves the supplies of vitamins and minerals in human nutrition, and can potentially generate employment in urban and rural areas (Villareal, 1980). The versatility of the tomato crop contributes greatly to its popularity as a food product: tomatoes can be processed and canned easily as a whole or as paste, juice, sauce or powder, or eaten raw, alone or in combination with other foods. The tomato was the first vegetable crop to be processed for canning in the 18th century by the Frenchman, Nicholas Appert.

To this day, the tomato remains by far the world's most important vegetable for processing in terms of tonnage and value, and the production for processing varies between 16 and 20 million tonnes, about one third of the world total tomato production (Portas, 1987). The processing tomato tonnage in 11 important producing countries was forecast for 1987 at 14.9 million tonnes by the US Foreign Agricultural Service (Table 1) which is up by three percent over 1986.

Water plays a crucial role in determining the yield of tomato (Rudich and Luchinsky, 1987), and it is no wonder that average yields of indeterminate trellised tomato are in excess of 200 t/ha are achieved in the Netherlands under precise water and nutrient controlled conditions in glasshouses (Van de Vooren et al. 1987). In arid and semiarid climates where precipitation is not a factor during most of the growing season, irrigation management requires knowledge of the crop water requirement in relation to the soil water capacity, the atmospheric demand and the plant physiological water status.

In the tropics and other humid regions, the problems of normal irrigation management are aggravated by erratic rainfall which may exceed the soil storage capacity, causing nutrient losses

from the root zone and deficient aeration (Wacquant et al. 1975; Phene and Beale. 1976; and Feddes et al. 1978).

Boyer (1982) tried to determine which environmental factors were responsible for crop productivity falling short of its genetic potential: Table 2 shows an area breakdown of the soils in the US subject to environmental limitations of various types (USDA-SCS. 1975). The area of US soils affected by water management factors such as drought (25.3%), wetness (15.7%), and salinity and alkalinity (7.4%) accounts for nearly half of all the agricultural land (48.4%), but the cost of crop losses associated with the above water management problems, estimated from insurance indemnities from 1939 to 1978, is 59.3% of all losses (Table 3) (USDA-Agr. Stat. 1979).

Hence, improvements in crop productivity can be achieved by improving water management practices to alleviate problems caused by drought, salinity and alkalinity, and waterlogging of the soil. The problems associated with soil wetness can be solved by growing tomatoes in greenhouses (Kratky et al. 1980), under narrow plastic rainshelters (Kratky and Roan. 1986) or protective plastic tunnels (Brochier. 1979). Good results can also be obtained by raising the beds in combination with the use of compost, by mulching with rice straw, and by selecting sandy soils which are better drained than loamy or clay soils (Villareal. 1981). In the humid southeast of the US, Phene and Beale (1976) solved the problems generated by high precipitation and waterlogging by minimizing the use of the soil as a storage reservoir for water and nutrients. Frequent small quantities of irrigation water and nutrients were applied directly to the root zone by subsurface drip irrigation. These frequent applications provided the water and nutrient needed by the crop, at least on a daily basis, leaving considerable soil volume available for storing

Table 1. Processing tomato yield for 1986 and 1987 (estimated) and percentage change between two years for 11 important producing countries.

Country	Processing Tomato Yield (t/year)		
	Estimated 1987	1986	% Change
United States	6,775	6,707	+1
Canada	475	474	N.C.
Mexico	370	300	+23
Italy	3,150	3,240	−3
France	290	242	+20
Greece	1,180	1,149	+3
Spain	761	618	+23
Portugal	500	545	−8
Turkey	900	700	+29
Israel	220	186	+18
Taiwan	310	384	−19
Total	14,931	14,546	+3

Table 2. Area of farmlands in the United States with soils subject to environmental limitations listed.

Environmental limitation	Area of U.S. soil affected (%)
Drought	25.3
Shallowness	19.6
Cold	16.5
Wet	15.7
Alkaline salts	2.9
Saline or no soil	4.5
Other	3.4
None	12.1

Source: USDA-SCS 1975.

Table 3. Proportion of insurance indemnities for various types of crop losses in the United States form 1939 to 1978.

Cause of crop loss	Proportion of payments (%)
Drought	40.8
Excess water	16.4
Cold	13.8
Hail	11.3
Wind	7.0
Insect	4.5
Disease	2.7
Flood	2.1
Other	1.5

Source: USDA-Agr Stat. 1979.

water from precipitation, reducing leaching losses of nitrate-nitrogen, improving soil aeration, and significantly increasing yields and quality of sweet corn, tomato, pepper, potato, and tobacco.

The objectives of this paper are to consider the water requirement of the tomato, describe basic irrigation scheduling concepts, discuss the various alternatives introduced above, and propose a management method which integrates several of the concepts above.

Water Requirement of Tomato

Haise and Hagan (1967) defined the main objective of irrigation as the application of water to provide plants with sufficient water to prevent stress that may cause reduced yield or poor quality of harvest. The frequency and amount of applied water is a function of climatic and weather conditions, crop species, variety, stage of growth and rooting characteristics, soil water retention capacity and texture, irrigation system and management factors. Many other factors may interact and affect irrigation water requirements indirectly (Table 4), but they are more difficult to quantify precisely (Phene, 1986).

Irrigation requirements can be determined by using several different methods based on soil water measurements, plant water or water stress measurements, atmospheric heat and mass transfer and combinations of the above (Burman et al. 1981; Stegman et al. 1981). With the advent of computerized weather station networks, telecommunication, and personal computers (PCs), much attention has been devoted to calculations of water requirements of crops, based on evapotranspiration of reference crops (Doorenbos and Pruitt, 1977). Lysimetric measurements have been used to determine the evapotranspiration (Etc) of tomatoes in semiarid regions, and crop coefficients (Kc) were derived with respect to a grass reference (Eto) (Pruitt et al. 1984; Phene et al. 1985). Table 5 shows the Etc of processing tomatoes measured in California for three years using a precision weighing lysimeter. These data indicate that Etc of high-yielding tomatoes is about 710 mm for the semiarid climate of the San Joaquin Valley of California. The yield of large red tomatoes was 220 t/ha and the water use efficiency (WUE) was 3.1 t/cm of water evapotranspired.

By contrast, Lin et al. (1983) reported water added for tomatoes in Taiwan ranging from 280 to 580 mm with corresponding WUEs ranging from 2.3 to 1.0 t/cm of water; however, there was an additional 75-85 mm of precipitation and the water table varied between 1.4 and 1.8 m from the surface so that the crop could have extracted some of its water from the soil above the water table.

In Tunisia, Van Ootegem et al. (1982) studied the tomato response to water application and concluded that the water requirement of tomato was 525 mm when the maximum yield was 113 t/ha, and a maximum WUE of 2.95 t/cm of water.

Table 4. Factors affecting irrigation water requirement.

Water Factors	**Soil Factors**
Water availability (amount and time)	Soil structure
Water quality	Soil texture
Climatic/Weather Factors	Soil depth
Ambient temperature (day/night)	Mechanical impedance
Solar radiation	Infiltration rate
Wind speed	Drainage rate
Rainfall	Soild aeration
Humidity	Water retention characteristics
Day length	Hydraulic conductivity
Length of growing season	Water table
Plant Factors	Soil salinity
Crop variety	Soil fertility
Rooting characteristic	Soil temperature
Drought tolerance	Soilborne organisms
Growth stage	
	Management Factors
Harvestable constituent	Dates of planting/harvesting
Yield and quality	Plant population
Length of growing season	Irrigation system
Salt tolerance	Critical growth stages
Nutrient requirement	Fertilization
Stomatal mechanism	Crop protection
Canopy architecture	Cultivation

Table 5. Water balance of processing tomatoes grown in a lysimeter in 1984, 1985 and 1987 at Five Points, California, USA [2]

Components of water balance	Water balance of lysimeter treatment		
	1984	1985	1987
Planting – Harvesting dates	67-208	53-214	56-219
Number of days	141	161	163
Reference ET (mm)	1008	910	940
Water applied (mm)	692	811	723
Drainage (mm)	0	28	29
Soil water content change (mm)	+ 34	+ 19	-17
Crop ET (mm)	658	764	711
Application efficiency (%)	95	94	98

Reference ET is the evapotranspiration of well-irrigated, short-chipped grass. Application efficiency is the ration of crop ET/water applied

Rudich and Luchinsky (1987) clearly demonstrated that the water requirement of tomatoes is affected by the cultivar used and showed that the crop production functions (yield as a function of evapotranspiration) varied widely.

Phene (1987) showed that the method of irrigation also affects the Etc requirement of a crop (Figure 1) and that to maximize WUE and yield, one must maximize crop transpiration and minimize evaporation from the system (Figure 2). Hence, either the water requirements

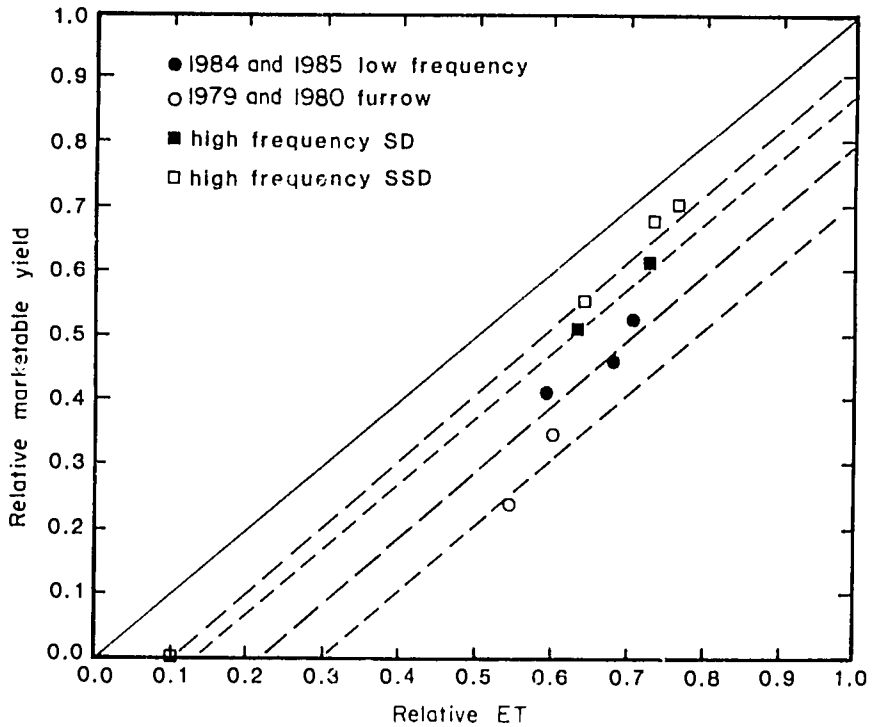

Figure 1. Effect of irrigation system and irrigation frequencies on relative marketable yield (Y_r) of tomatoes. (SD = surface drip; SSD = subsurface drip). Yr = marketable yield ÷ potential yield where potential yield was assumed to be 300 t/ha. Relative ET = crop ET ÷ potential crop ET and potential crop ET = 900 mm).

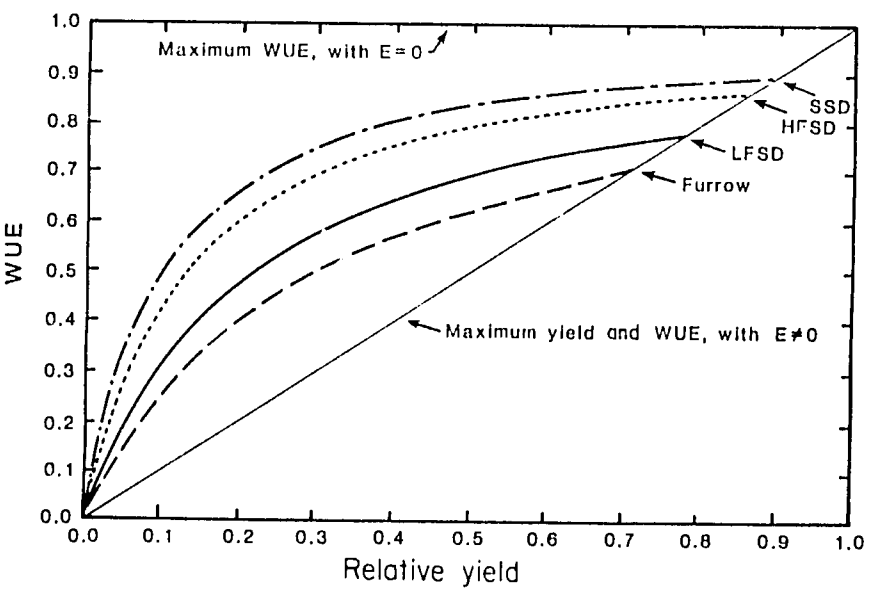

Figure 2. Effect of irrigation systems and frequencies on water use efficiency (WUE) of tomatoes.

for a crop are site specific and the specifics of the soil-plant-atmosphere system play an important role in determining its water requirement, or the methods used for determination of plant water requirements need to be refined, standardized and better understood.

Soil Water Balance Method for the Determination of Evapotranspiration

Water is lost from an irrigated field in several ways: evaporation from the soil and plant surfaces, transpiration from the plant leaves, and deep percolation below the root zone. The combined evaporation and transpiration is referred to as evapotranspiration (Etc) which is the amount of water actually used by the crop to satisfy its water requirement. Water is added to a field by rainfall (P), irrigation (di) and by contribution from a shallow water table (Wt), when one is present. In the process of delivering water to the farm and applying it to the field, water losses are incurred by leakage and spills (L), runoff (Ro) and canal seepage (S). Furthermore, since, conventionally, soil water is allowed to fluctuate, the soil water content will change drastically upon irrigation (ΔW if measured by weight or ΔO if measured by volume) and this change must be accounted for. In semiarid and arid areas, rainfall is not sufficient to leach the salts added to the soil by irrigation and additional water must be applied to the soil to prevent a build-up of salt (salinity). This term is referred to as the leaching requirement or leaching fraction (Lr). Dp is the water percolating below the root zone in excess of Lr. Figure 3 schematizes the partitioning of the water diverted for irrigation at the farm. Burman et al. (1981) have defined the unit efficiency factor as the ratio of the depth or volume of irrigation water required for beneficial use (dbu) in the specified irrigated area to the depth or volume of water delivered to this area (di):

$$di = Etc + Dp + Ro + Lr + L - P - \Delta O - Wt \qquad [1]$$

where di represents the total depth of water delivered to the area and required for irrigation (all units are in mm except for Ei which is a dimensionless fraction). The terms Dp, Ro, and L can be lumped into the nonbeneficial uses of water so that the eq. [1] can be rewritten as:

$$di = \frac{Etc + Lr - P - Wt - \Delta O}{Ei} \qquad [2]$$

Other water requirements include: seed germination, chemical application, frost protection, climate modification, soil temperature and dust suppression (Burman et al. 1981).

Measurement of water requirement variables is difficult and requires time, labor, and instrumentation. Therefore, irrigation systems and measurement methods which minimize these measurements are desirable. For instance, Dp in excess of leaching requirements for salinity control (Lr), Ro and L, all waste water and usually require additional management. Those systems which are not dependent on soil to transport the water across the field, (sprinkler, center pivot, lateral move, and drip systems) can be managed so that Ro and L are minimized or eliminated and Dp can be reduced to Lr. Under nonsaline conditions and in the absence of a water table Lr and Wt can be ignored. High- frequency irrigation applications can maintain O constant, so that $\Delta O = 0$, and under saline conditions leaching can be performed continuously during the irrigation season by applying the Lr plus Etc or by applying one large amount for leaching before or after the growing season so that during the growing season.

$$di = \frac{Etc + Lr - P}{Ei} \qquad [3]$$

Thus, under high-frequency irrigation regimes, Etc, Ei, Lr, and P are the principal factors in determining irrigation water requirements. Precipitation and Lr can be measured and Ei can

be measured or estimated based on design or on previous years' experience. Evapotranspiration is the most difficult factor to quantify and utilizing lysimeters is the only direct method for quantifying Etc. Indirect methods include: the combination method (energy balance and mass transport), evaporation pans, the constant soil matric potential method, measurement of canopy resistance, and dynamic plant simulation models.

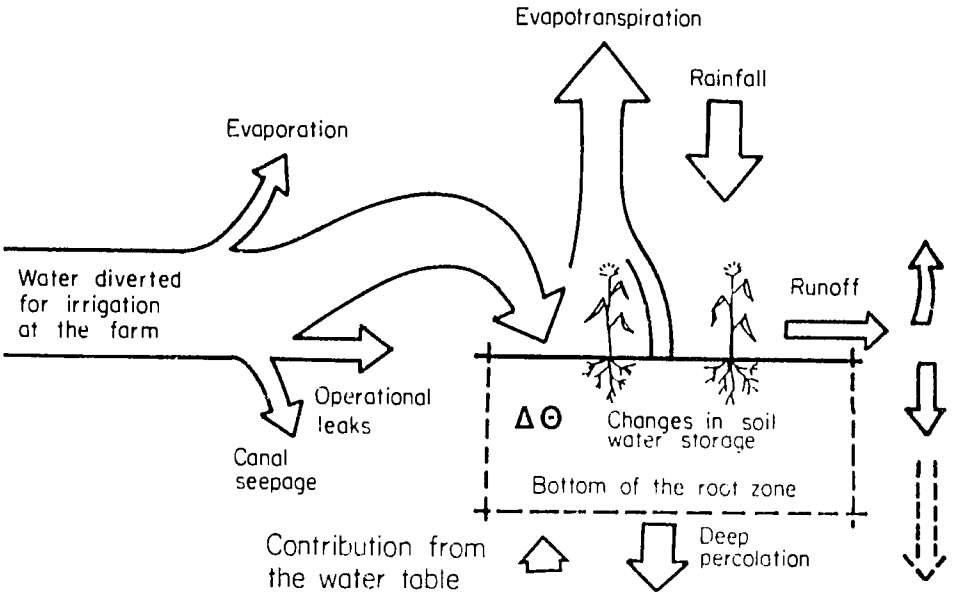

Figure 3. Partitioning of the water applied and used in the determination of irrigation water requirements of crops in irrigated areas.

Basic Irrigation Scheduling Concepts

Irrigation scheduling involves two decisions: how much water to apply (volume or depth), and how often to apply water (frequency). Irrigation timing is usually based on either soil water measurements (Phene et al. 1973; Phene and Howell. 1984), plant measurements (Hiler and Clark. 1971; Jackson. 1982; Stegman et al. 1976), soil water accounting using climate, crop and soil data (Jensen et al. 1971), and weather data (Doorenbos and Pruitt. 1977; Pruitt et al. 1984), or various combinations of these methods. Irrigation quantity is usually based on the type of irrigation system, plant response to water deficit, plant growth stage, soil infiltration, salinity control and soil water deficit. These decisions are critical to the management of any irrigation system but even more critical with drip irrigation since the primary objective of drip irrigation is to maintain a small portion of the soil profile at optimal soil water potential with relatively small and frequent applications of water. Therefore, the concept implies that irrigation frequency increases as the soil texture becomes coarser, the soil becomes shallower, or the probability of rainfall is high (Phene and Beale. 1976). Similarly, one needs to know precisely how much water is applied to the field and how this water is distributed in the soil profile throughout the field.

There are two potential objectives for scheduling irrigations: (1) maximum yield per unit of land area, and (2) maximum yield per unit of applied water.

Most managers hope to achieve the first objective; however, as irrigation costs increase and water supplies diminish, more will tend to adopt the latter objective. To maximize yields of many crops, plant water potential should be maintained at high levels that are conducive to maximum seasonal net photosynthesis. Hsiao (1973) suggested that stresses are mild when

midafternoon plant water potentials are not less than about -1.2 kJ/kg, moderate in the range of -1.2 to -1.6 kJ/kg, and extreme below 1.6 kJ/kg for many crops. (1 kJ/kg ≃ 1 bar)

Irrigation scheduling methods based on evapotranspiration and soil water measurements are becoming very popular because of the increased availability of computers and sensing equipment. In the future, methods based on plant and water stress measurements may also become more popular as the instrumentation becomes more available. In this paper we will restrict the discussion to irrigation scheduling based on evapotranspiration models and direct soil water measurements.

Irrigation Scheduling Based on Evapotranspiration Models

Irrigation scheduling models based on evapotranspiration have been widely used worldwide (Jensen et al. 1970; 1971). Essential crop evapotranspiration (Etc) information required for these models and the irrigation decision criteria include:

1. a climatically estimated reference evapotranspiration (Eto);
2. an index for relating 'expected' crop water use to Eto (crop coefficient curve Kc);

$$Kc = \frac{Etc}{Eto} \qquad [4]$$

3. an index for estimating the additional soil water evaporation from a wet soil surface;
4. an index for estimating the effect of soil water depletion on the actual Etc rates;
5. an estimation of extractable soil water amounts by specific crops from specific soils;
6. a relationship between 'expected' crop yield and crop water use.

Many of the input variables needed to operate the model are still not well defined and need to be estimated. Although the model can predict irrigation requirements accurately for low frequencies, it is not presently feasible for scheduling high frequency drip irrigation since hourly input data are needed.

An Etc model which employs an hourly version of the Modified Penman equation (Pruitt and Doorenbos, 1977) has been used in California for three years on a statewide network of approximately 60 automatic weather stations. The program, California Irrigation Management Information System (CIMIS), provides reference crop (grass) evapotranspiration (Eto) data to growers on an hourly and daily basis. A telephone modem, keyboard, and terminal are needed by the users to communicate with a computer located in Sacramento, California, through a menu-driven software package. Daily, at midnight, the computer automatically calls each weather station in the system, transfers all the weather data into its storage medium, and calculates Eto for each hour of the past 24 hours. The grower uses the previous day's or several days' Eto with Equation 4, and makes the essential irrigation decisions of when and how much to irrigate. Normally a well trained irrigation advisor, employed either full-time or hired on a consulting basis, will schedule irrigation on a large farm.

Results from statewide field verifications by CIMIS field staff with cooperating growers indicated that:

1. Various CIMIS-supplied Kc's needed adjustments downward;
2. growers were often applying too much or too little irrigation water;
3. long-term average irrigation schedules are inadequate for meeting month-to-month and day-to-day changes in the evaporative demands even in the San Joaquin Valley where the weather changes relatively little from one day to the next during the spring and summer months;
4. CIMIS-based irrigation scheduling could improve crop productivity.

In general, the application of this method required relatively uniform climate over large irrigated areas in order to minimize the number of weather stations required; even under these conditions the effective radius of a weather station is 40 km at best.

Irrigation Scheduling Based on Direct Soil Water Measurements

In areas where the rainfall distribution is erratic, irrigation scheduling is more reliable if it is based on specific field site measurements of soil water. Scheduling frequent irrigations can be accomplished with automatic feedback control based on soil water potential. With drip irrigation, the storage capacity of soil is de-emphasized and water is applied to supply the water potential continuum and match the evapotranspiration rate; thus, there is less margin for error and timeliness is important.

Irrigations based on soil water potential are among the oldest irrigation scheduling techniques used. Tensiometers (Richards and Gardner, 1936), thermal methods (Shaw and Baver, 1939), gypsum blocks (Bouyoucos and Mick, 1947) and thermocouple psychrometers (Richards and Ogata, 1958) have all been used successfully. Recently, Cary and Fisher (1983) used microprocessors and soil water sensors to simplify irrigation decisions. In one system, a microprocessor-based circuit, coupled to a programmable calculator, provides an on-site estimate of the allowed time until the next irrigation, based on field data and an operator-supplied parameter.

A thermal method which measures soil matric potential independent of soil texture, temperature or salinity is based on frequent measurements of the ability of a porous ceramic sensor to dissipate a small amount of applied heat (Phene et al. 1971; Phene et al. 1973; Phene and Howell, 1984). With proper calibration, the sensor can be used to monitor soil matric potential and control irrigation automatically. In addition to water availability, soil physical properties such as oxygen diffusion (aeration) and soil mechanical strength (impedance) are used to define the range of soil matric potentials (Ψm) optimal for root growth and activity. Figure 4 shows an example of the optimal Ψm for a Hanford fine sandy loam. Within this range, a soil matric

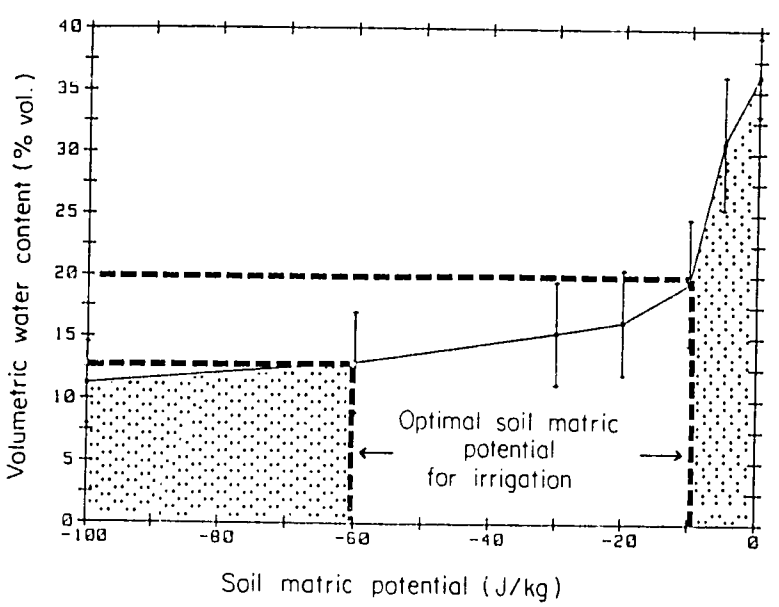

Figure 4. Water desorption curve and optimal Ψm for irrigation of a Hanford fine sandy loam soil (Typic Xerorthents).

potential is defined at which irrigations are to be started (threshold). The optimal Ψm should be about -25 to -35 J/kg and has a range extending between about -10 and 60 J/kg. The optimal Ψm has a range which increases as soil texture becomes finer but is extremely narrow in compacted coarse-textured soils.

Therefore, physical characterization of sandy soils is usually necessary, whereas the optimal Ψm for fine-textured soils can be approximated.

For close loop feedback automated irrigation, the soil sensor should be placed near the center of the root zone. In this location the majority of the root zone is never allowed to dry below the soil matric potential threshold before the sensor detects the drying trend and triggers another irrigation.

Monitoring soil matric potential and controlling an irrigation system automatically requires equipment to:

1. sample automatically several sensors sequentially;
2. compare each sensor output to the threshold value; and
3. have computer outputs capable of controlling and monitoring the irrigation system.

Desktop computers and microprocessors have been successfully applied (Phene and Howell, 1984) and commercial equipment is also available to measure soil matric potential and control irrigation systems automatically (Phene and Phene, 1987).

Alternative Water Management Techniques

Tomatoes require large amounts of water for growth and development with adequate distribution in time and space (Villareal, 1980). Using the 1987 data reported in Table 5, it was calculated that 32.3 kg of water are required to produce 1 kg of red tomatoes under the climatic conditions of the California San Joaquin Valley. In order to maximize productivity (where productivity is defined as yield/inputs as opposed to production which does not take into consideration the inputs) tomatoes also require adequate soil aeration (well drained soil), solar radiation, warm day temperature and moderately cool night temperature. Water management of crops subjected to large precipitation which causes waterlogging of the soil is much more difficult than managing irrigation in arid or semiarid areas where the probability of rainfall is low. In this section, we will address the water management aspects of irrigated crops under rained conditions, firstly with the use of protective shelters, and secondly by selecting cultural practices which minimize the effects of rainfall without protective shelters.

Greenhouse, Rainshelter and Protective Tunnels

Protected cultivation of tomatoes can be achieved with a wide range of technologies ranging from a simple plastic tunnel to a complete environmentally controlled greenhouse. The objectives are usually to control the climate, insects, root environment, and leaching of fertilizers, and to enrich the atmosphere with carbon dioxide.

Kratky et al. (1980) conducted extensive varietal testing to select the best tomato cultivar for intensive greenhouse production in three of Hawaii's vegetable-producing areas. Unfortunately the grading standards were not uniform over the three locations. Although its performance varied markedly due to differences in soil, temperature, light, cultural procedures and grading standards, the cultivar Tropic yielded in excess of 10 lb./plant total yield in all tests and up to 16 lb./plant in the Pulehu trial no. 2. Since the greenhouses were mostly used as rainshelters rather than as controlled environment systems, the full benefits of the practice cannot be evaluated accurately, although these results indicate that yields could reach levels approaching those observed in The Netherlands (Van de Vooren et al. 1987).

Kratky and Roan (1986) grew trellised tomatoes with narrow rainshelters at the Asian Vegetable Research and Development Center (AVRDC) in Taiwan. Two AVRDC heat-tolerant cultivars were used, a large-fruited type (CL 5915-206-2-2-0) and a small-fruited (CL 5915-553-D4-3-0). Trellised vines were protected by 1.75 m-high × 0.8 m-wide plastic covered rainshelters during the hot rainy summer season. Grade number 1 (fruits of good shape and appearance with diameter greater than 5 cm) yields of the large-fruit and small-fruit cultivars were respectively 0.96 and 0.51 kg/plant higher than unprotected plants grown under otherwise similar conditions. The beds were furrow-irrigated during the dry part of the growing season. Other benefits of this practice included: improved early establishment of transplanted seedlings during high rainfall, less fruit cracking in the large-fruited cultivar, and lower occurrence of insect damage due to the prolonged persistence of insecticides not washed off by the rain. Results from this study suggest that narrow plastic rainshelters can improve tomato production for hot and humid tropical areas but that further investigations should be conducted.

Brochier (1979) described the use of tunnel structures with galvanized framework, constructed without gable-ends and oriented along the predominant direction of the wind. These tunnels have been used successfully in Gabon and in French Guyana. I have observed many of these in Algeria, and particularly in the Sahara desert, where they are used to protect the crops against the blowing sand and hot winds. These tunnels are 54 m long by 7 to 8 m wide and 2 to 3 m high and polyethylene is stretched tightly over the standard galvanized framework. The structures are more resistant to high wind than wooden structures, which tend to deteriorate with time and eventually collapse. Tornadoes with wind speeds of up to 120 km/h oriented along the length of the structure have been encountered in Gabon without causing damage either to the crop or to the structure. Because of the impossibility of rotating herbaceous species to control fungal diseases, nematodes and bacterial infestations, soilless cultivation techniques are essential with the use of protective structures. Various substrate materials and techniques for irrigation and fertigation are described, but one which is easily accessible and can easily be maintained from year to year is sand. In Guyana sea sand is used while in Gabon, sand of fluvial origin from a quarry is used. The sand is sterilized against all diseases and nematodes using a two percent solution of formalin 40% by volume. The yield grown under these tunnels have reached 30 kg/m^2/year. There is no laborious work, and one family can cultivate 2000 m^2 with additional labor at certain peak labor requirement times. The author concludes that plasticulture has developed in the equatorial regions and is being closely followed by the adoption of simplified hydroponic techniques.

Management Without Protective Shelters

Villareal (1981) described the constraints encountered when growing tomatoes during the rainy season: "Land is muddy or flooded, which restricts entrance to plantings; weeds grow vigorously; diseases thrive above and within the soil; applied chemicals are washed off plants; fertilizer is leached; the high water table prevents the roots getting oxygen; and light intensity is low. All this makes vegetable production risky, if not impossible, but there have been several significant developments towards combating these hazards in the tropics." Several factors which significantly improve tomato growing conditions in the tropics include: (1) raising beds 30 cm with compost (20-40 t/ha) in the center covered by rice straw mulch (10-20 t/ha); (2) selecting sandy soils for planting tomatoes, which improves drainage and aeration of the soil in the beds but requires more frequent fertilizer applications; and (3) selecting insect- and disease-resistant varieties combined with appropriate chemical and management practices.

Phene and Beale (1976) designed a water-nutrient management system for sandy loam soils in humid regions to prevent plant water and nutrient stresses and to maximize available soil water storage to accommodate rainfall. This method, based on subsurface drip irrigation, minimizes the need for the soil to act as a storage reservoir for water and nutrients by frequently irrigating a small portion of the root zone with small amounts of water and nutrients.

Measurements of soil oxygen diffusion rate (ODR), soil strength, water desorption characteristics and unsaturated hydraulic conductivity were used to determine the high-frequency irrigation schedule and threshold soil matric potential for initiating irrigation (Figure 4). When compared to sprinkler and furrow irrigation, the subsurface drip irrigation system reduced the losses of NO_3-N from the root zone, increased yield and quality of sweet corn and N uptake efficiency. Similar results were later obtained with potatoes, tobacco, and tomatoes when rainfall in July and August averaged 245 mm/month.

Proposed Water Management Method for the Tropics

The water management constraints on high productivity outlined in the previous section should be used as basic criteria for a new method to increase productivity. This method should: (1) minimize waterlogging conditions in the soil beds; (2) control weed growth; (3) control diseases within and above the soil; (4) prevent washing of chemicals from the plants; (5) prevent leaching of fertilizer; (6) control level of water table; (7) improve sunlight interception by the canopy (we cannot control sunlight intensity); (8) minimize plant water and nutrient stresses. The various methods discussed above need to be integrated into a total water management system. Water management constraints and suggested systems and procedures for correcting or preventing the problems are as follows:

1. Control waterlogging of soil bed:
a) select coarse-textured soils
b) raise bed with organic matter (compost)
c) use organic mulching (rice straw)
d) install plastic mulch (where possible)
e) install subsurface drainage system
f) level land to a given slope to promote surface drainage
g) irrigate with high-frequency subsurface drip system.

2. Control growth of weeds:
a) use organic mulching
b) install plastic mulch
c) fumigate soil with subsurface drip system and plastic mulch
d) maintain dry soil surface on bed
e) use herbicides.

3. Control diseases within soil and above soil:
a) fumigate soil with subsurface drip system and plastic mulch
b) apply pesticides with electrostatic sprayer
c) install rainshelters
d) practice integrated pest management.

4. Minimize chemical wash-off from plants:
a) spray pesticides with oil-based carriers or with chemical sticking agents.
b) spray with electrostatic system for adhesion to bottom of leaves
c) install rainshelters.

5. Prevent leaching of fertilizers:
a) use plastic mulch
b) fertigate with subsurface drip irrigation
c) use rainshelters.
d) use slow release fertilizers.
e) use organic fertilizers and compost.

6. Control level of water table:
a) grade soil surface to promote surface drainage
b) improve irrigation scheduling and use high-frequency irrigation
c) install controlled subsurface drainage system.

7. Improve sunlight interception by canopy:
a) space and orient beds for maximum sunlight interception
b) adopt plant population for incoming sunlight.

8. Minimize plant water and nutrient stresses:
a) irrigate and fertigate with high-frequency subsurface drip system.

Except in a few cases, existing techniques of organic and plastic mulching in conjunction with land grading, installation of subsurface drip irrigation and drainage systems, high-frequency irrigation, and fertigation and fumigation and chemigation practices should be sufficient to raise the productivity of tomato cropping in the tropics. Installation of plastic rainshelters and tunnels may be required under extreme conditions. Figure 5 shows a schematic representation of the system visualized. The advantages of subsurface drip irrigation have been discussed in detail by Phene and Phene (1987).

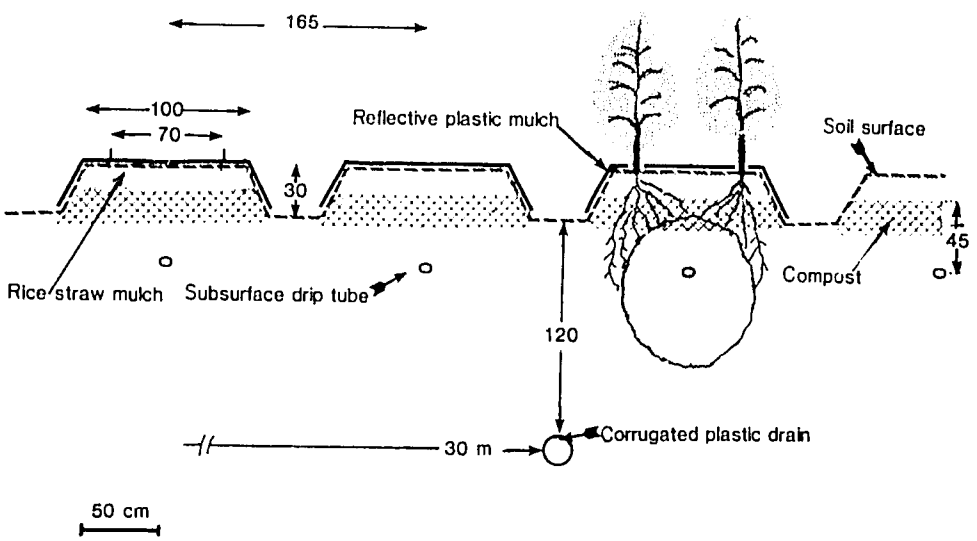

Figure 5. Proposed integrated water management system for growing tomatoes in the tropics. (Shaded area around drip tube represents wetted soil volume from irrigation water.)

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Water-fertility Management for Subsurface Drip Irrigated Tomatoes

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Abstract

Different water and fertility management regimes for drip irrigation were compared at Five Points, California, in 1987, in a study conducted on Panoche clay loam soil (Typic Torriorthents) planted to tomato (*Lycopersicon esculentum* Mill., cv. UC82B). The experiment was designed to test the effects of irrigation frequency, fertilizer injection of P at three levels, and surface versus subsurface drip irrigation, on crop productivity, harvest quality, and water use efficiency. The main irrigation treatments, high-frequency subsurface drip (HFSSD) (several irrigations each day), high-frequency surface drip (HFSD), and low-frequency surface drip (LFSD) (irrigation every two or three days), were arranged in a randomized block design and replicated four times. All treatments were irrigated with the same volume of water. Fertilizer variables consisted of three levels of P injected daily: Po, P_1 and P_2 equal to 0, 67 and 134 kg/ha of P, respectively. Mean yields of large red tomatoes were 206, 190 and 179 t/ha for the HFSSD, HFSD and LFSD treatments, respectively. The mean percentage of culls in each treatment were respectively 2.2% (HFSSD), 3.2% (HFSD) and 3.8% (LFSD) of the total fruit yield. The water use efficiencies (WUE) of the HFSSD and the HFSD treatments, respectively 0.33 and 0.32 g yield/g water, were significantly greater than the LFSD treatment (0.030). The lysimetric measurement of evapotranspiration for the HFSSD treatment was 711 mm for the entire growing season and drainage collected from the 2.3-m deep lysimeter was 29 mm. Results show that subsurface drip irrigation can help conserve natural resources (water and fertilizers) and the quality of the environment (minimal deep percolation and leaching losses) while achieving greater crop quality, productivity and long-term agricultural sustainability.

Introduction

Irrigation has played a strategic role in the continuous process of human evolution and cultural development. In most of the early civilizations, as in many of today's nations, irrigated agriculture has provided and continues to provide the agrarian basis of society (Gulhati and Smith, 1967). The control of water resources for the establishment of highly productive agricultural systems and the subsequent expansion of human population in areas where rainfall is inadequate involves the operation of complex irrigation systems with certain technological and social constraints which, if ignored, may lead to ecological disaster. Problems arise when irrigation is practiced without restraint or knowledge of basic factors governing soil, irrigation water requirements, salinity and plant water use.

Processing tomato (*Lycopersicon esculentum* Mill.) is an important crop in California where it ranks 13 in commodity value (California Crops and Livestock Reporting Service, 1980). Approximately 85,000 ha of processing tomatoes were grown in California in 1987 (83% of total area cropped in US) producing 87% of the total US production (Table 1) (California Agricultural Statistics Service, 1987).

Table 1. 1987 area and yield of processing tomatoes for the major producing states in the USA

State	Harvested area (ha)	Yield (t/ha)	Percentage of total US area (%)	Percentage contracted by processors ('000 t)
California	85,000	70	83.0	6,070
Colorado	251	36	0.2	9
Indiana	2,590	52	3.0	136
Maryland	607	29	1.0	17
Michigan	2,064	57	2.0	121
New Jersey	1,214	43	1.0	53
Ohio	6,475	57	6.0	378
Pennsylvania	1,255	37	1.0	47
Other states	2,578	39	3.0	
United States	102,019	67	100.0	6,938

Source: California Agricultural Statistics Service. 1987.

Processing tomato production in California is dependent upon irrigation to supply most of the crop's water requirement. In climates where water is the primary growth-limiting factor, optimum irrigation management requires knowledge of the crop water requirement in relation to the environmental conditions. However, once the water-limiting factor has been eliminated, precise fertilization in time and space and control of insects and diseases become the most limiting factors in the productivity of irrigated processing tomatoes.

Traditionally, processing tomatoes have been irrigated by sprinkler (Vittum et al. 1958) or furrow irrigation (Aljibury and May, 1970); however, several tests have been made with drip irrigation (Rudich et al. 1977; van Ootegem et al. 1982; Pruitt et al. 1984; Davis et al. 1985) and with subsurface drip irrigation (Phene et al. 1982b; 1983b; 1986a; 1987). Drip and subsurface drip irrigation have improved water management of tomatoes with corresponding increases in productivity and in water use efficiency (Davis et al. 1985; Phene et al. 1985a; 1985b). The importance of precise irrigation scheduling of tomatoes to avoid water stress has been demonstrated by Cannell and Asbell (1974), Rudich et al. (1977) and Phene et al. (1982a). In contrast, excess water applications have caused deficiencies in soil aeration, leaching of nutrients and subsequent yield reductions (Wacquant et al. 1975; Feddes et al. 1978).

Bar-Yosef et al. (1980) have shown that the soil-root volume with drip irrigation is substantially smaller than with sprinkler irrigation and have stated that large water and nutrient gradients can develop rapidly (as in a greenhouse pot) unless irrigation and nutrient applications are frequent. This is especially true of phosphorus (P) which is adsorbed quickly by the soil. Phene et al. (1986a and 1987) demonstrated that daily injection of P through the drip system in addition to conventionally banded P under the seeds at planting significantly increased the yield of tomatoes. The acute salinity and drainage water disposal problems on the west side of the San Joaquin Valley and the increased cost of fertilizers necessitate that on-farm irrigation and fertilizer efficiencies be optimized with respect to yield. The potentially high application uniformity of water and nutrients with drip irrigation (Phene and Beale, 1976) and the elimination of leaching and runoff losses can increase irrigation and fertilizer efficiencies, minimize drainage, conserve soil, and minimize the degradation of surface and groundwater supplies (Phene et al. 1988). The ability of scheduling frequent irrigations and fertilization to precisely meet evapotranspiration and fertilizer demands has been demonstrated (Davis et al. 1985; Hutmacher et al. 1985; Phene et al. 1983a; 1985b). With proper consideration of soil infiltration and water-holding characteristics, crop water and nutrient requirements can be precisely supplied, producing not only high yields but maximizing water use efficiency.

The objectives of this paper are to report the preliminary results of a drip irrigation experiment where three rates of P injections were used to fertilize tomatoes, and to evaluate the effects

of this fertilization on crop evapotranspiration, irrigation and water use efficiency, and on yield and quality of the crop.

Materials and Methods

Processing tomatoes (cv. UC82B) were grown during 1987 in a Panoche clay loam soil (Typic Torriorthents) at the University of California, West Side Field Station. The treatments were arranged in a randomized split plot design and were replicated four times. The main treatments were high frequency subsurface drip (HFSSD); high frequency surface drip (HFSD); and low frequency surface drip (LFSD). The subtreatments were 0, 67, and 134 kg/ha of added phosphorus (P) by injection in the irrigation water. Each main plot was 91 m long and contained 10 beds spaced 163 cm from center to center. The HFSSD laterals were permanently installed in 1984 in the center of each bed at a depth of 45 cm from the top of the bed. The HFSD and LFSD laterals were installed after planting in the center of each bed. All drip irrigation laterals consisted of in-line turbulent flow emitters (Netafim Irrigation, Inc., trade names are given for reference only and do not imply endorsement by the US Department of Agriculture) with a flow rate of 4 l/h and spaced 0.91 m apart. Additional details of the field installation of the irrigation system are found in Davis et al. (1985).

A large weighing lysimeter was used in a feedback mode to schedule irrigations automatically in the HFSD and HFSSD treatments after 1 mm of crop evapotranspiration (E_{tc}) had been measured by the lysimeter and 25 mm was applied to the LFSD treatment after 25 mm of E_{tc} was measured (25 mm is the amount usually applied commercially for drip irrigated tomatoes). The lysimeter was irrigated by subsurface drip irrigation at a rate exactly corresponding to the HFSSD treatment. Drainage was measured with the lysimeter and was assumed to be zero in the field based on an upward soil matric potential gradient and no increase in water content. Precipitation was measured with an automated rain gauge from a nearby weather station; irrigation water applied was measured daily with flow-meters; and E_{tc} was calculated from the water balance equation for the field plots and measured directly by the lysimeter. Details of the lysimeter are available in Howell et al. (1985) and the lysimeter control system in Phene et al. (1986b). A soil fumigant (Vapam, ICI chemicals) was applied through the surface and subsurface drip systems at a rate of about 346 l/ha with one 25-mm irrigation about 25 days before planting in order to fumigate the soil and control weeds and pests. Nitrogen and phosphorus fertilizer (11-48-0) was applied at the rate of 112 kg/ha at planting directly below the seeds. The remaining fertilizers were applied through the trickle irrigation system, starting on day 120. Fertilizers injected were potassium nitrate (KNO_3) and 17-0-0 (CAN-17, calcium-ammonium nitrate). The applications of N and K from KNO_3 were 136 kg N/ha and 381 kg K/ha, respectively. The CAN-17 provided 165 kg N/ha. Total amounts of N and K injected were 301 and 381 kg/ha, respectively. The subtreatment P (phosphoric acid) application of 0, 67 and 134 kg P/ha (P_0, P_1, and P_2, respectively) were injected through the drip irrigation systems. Sprinkler irrigation (18 mm) and rainfall were used to germinate and establish the tomato crop. Twenty-one days before harvest, irrigation applications in the field were reduced progressively to about 60% of the water applied to the lysimeter to increase soluble solids. Processing tomatoes were directly seeded in two rows per bed at a density of 25 seeds/m on February 25 (day 56), emerged on March 20 (day 79) and were harvested manually from August 3 (day 215) to August 6 (day 218). A 10 m^2 area was manually harvested in each of three field replications in order to determine tomato fresh weight yields. Twenty-seven 3 m-long neutron probe access tubes were installed in three replications; the soil water content was measured every two weeks, and these were used in water balance calculations. Leaf petiole samples from the fourth mature leaf down from the terminal (a standard position for tomatoes) were obtained before 10 AM weekly (to prevent depletion of stored NO_3-N) from May 12 (day 132) to July 23 (day 204) and were analyzed for NO_3-N, P and K. Harvested tomatoes were manually separated into four major

categories: (1) large red (diameter > 4 cm), (2) large green, (3) small and (4) culls (rotten, sunscald, cracked, etc.).

A random subsample of tomatoes was used to determine soluble solids. The tomatoes were cut and pulverized in a blender, and the juice was analyzed with a hand-held refractometer, and the measurements were adjusted for temperatures according to the NTSA Standard Table. The mean weight of the red tomatoes was obtained by weighing a bucket full of tomatoes and counting the number of tomatoes in the bucket (approximately 200 tomatoes per bucket).

Results and Discussion

Evapotranspiration

Two levels of water stress severity have been defined by Hsiao (1973): (1) "Stress is too mild to close stomata and inhibit photosynthesis but sufficient to affect expansive growth; and hence leaf area expansion will be reduced and total field CO_2 assimilation and transpiration will be reduced permanently, although, on a per-leaf basis, CO_2 assimilation and transpiration will not be affected; and (2) Stress is severe enough so that the leaf water potential drops below the threshold level for stomatal closure, leading to reduced CO_2 assimilation and transpiration both per unit leaf area and for the total field. However, when the stress ceases, photosynthesis and transpiration recover." Hence, irrigation should replace crop evapotranspiration (E_{tc}) to avoid mild stresses and achieve a maximum rate of leaf area development. We have used high-frequency irrigation scheduling in all of our drip irrigation tests; and we have shown that even in a fine-textured soil, growth and yield of tomato and cotton were increased significantly by high-frequency irrigation (1 mm of crop evapotranspiration replaced by each irrigation) when compared to low-frequency (25 and 50 mm of crop evapotranspiration replaced by each irrigation); however, yields were significantly increased only when the crop evapotranspiration was satisfied precisely by irrigation and the fertility was managed adequately for the root zone generated by the high-frequency irrigation systems (Davis et al. 1985; Phene et al. 1986a).

The evapotranspiration of the HFSSD tomato treatment was measured hourly with the computerized, precision-weighing lysimeter; hourly measurements were accumulated daily and are shown in Figure 1. Table 2 shows the components of the water balance equation for 1987, and these results indicate that crop evapotranspiration of the three irrigation treatments were similar to that measured by the lysimeter even though irrigation in the field plots was gradually cut back over a three-week period to 60% of the water requirement and terminated one week before harvest, while irrigation in the lysimeter continued unrestricted until harvest. The P subtreatments did not affect the evapotranspiration of the crop. Differences in water applied between the lysimeter and the field plots were made up by soil water extraction in the field. As in the lysimeter, drainage in the field was assumed to be negligible below the root zone. Data in Figure 1 indicate that even in a nearly uniform climate, precise irrigation scheduling based on long-term averages is not easily achievable because of variations in crop evapotranspiration and Kc.

Figure 2 shows the mean of three volumetric soil water content profiles on days 135 and 173 and the end of the 1987 experiment (day 212) for the tomato plots irrigated by the HFSSD system at the P 1 level when 67 kg/ha was applied. The differences between the lines represent the change in volumetric water content ($\Delta\Theta$) at each depth during the growing season. The other measurements taken every two weeks during the season are not shown in Figure 2, but their values are between the values for the profiles for day 135 and 212. When the soil water content differences between days 135 and 212 are summed over the entire 2.85 m soil profile, the sum is 44 mm of water depleted from the soil profile during the season (Table 2). Because of the precision of the management of irrigation and the measured upward gradient in soil matric potential (not shown here), we can assume that there was no deep drainage in the field. The time courses of the mean volumetric water content for the three treatments, summed over a

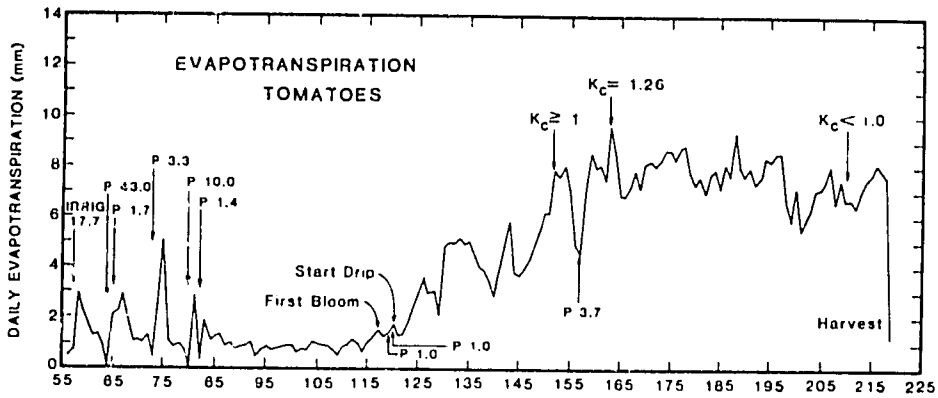

Figure 1. Evapotranspiration of high-frequency subsurface drip (HFSSD) irrigated tomatoes between days 55 and 218 for 1987 as measured hourly by a precision-weighing lysimeter at Five Points, California,

(P = precipitation, Kc is the crop coefficient, where $Kc = \frac{E_{tc}}{E_{tr}}$

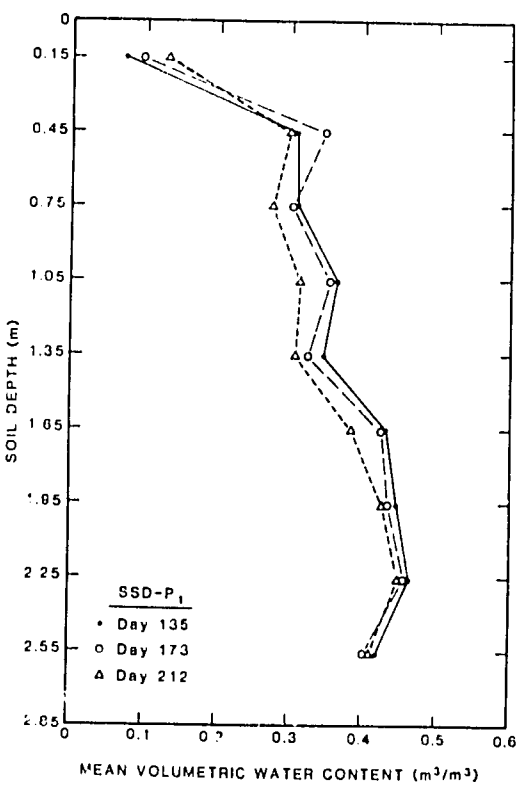

Figure 2.
Mean volumetric soil water content profile at the beginning (day 135) and at the end of the test (day 212) for the tomato plots irrigated by the high-frequency subsurface drip (HFSSD) irrigation system when P was applied at 67 kg/ha (P_1 treatment) in 1987.

soil depth of 2.85 m, are presented in Figure 3. The mean volumetric soil water content of the HFSSD treatment at the P_1 level was 0.331 ± 0.062 m^3/m^3 from day 135 to day 191. The three treatments decreased to nearly the same profile water content from day 191 to day 212

when irrigation was decreased. Figure 4 shows seasonal changes in soil water content profiles for the tomato plots in the HFSD treatment at the P_1 subtreatment level. The results are similar to those obtained for the HFSSD treatments (Figure 2) except for the typical drier soil in the top 45 cm of the HFSSD plots and a slightly drier profile at 1.65 m depth. The mean volumetric soil content of the HFSD plots was maintained at 0.358 ± 0.005 m^3/m^3 from day 135 to day 191 with slightly less precision than that of the HFSSD plots (Figure 3). Results for the LFSD treatment are shown in Figures 3 and 5 and Table 2 with soil water content profiles very similar to those for the HFSD treatment.

Table 2. Components of the water balance for tomatoes irrigated by three water treatments (HFSSD, HFSD and LFSD).

Treatments[z]	Drainage (D)	Soil water depletion (Δ)	Precipitation (P)	Irrigation Sprinkler (I)	Irrigation Drip (I)	Evapotranspiration (E_{tc})
	(mm)					
HFSSD	0	44	65	18	581	708[y]
HFSD	0	30	65	18	582	695[y]
LFSD	0	66	65	18	560	709[y]
Lysimeter	29[x]	17	65	18	640	711[w]

[z]HFSSD = high-frequency subsurface drip, HFSD = high-frequency surface drip irrigation, LFSD = low-frequency surface drip irrigation. [y]Irrigation cutback from day 194 and no irrigation after day 212. [x]Drainage occurred soon after sprinkler irrigation (17.7 mm) was applied for germination and was followed by a large precipitation (44.7 mm). [w]No irrigation cutback or cutoff

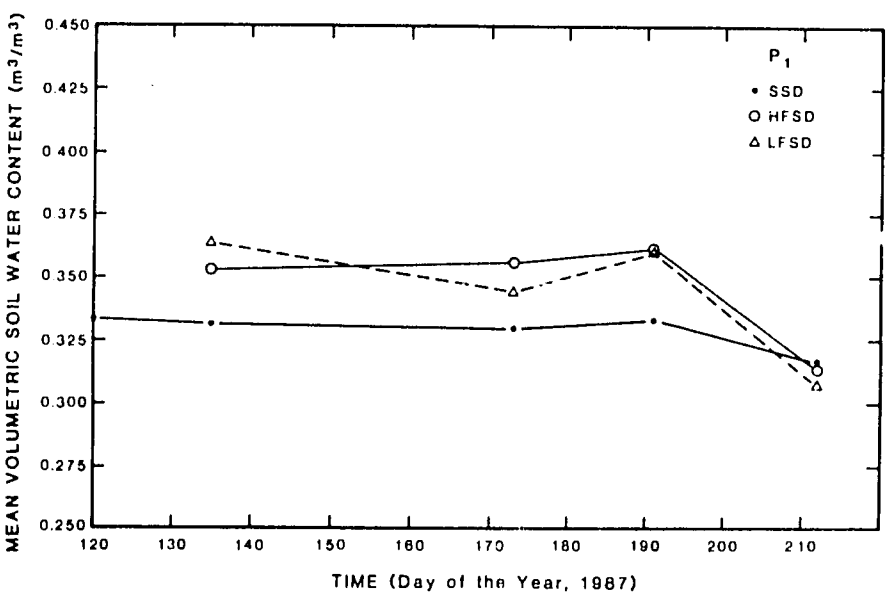

Figure 3. Changes in the mean volumetric soil water content (Δα) of the 2.85 m soil profiles for the plots irrigated respectively by the high- (HFSD) and low-frequency surface drip (LFSD), and the subsurface drip (HFSSD) irrigation systems when P was applied at 67 kg/ha (P_1 treatment) (1987).

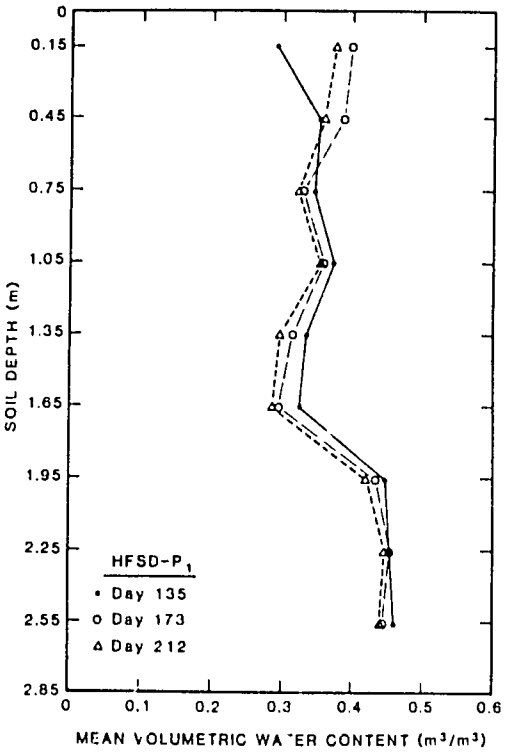

Figure 4. Mean volumetric soil water content profile at the beginning (day 135) and at the end of the test (day 212) for the tomato plots irrigated by the high-frequency surface drip (HFSD) irrigation system when P was applied at 67 kg/ha (P_1 treatment) in 1987.

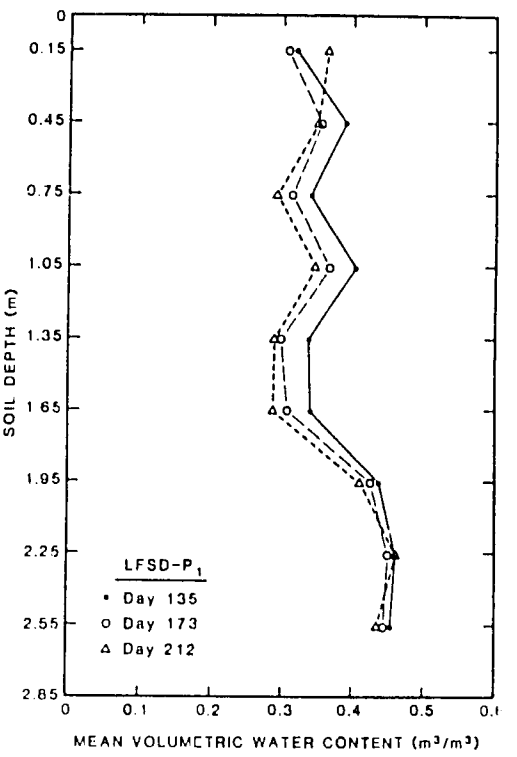

Figure 5. Mean volumetric soil water content profile at the beginning (day 135) and at the end of the test (day 212) for the tomato plots irrigated by the low-frequency surface drip (LFSD) irrigation system when P was applied at 67 kg/ha (P_1 treatment) in 1987.

Irrigation System Efficiencies

The choice of the best irrigation system for the conditions and objectives to be achieved will, in conjunction with proper irrigation water management, play a major role in assuring that crops receive the desired water quantity and/or quality with minimum nonbeneficial water losses occurring in the process. One of the first goals of water management should be to select and use irrigation systems which allow the application of water at frequencies and amounts necessary to achieve high water use efficiency levels.

Performance of irrigation systems can be evaluated theoretically by several criteria; one of them is application efficiency (AE), which is expressed as a percentage and defined as:

$$\text{Application Efficiency (AE)} = \frac{\text{Mean depth of water added to root zone}}{\text{Mean depth of applied water}} \times 100 \quad (1)$$

where the water stored in the root zone is available for unrestricted evapotranspiration. This definition assumes that the root zone is constant and definable which is not an easy task in practice. The application efficiency of the four treatments, calculated using equation (1), are shown

in Table 3. The efficiencies of the field systems are above 100% because irrigation applications were decreased below plant water requirements prior to harvest, and soil water stored before the beginning of the season was extracted by the crop to satisfy the evapotranspiration process. This indicates that it is possible to irrigate without water losses if the system is well designed and managed.

Another criterion for evaluation of irrigation systems is the distribution uniformity (DU). The distribution uniformity indicates the magnitude of the distribution problems of irrigation water within a field (Merriam et al. 1981). Generally, DU is defined as the ratio of the average depth of irrigation water infiltrated in the quarter portion of the field receiving the lowest amount of water to the average depth of irrigation water infiltrated or caught. It is expressed as a percentage:

$$\text{Distribution Uniformity (DU)} = \frac{\text{Mean low quarter depth of infiltrated water}}{\text{Mean depth of infiltrated water}} \times 100 \quad (2)$$

A low AE can result from soil evaporation, runoff and deep percolation due to poor water management. In the presence of a low DU, deep percolation will also be caused by over-irrigation to try to make up for the low DU. With drip irrigation, DU depends mostly on emitter discharge variations and the hydraulics of the pipe network (Bralts, 1986) which are a function of the slope of the field, the pipe length and diameter, and the emitter. Wu et al. (1979) and Bralts (1986) have treated in detail the complex evaluation of drip system emission uniformity (EU) and the many factors which affect them. Throughout the last few years, the authors have measured EU of surface drip systems and found that they are above 95% uniform when adequate design and management procedures are followed. When using high frequency, one must consider the hydraulics of the system to insure that EU is not reduced by the frequent on/off control of the water. It was not a significant factor in this experiment; however, in some cases, where long lines are used on sloping soil, pressure-compensated systems should be used. In addition, high-frequency subsurface drip irrigation can maximize AE because (1) soil evaporation is minimal (6 to 8% of grass-referenced evapotranspiration with bare soil), (2) there is no runoff, (3) the spatial variability of infiltration at the soil surface is not a limiting factor, (4) the temporal variability of water application is nearly eliminated, (5) the effect of ambient temperature on discharge uniformity is eliminated (Peng et al. 1986), and (6) deep percolation can be minimized with good irrigation scheduling using high-frequency methods. In our past research, a portion of the yield increase with HFSSD has been attributed to an improved crop uniformity over the whole field. However, in fields where infiltration is not a problem, factors 3 and 6 above can also apply to HFSD.

Table 3. Application efficiency and water use efficiency calculated for 1987 data for each treatment.

Treatments	Lysimeter	HFSSD	HFSD	LFSD
Application efficiency (%)	98	107	105	110
Water use efficiency (g yield/g water)	0.039	0.033a[z]	0.032a	0.030b

[z]Row means followed by similar letters are not significantly different at the 95% confidence level as determined by Duncan's multiple range test on separation of means.

Fertility, Yield and Quality

The application of plant nutrients through drip irrigation systems can be convenient, safe, and efficient (Bar-Yosef et al. 1980; Phene et al. 1988). The use of drip irrigation without direct

injection of fertilizers is often inefficient due to suboptimal matching of root volumes with available nutrients, often resulting in limited crop performance and reduced yields (Bar-Yosef et al. 1980). A drip irrigation system managed for maximizing yield and water use efficiency will usually cause a limited root system with a high root density near the source of water so that total nutrient uptake and the uptake rate increase greatly per unit volume of soil irrigated. Rooting patterns and nutrient placement requirements under high-frequency drip irrigation often do not correspond to typical fertilizer distribution and rooting patterns for conventionally irrigated row crop production (Bar-Yosef, 1977; Bar-Yosef et al. 1980; Phene et al. 1986c). The fertilizer distribution problem is further magnified with phosphorus and some minor elements which may be strongly adsorbed and immobilized close to the placement site. This is particularly true in fine-textured soils with high pH where large water and nutrient gradients can develop rapidly unless irrigation and nutrients are applied frequently to the relatively restricted root zone. Although irrigation management must be more tightly controlled, the application of fertilizers through drip systems using the irrigation water as the carrier otherwise reduces labor, energy and equipment costs as compared to conventional application practices.

The N-P-K injection schedules are shown in Figure 6. From previous studies of plant nutrient status in this field and soil (a clay loam), it was determined that residual N, P and K in the

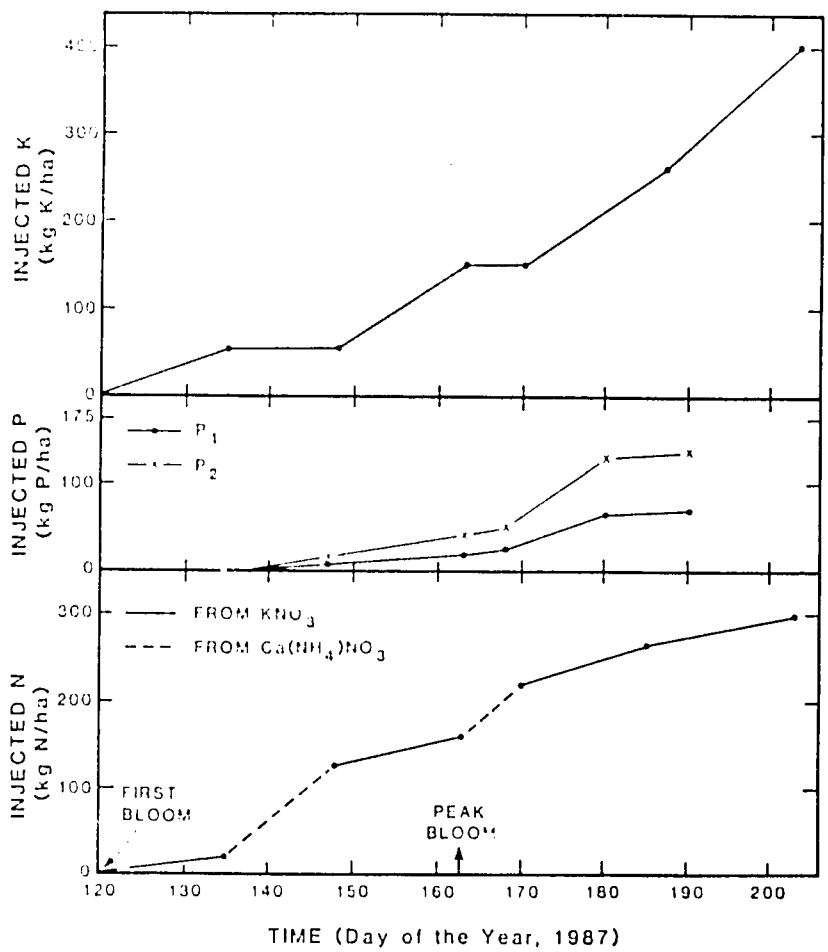

Figure 6. Fertilizer N, P and K injection application schedule for tomatoes under the three irrigation treatments when P was applied at 67 and 134 kg/ha (P_1 and P_2 subtreatments, respectively) in 1987.

top 30 cm of soil supplemented by a small application of N and P at planting were sufficient to meet these nutrient requirements of tomatoes until first bloom (day 120) (Phene et al. 1986a). This differs from the uptake rates reported by Bar-Yosef (1977) who used a fine sand in his studies. During the rapid growth period following first bloom, demand for N is great and by peak bloom (day 163) half of the N requirement (150 kg/ha) should be applied. The demand for K increases after first bloom (103 mg/plant/day) but seems to be the greatest (155 mg/plant/day) when fruits are setting and developing (Bar-Yosef 1977). Similarly, the demand for P reaches its maximum at peak bloom (17 mg/plant/day) and slowly decreases following peak bloom (Bar-Yosef, 1977). Figure 7 shows the petiole concentration of PO_4-P for the three

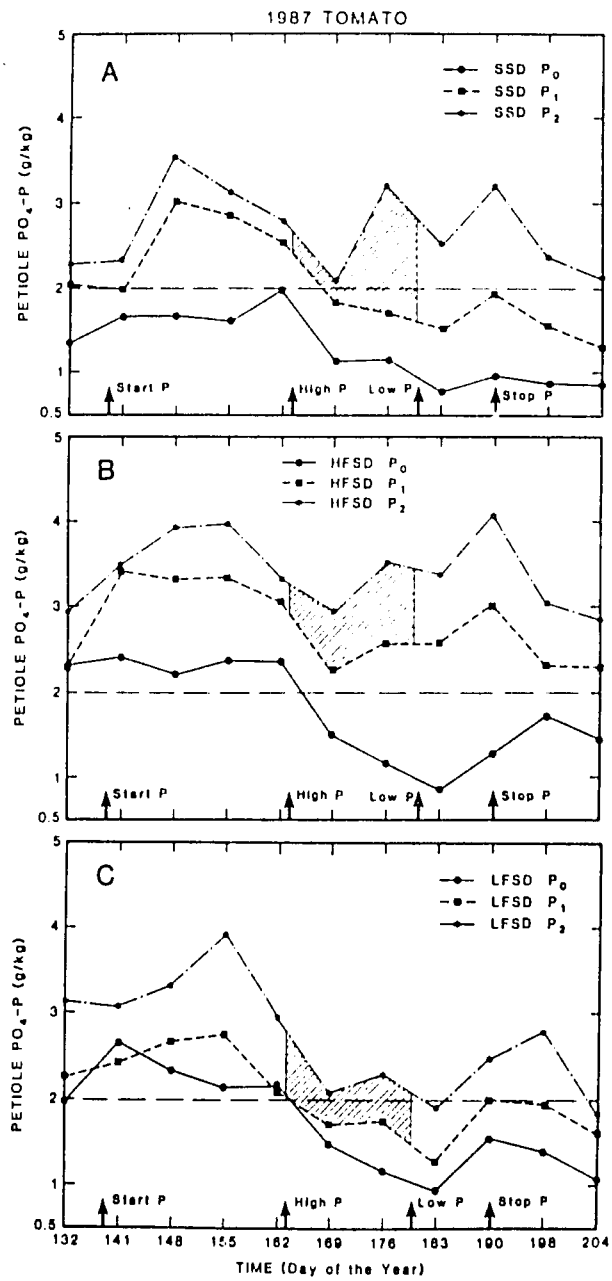

Figure 7.
Seasonal phosphorus level in tomato petioles for the three irrigation treatments HFSSD (A), HFSD (B), and LFSD (C) and for the three F subtreatments in 1987. Shaded portion of graphs is the period following full bloom during which injection of P was increased to maintain petiole P level 2 g/kg.

irrigation treatments and the three P-fertility subtreatments. Subtreatment P_0 shows that the petiole concentration of PO_4-P is above the deficient level of 2 g/kg for the HFSD and LFSD treatments until peak bloom (Western Fertilizer Handbook, 1975); this is presumed to be due mostly to greater P availability to the shallow roots early in the season for these two irrigation treatments. However, this was not the case for the HFSSD-P_0 treatment, presumably because HFSSD rapidly stimulates deeper rooting where less residual P is available. Continuous injection of P at P_1 and P_2 levels maintained the petiole concentration of P above the deficient level of 2 g/kg for all irrigation treatments until peak bloom; but soon after peak bloom, petioles in the HFSSD-P_1 and LFSD-P_1 tomatoes dropped below the deficient level. Again this presumably may have to do with rooting volumes and rooting depth in both of these treatments. In the LFSD-P_1 treatment, larger water application volumes (25 mm) with each irrigation creates a deeper wetted volume of soil. It is our hypothesis that in the LFSD treatments, much of the applied P is adsorbed near the surface, while the root system is spread out over a much greater area; resulting in lower average P availability per unit of the root zone than in the HFSSD or HFSD treatments. These data also show that tomatoes fertilized at the P_2 level had higher concentrations of P in the petioles than those fertilized at the P_1 level; however, this increase in P concentration in the petiole did not produce a yield increase; perhaps other limiting or interacting factors prevented it or perhaps excess levels existed. Seasonal N and K levels in the petioles of these tomatoes were satisfactory throughout the whole season and were not significantly affected by the three P treatments.

The yields of large red tomatoes obtained from these irrigation and fertility treatments are shown in Table 4. These data indicate that the HFSSD irrigation treatment produced a significantly greater red tomato yield than either the HFSD or LFSD treatments and that maximum yields occurred with P fertilizer injected at least at the P_1 level of 67 kg/ha. The extremely high yields of tomatoes achieved in this study were only possible because of the precision and accuracy of the irrigation and fertilization methods used: a very uniform irrigation system applying water and nutrients on a nearly hour-by-hour basis to replace the water lost by evapotranspiration and maintaining very constant soil water and fertilizer levels in the root zone. Components of the yield increase in the HFSSD treatments included somewhat larger fruit sizes (although not statistically significant), and a greater marketable percentage of tomatoes than in the HFSD and LFSD treatments (Tables 5 and 6). Similar results were obtained in an experiment at the same site conducted in 1985 (Phene et al. 1986a).

Water Use Efficiency

Water use efficiency (WUE) has important implications when considering irrigation, soil and water conservation, productivity, and sustainability of irrigated agriculture. Although there are

Table 4. Yield of red tomatoes from three irrigation treatments (HFSSD, HFSD and LFSD), and three subtreatments, 1987.

Irrigation treatment[z]	P-Level treatments (kg/ha)			
	0	67	134	Means
	Red tomato yield (t/ha)			
HFSSD	184.2	220.0	214.9	206.4a
HFSD	176.9	200.7	191.8	189.9b
LFSD	168.9	186.7	182.5	179.4b
Means	176.7b[y]	202.5a	196.4a	Lysimeter 254.9

[z]HFSSD = high-frequency subsurface drip, HFSD = high-frequency surface drip irrigation, LFSD = low-frequency surface drip irrigation. [y]Column and row means followed by similar letters are not significantly different at the 95% confidence level, as determined by Duncan's multiple range test. Irrigation treatments and P-level subtreatment differences are significant; interaction is not significant.

Table 5. Mean weight of single red fruits measured from a sample of approximately 200 tomatoes, 1987.

Irrigation treatment[z]	P-Level treatments (kg/ha)			
	0	67	134	Means
	Mean tomato weight (g)			
HFSSD	62.9	66.1	67.8	65.6a
HFSD	60.5	62.3	64.2	62.3a
LFSD	58.9	62.9	62.3	61.3a
Means	60.8b[y]	63.8a	64.8a	Lysimeter 61.0

[z]HFSSD = high-frequency subsurface drip; HFSD = high-frequency surface drip irrigation; LFSD = low-frequency surface drip irrigation. [y]Column and row means followed by similar letters are not significantly different at the 95% confidence level, as determined by Duncan's multiple range test on separation of means.

Table 6. Cull tomatoes as a percentage of total fruit yield, 1987.[z]

Irrigation treatment[y]	P-Level treatments (kg/ha)			
	0	67	134	Means
	Damaged and rotten fruit, percentage of total yield (%)			
HFSSD	1.4	2.0	3.3	2.2a
HFSD	2.7	2.8	4.0	3.2ab
LFSD	2.3	4.5	4.7	3.8b
Means	2.1a[x]	3.1ab	4.0b	Lysimeter 2.3

[z]Total fruit yield includes large red and green, small, and culls. [y]HFSSD = high-frequency subsurface drip; HFSD = high-frequency surface drip irrigation; LFSD = low-frequency surface drip irrigation. [x]Column and row means followed by similar letters are not significantly different at the 95% confidence level, as determined by Duncan's multiple range test.

several definitions for WUE, it is usually defined as the ratio of dry matter yield (Y) per unit of water evapotranspired (E + T) where E is the evaporation from the soil and wetted plant surfaces, and T is the transpiration from the plant:

$$\text{Water use efficiency (WUE)} = \frac{Y}{(E + T)} \qquad (3)$$

Hence, the variables Y, E and T are stated explicitly. It has been shown (Feddes et al. 1978; Ootegem et al. 1982) that harvestable dry matter and often crop yields increase linearly with T but that E is generally nonbeneficial. Irrigation systems such as subsurface drip (HFSSD) should therefore improve WUE since E of HFSSD systems is minimal. However, it is recognized that the following other major factors affect Y as well as T: soil; climate and weather; water management; fertility management; crop variety; crop management; pest management; social and human factors; and economics. Water and fertility management are the two most limiting factors over which growers can exercise some control. Water use efficiencies of the treatments are shown in Table 3. The WUE of the HFSSD and HFSD treatments are greater than that of the LFSD, most likely because these treatments minimize mild water deficits and thus increase total photosynthesis on an area basis. However, since in this experiment the WUE was calculated by dividing the total fruit yield by the E_{tc}, and the E_{tc}'s of the major treatments were not significantly different, the increase in WUE of HFSSD and HFSD was due to an increase in fruit yields. It should also be noted that these WUEs are much greater than usually reported in the literature for processing tomatoes. It remains to be established to what extent increased photosynthetic productivity or changes in photosynthate partitioning to fruit are involved in

increases in fruit size and number and total production. The high-frequency irrigations (several times per day) replenish the rhizosphere by mass flow of water which decreases the water potential gradient between the leaf surface and the rhizosphere and minimizes mild stresses (Phene et al. 1983a).

Conclusions

Drip irrigation provides many advantages over other irrigation methods (Phene et al. 1987). In a test designed to study the effects of frequent phosphorus injections on tomato yield and quality it was found that evapotranspiration of tomatoes, measured by a weighing lysimeter, was 711 mm and that it was not affected by the mean irrigation treatments or by the three P-fertility subtreatments. The mean WUEs of the HFSSD and HFSD treatments were 0.033 and 0.032 g yield/g water, respectively, and were significantly higher than that of the LFSD treatment (0.027). Mean yields of large red tomatoes were 206, 190 and 179 t/ha for the HFSSD, HFSD, and LFSD treatments, respectively. The large red tomato yield of the HFSSD treatment was significantly higher than those of either the HFSD or LFSD, and the large red tomato yield of the HFSSD-P_1 was highest of all with 220.0 t/ha. Soluble solids were not affected by any of the treatments or the subtreatments. The mean percentages of culls were 2.2% (HFSSD) and significantly lower than 3.2% (HFSD) and 3.8% (LFSD), respectively.

In general, complex irrigation systems require high-level skills and intense management in order to achieve high irrigation efficiency; however, most of the functions of the control system are easily automated. Subsurface drip systems provide the means of by-passing the spatial variability at the soil surface which is one of the dominant factors controlling the distribution uniformity of surface irrigation systems including drip systems and one of the limiting factors in achieving a high application efficiency. Where subsurface systems are installed deep below the surface (35 to 60 cm), runoff is also eliminated and evaporation losses and salt accumulation at the soil surface are minimized under good management. Since the HFSSD system is installed permanently, it is not subject to manual or machine handling; the aging of the polyethylene due to ultraviolet radiation is eliminated and emitter discharge uniformity remains more constant with time because variations in temperature are damped out. Since the water and fertilizers are applied directly to the root zone, the roots can intercept all the water and nutrients if these are added at rates equal to those needed for growth processes. Hence, losses to the water table can be greatly reduced or eliminated, and the potential for drainage reduction is highest of all irrigation systems because spatial and temporal nonuniformities of water application are minimized.

Acknowledgments

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Symposium Discussion

Y. Haile: What is the water requirement of tomato under fertilized and manured conditions?

C.J. Phene: The water requirement of tomato **is not a constant**. For the conditions of the San Joaquin Valley of California, using UC-82B variety, it is about 710 ± 50 mm/season. There are many factors affecting crop water requirements, certainly too many to list here; however, they are listed in Table 4 of the paper entitled "Water Management of Tomatoes in the Tropics".

D.M. Hegde: (1) If a crop requiring different spacing is to be grown, subsurface drip may not be useful. Such permanent subsurface drip system necessarily requires monoculture or crops with the same spacing. (2) What do you think is the ultimate yield potential of tomatoes under field conditions, under ideal conditions? (3) What was the reason for better performance of high-frequency subsurface drip as compared to high-frequency surface drip? Were the differences significant?

C.J. Phene: (1) Crop spacing can be standardized – in some soils with high capillarity, the spacing of the line is not critical. (2) Probably about 250-300 t/ha. (3) Yes, the differences are significant. One of the explanations is that water and nutrients are more uniformly distributed with subsurface drip irrigation which results in a uniformly better crop.

E.S. Lim: Have you experienced roots growing into the drip nozzle and supply line with the subsurface drip? How simple is it to clear a blockage?

C.J. Phene: We prevent root growth into the emitters and supply line by our management process as follows: (1) yearly, **30 days before planting** we fumigate the system with Vapam to control bacterial growth, nematodes weeds etc. ususally at a rate of about 300 l/ha. (2) We irrigate very frequently to maintain a saturated zone of water around the emitters. (3) We monitor flow rate and pressures to detect any plugging problems. (4) After harvest we fumigate with Vapam at 50 l/ha.

A. Sajjapongse: What is the minimum pressure required to run the subsurface drip irrigation effectively?

C.J. Phene: Pressure requirements are dependent mostly on the type of emitters or drip tubes being used and the system design characteristics. For example, some pressure-compensated emitters can operate well at pressure ranging from 0.3-3.0 atmospheres.

Effect of Irrigation Rates on Rainshelter-protected Tomato Yields with and without Methyl Bromide Fumigation of the Soil

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Abstract

Rainshelter-protected tomatoes growing in methyl bromide-fumigated soil were irrigated with 53 to 374 liters of water/m of row. Yields increased with increasing water application rates from 53 to 267 liters of water/m of row and the amount of water applied to produce 1 kg of salable tomatoes increased from 7.4 to 20.8 liters, respectively. Daily irrigation was superior to weekly irrigation. In a trial where the soil was not fumigated, rootknot nematode (*Meloidogyne* spp.) larvae increased 51-fold in the soil as the water application rate was increased from 49 to 487 liters water/m of row; also, severe injury occurred to the plant roots, salable yield was reduced by half and water was clearly wasted at the highest water application rates.

Introduction

Moisture is the most important factor contributing to high nematode populations in soils (Norton, 1979). Yields of field-grown tomatoes resistant to rootknot nematode (*Meloidogyne* spp.) (Gilbert et al. 1969) increased with increasing irrigation rates up to 47 cm (Sammis and Wu, 1986). Bower et al. (1975), obtained 14% higher tomato yields in plots maintained at a soil-water tension of 0.2 bar than those at 0.6 bar in a plastic covered rainshelter.

Tomatoes are grown in plastic-covered rainshelters in Hawaii's higher altitude and high rainfall areas. The water source is either a rain catchment reservoir or expensive domestic water. Thus, the limited nature of water supply requires careful water management. For this intensive culture system of growing tomatoes in rainshelters, growers have chosen cultivars with shorter internodes and other favorable characteristics. These cultivars often have lower resistance to rootknot nematodes, but methyl bromide fumigation between crops has largely controlled rootknot nematodes. However, fumigation is inconvenient, costly and subject to regulatory laws.

The purpose of this study was to determine the effects of a wide range of irrigation rates on the yield of rainshelter-produced tomatoes with and without methyl bromide soil fumigation in an effort to learn whether water management can be used as a tool for controlling rootknot nematodes.

Materials and Methods

Experiment I

Tomatoes (cv. GS-130) were seeded on July 7, 1983, and transplanted on August 18, 1983, at an elevation of 800 m in the Glenwood area on the island of Hawaii. Tomatoes had been

in continuous production for about eight years. The Akaka silty clay loam soil (Typic hydrandept, thixotropic, isothermic) was fumigated with methyl bromide prior to transplanting. The entire plot area was covered with a plastic rainshelter to protect plants from the 500-cm annual rainfall. Plant and row spacings were 0.36 and 1.02 m, respectively.

Approximately one centimeter of water was applied to each treatment at transplanting. No additional water was applied in the following 42 days since some subsurface water was present due to heavy rains. Then, water was applied at seven rates ranging from 1.86 to 13.02 liters/m of row/week. These rates were increased by one-third (2.48 to 17.36 liters/m of row/week) from December 21 to March 23. Total amounts of water applied for the crop (±3%) were 53, 107, 160, 214, 267, 320, and 374 liters/m of row.

Water was applied either once per week with a 'Submatic' irrigation system or six times per week with a 'Drip In 2 L' irrigation system; the latter is hereafter referred to as daily irrigation. The experiment was arranged as a continuous function design with three replications. Harvest yield data were collected from single rows, 15 m long, between 26 October 1983 and 30 March 1984.

Experiment 2

One-month-old tomato seedlings (cv. Tropic) were transplanted on November 7, 1986 under a plastic rainshelter at an elevation of 800 m in the Mealani area on the island of Hawaii where the average annual rainfall is 165 cm. The Maile silty clay loam soil (Hydric Dystrandept) which was not fumigated prior to transplanting was last treated with Telone for nematode control in 1985, after which similar continuous function irrigation trials were performed on cucumber and tomato crops. Treatments consisted of water application rates of 49, 109, 243 and 487 liters/m of row. The initial watering rates were 0.36, 0.71, 1.42 and 2.84 liters/m of row/day for the first 83 days of the experiment; rates were altered to 0.21, 0.57, 1.42 and 2.84 liters/m of row for the next 88 days because plant water stress was not observed at the lowest watering rate. Water was applied daily with 'Drip In 2L' irrigation tubing with 30-cm emitter spacings. Plant and row spacings were 0.45 and 1.06 m, respectively. The plot was arranged in a continuous function design with three replications. Tomatoes were harvested from February 18 to April 24, 1987. Nematode ratings of roots and nematode populations were evaluated after the experiment was terminated.

Results and Discussion

Yields of salable tomatoes in the daily irrigation treatments increased as the water application rate increased from 53 liters/m of row to 267 liters/m of row (Figure 1). However, yields from the 267 liters water/m of row treatment were essentially the same as when 374 liters water/m of row were applied. This is consistent with the results of Sammis and Wu (1986) and Bar-Yosef and Sagiv (1982).

In the weekly irrigation treatments, yields of salable fruit increased with increasing water rates from 53 liters/m of row to 374 liters/m of row. Yields were lower in the weekly application treatments than in the daily irrigation treatments. For example, at an irrigation rate of 267 liters/m of row, tomatoes yielded 18% higher in the daily irrigation treatment than in the weekly irrigation treatment. Thus, tomatoes responded favorably to small frequent applications of water; apparently, water was consistently more available to the plants in the daily water application treatment than the weekly water application treatment. Clearly, tomato yields were responsive to both water application amount and timing in this trial.

In Experiment 2, tomato yields decreased (Figure 2) and rootknot nematode galling became more severe with increasing water application rates (Table 1). Rootknot nematode presence was low and nematode galls were inconspicuous at the lowest irrigation rate of 49 liters of water/m of row for the crop. However, when 487 liters of water/m of row were applied, rootknot nematode

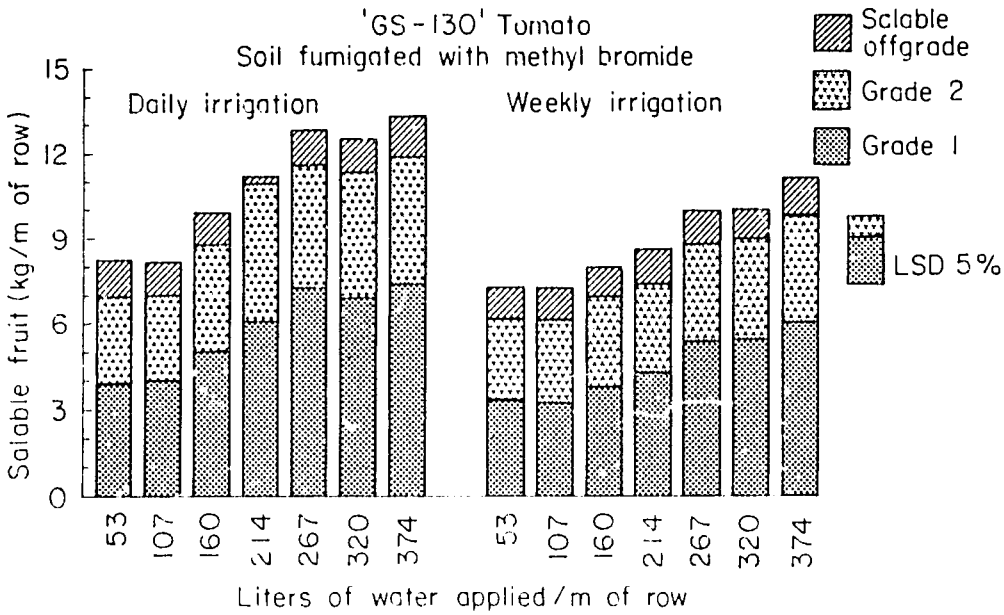

Figure 1. The effects of seven daily and weekly irrigation rates on the yield of GS-130 tomatoes growing on a soil fumigated with methyl bromide.

Table 1. The effects of irrigation rate on soil rootknot nematode larvae population and nematode damage to roots of Tropic tomatoes growing in a rainshelter-protected soil bed which was not treated for nematodes.

	Liters of water applied m of row				
	49	109	244	487	LSD 5%
Meloidogyne spp. (Larvae liter of soil)	25	260	1210	1270	764
Nematode rating of roots[z]	1.0	2.1	3.9	4.5	1.3

[z] 1 = no root damage, 2 = small and medium galls present, 3 = small medium and large galls present, no swollen roots; 4 = many galls plus two large deformed roots present, and 5 = many galls plus five or more large deformed roots present

larvae population increased 51-fold in the soil, severe root-galling was present and salable yield was reduced by one-half.

This is consistent with the observations of Godfrey (1926) who found less root-galling from *Meloidogyne* spp. at low and very high soil moisture levels, but maximum root-galling at the optimum moisture range for tomato growth. Similarly, Linford (1941) found that root damage from *Heterodera marioni* was low near the wilting point of soil, reached a maximum around the field capacity point, and declined in wetter soil.

Water use was very efficient in the fumigated trial, especially at application rates resulting in yield increases. The amount of water applied to produce one kilogram of salable tomatoes increased from 7.4 to 20.8 liters of water as the application rate increased from 53 to 267 liters/m of row, respectively (Figure 3). Water was clearly wasted in the nonfumigated trial at the high application rates where nematode population and damage to plants was greatest. The amounts of water applied to produce one kilogram of salable tomatoes were 67.6 and 180 liters of water at application rates of 244 and 487 liters/m of row, respectively. An optimal input cultural

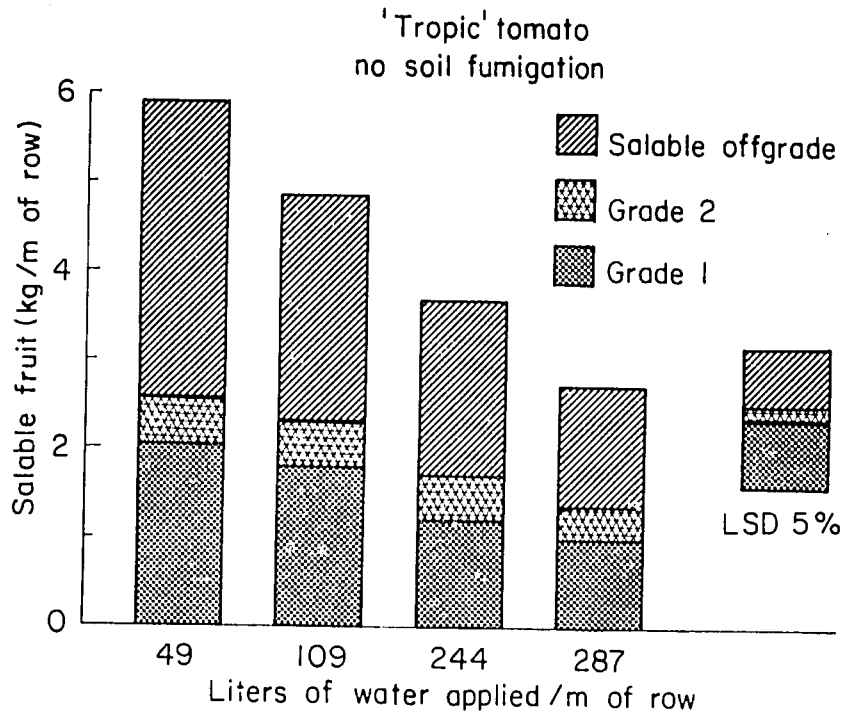

Figure 2. The effect of four daily irrigation rates on the yield of Tropic tomatoes growing on a nonfumigated soil.

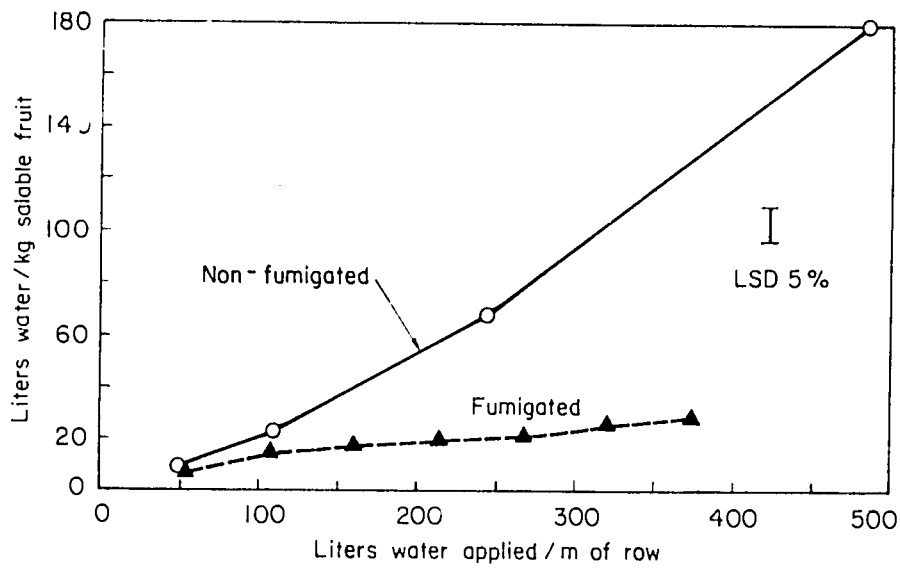

Figure 3. The effects of irrigation rate and methyl bromide fumigation for rootknot nematode control on the quantity of water applied (liters) per kilogram of salable fruit produced.

management system for continuous cropping of tomatoes in a rainshelter would consist of an optimal daily irrigation rate, use of a nematode-resistant cultivar and nematode treatment of the soil after every crop. However, if the latter two options are not possible, even a moderate irrigation rate will clearly decrease rather than increase production and will waste water.

Growers would be advised to apply an optimal daily irrigation rate following fumigation of the soil. Alternatively, a low irrigation rate should be applied to the succeeding crops if the soil was not fumigated. Additional research is needed to develop an irrigation management scheme which would result in the lowest nematode damage and the highest cumulative tomato yield over a prolonged continuous-cropping cycle.

Acknowledgments

The technical assistance of D. Ito, S. Young, K. Fujii, B. Strehler and M. Yamasaki is greatly appreciated.

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Symposium Discussion

I.D. Erinle: What type of soil did you use in your second experiment, in view of the critical nature of soil type in irrigation scheduling and level of nematode infestation?

B.A. Kratky: Maile silty clay loam (Hydric Dystrandept). Note: this is indicated in the 'Materials and Methods' section of the paper.

J.M. Meunier: One of the sources of resistance to *Meloidogyne incognita* was discovered in Hawaii a long time ago. Many varieties have since been developed with rootknot resistance. It is dangerous to promote the use of methyl bromide in tropical countries when western countries are going to stop using it.

B.A. Kratky: I agree that resistant cultivars should be used whenever and wherever possible. The main point of this paper is that control of soil moisture by drip irrigation in a rainshelter-protected environment presents an alternative nonchemical control method for *Meloidogyne* damage to tomatoes.

The Influence of Shade Nets on the Growth and Yield of Sweet Pepper

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Abstract

The effect of different shade levels on sweet pepper production was investigated. The shade levels were 40, 55 and 63%, achieved by placing black polyprobolin nets on solid iron framed tunnels (7.5 m width × 40 m long and 2.5 m high) provided by Tildent Co. Shading increased plant height, leaf area, plant fresh and dry weight, total yield and fruit quality and reduced the number of nonmarketable fruits. The highest number of fruits (17/plant) and yield (562 g/plant) were obtained with 40% shade under field conditions in the Kafr El-Sheikh area in the north of Egypt.

Introduction

The total area cultivated with vegetable crops in Egypt was about 503,031 ha/year during 1985 and 1986. The most important vegetable crops were tomato, potato, watermelon, squash, cucumber and sweet pepper which represented about 31.9, 15, 10.9, 5.3, 3.8 and 2.6% of the total area of vegetables, respectively. During the same period, the total production of vegetable crops was approximately 9,772,429 t/year, of which tomato represented 41%, potato 11.3%, water melon 12%, squash 4.9%, cucumber 3.3% and sweet pepper 2.2% (Central Administration for Agricultural Economics and Statistics, 1986). The average area cultivated with pepper during 1985 and 1986 was about 13,078 ha/year, with an annual production of more than 214,146 t/year (Ministry of Agriculture, 1986). More than 67% of this area was transplanted in July-August. This is locally known as a 'neely' crop.

Work conducted on tomato in Kafr El-Sheikh, northern Egypt (El-Aidy et al. 1983) showed that shaded plants (55% shade) produced the highest fruit yield, although the total soluble solids (TSS) of the fruits decreased. Shading studies with pepper in the West Indies indicated that shade increased leaf surface area, cell division and cell expansion, and also the overall dry matter weight by more than 40% (Schoch, 1972). In northern Italy, shading of more than 30% was found to decrease the number of flowers in comparison to full light (Quagliotti et al. 1974). Development of the fruits both in number and mean weight was most favorable when light intensity was reduced by 30%. However under Korean conditions yield of red fruits decreased as shading increased, and water, sugar, amino acids and capsaicin contents of the fruits were unaffected by shading (Joen and Chung, 1982).

The main objective of this study was to investigate the effect of shading on growth and yield of sweet pepper grown during the summer period in northern Egypt.

Materials and Methods

Experiments were conducted in the late summer in May 1984 and 1985 at the Experimental Farm of the Faculty of Agriculture, Kafr El-Sheikh, Egypt. The sweet pepper cultivar California Wonder and four shade treatments were used: 0, 40, 55 and 63% shading. Black shade nets

(Tildent Co., England) were placed on solid iron frame shaping tunnels, at one meter height from the soil level for the purpose of ventilation. Transplanting was 60 days after sowing. Shade nets were applied on 15 June, and removed on 15 September, and the plants left to produce, unshaded, for 35-40 days up to the end of harvest season. A complete fertilizer (N:P:K 1:2:1) was applied at a rate of 268 kg/ha twice, at 30 and 51 days after transplanting. Flood irrigation was every 10 to 12 days throughout the growth season. All other cultural practices were those practiced by local growers. The fruits were picked at the mature green stage at 10-days interval. The experiment was arranged as a randomized complete block with four replicates. Plot size was 2.6 × 7.0 m with a plant density of 6 plants/m^2. The seedlings were transplanted on paired rows with 80 cm between pairs, 40 cm between rows, and 30 cm between plants.

The leaf area was calculated according to the following formula (Derieux et al. 1973):

$$\text{Leaf area (cm}^2\text{)} = \frac{\text{Dry weight of leaves (g)}}{\text{Dry weight of leaf disks (g)}} \times \text{area of leaf disks (cm}^2\text{)}$$

Leaf disks had a constant area 0.988 cm^2. At 60 days after transplanting the leaf pigments (chlorophyll a, chlorophyll b and carotenoids) were measured spectrophotometrically as described by Wettstein (1957). Leaf samples were taken from the tip of the fifth leaf (10 disks/plot × 4 replicates = 40 samples).

The climatic conditions during the course of the vegetative and productive growth period are summarized in Table 1.

Table 1. Climatic conditions during the experiments.

	April	May	June	July	Aug.	Sept.	Oct.
1984							
Air temperature (°C)							
Ave. max.	26	32	32	33	31	32	31
Ave. min.	11	15	17	20	19	17	15
Max.	33	40	37	36	36	36	35
Min.	7	10	15	16	17	14	13
Relative air humidity (%)	66	64	63	72	75	74	75
1985							
Air temperature (°C)							
Ave. max.	27	32	33	33	33	31	28
Ave. min.	11	16	18	19	21	18	14
Max.	38	38	39	36	36	36	31
Min.	7	11	16	17	18	15	10
Relative air humidity (%)	65	62	62	72	77	71	68
Solar radiation cal cm^2-day	950	1100	1120	1100	1010	920	690

Results and Discussion

Plants grown under shade grew more vigorously than those in the open field. They exhibited greater plant height, and plant fresh and dry weight and leaf area were significantly increased (Table 2).

This may be attributed to the stimulation of cellular expansion and cell division under shaded conditions (Schoch, 1972). The tallest plants were obtained under the 63% shade level followed by plants under the 55% and 40% shade levels.

The harvesting duration was 81 days (from 2 August to 22 October) in 1984 and 71 days (from 15 August until 25 October) in 1985. Total fruit yield and average fruit weight was greater from the shaded plants (Table 3). Total yields decreased as shading increased. It has been

Table 2. Effect of shading on plant height, fresh and dry weight and leaf area at 90 days after transplanting during 1984 and 1985.

Shading (%)	Plant height (cm)	Plant fresh wt. (g)	Plant dry wt. (g)	Leaf area (cm^2/plant)
1984				
63	78 a[z]	196 a	38 a	3038 a
55	78 a	150 b	27 b	2650 b
40	66 b	125 c	29 b	2490 c
0 (unshaded)	43 c	76 d	18 d	1475 d
1985				
63	84 a	191 a	37 a	3980 a
55	69 b	129 b	30 b	3620 b
40	62 b	124 c	28 b	3404 c
0 (unshaded)	54 c	102 d	18 c	2476 d

[z]Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05).

Table 3. Effect of shading on sweet pepper yield and fruit quality in 1984 and 1985.

Shading (%)	Fruit yield (g/plant)	Average fruit wt. (g)	Marketable fruit/plant (no.)	Nonmarketable fruit/plant (no.)	fruit/plant (%)
1984					
63	367 b[z]	34.2 b	10.7 b	1.5 c	14
55	400 b	34.8 a	11.5 b	2.0 c	13
40	617 a	33.9 a	18.2 a	3.7 b	19
0 (unshaded)	436 b	23.4 b	18.6 a	5.5 a	32
1985					
63	383 c	31.8 b	12.0 d	1.2 d	9
55	531 b	35.2 a	15.0 c	1.5 c	12
40	567 a	33.7 a	17.0 a	3.5 b	21
0 (unshaded)	327 d	20.7 c	15.8 b	6.3 a	39

[z]Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05).

postulated that shading increases the quantity of chlorophyll and thus increases the photosynthetic efficiency of the plants (Collard et al. 1977; El-Aidy et al. 1983). Similarly, the number of nonmarketable fruits increased with decreasing shading. The unshaded plants produced significantly more unmarketable fruits than plants growing under shade. The highest yield was obtained from the 40% shade treatment in both years, while the lowest yield was obtained from the unshaded treatments. The chlorophyll and carotenoid content of leaves was found to be increased by shading (Table 4).

It is concluded from these trials that the optimum shade level for highest productivity and fruit quality under the environmental conditions prevailing in Kafr El-Sheikh is 40%. The effect of lower shade levels will be tested, together with an economic evaluation, before recommendations are made to the growers.

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Table 4. Effect of shading on leaf pigment content at 60 days after transplanting.

Shading (%)	Pigments			
	Chlorophyll a	Chlorophyll b	Carotenoids	Total
	(mg/g fresh wt.)			
1984				
63	0.52 a[z]	0.31 a	0.49 a	1.32 a
55	0.40 b	0.27 b	0.40 b	1.07 b
40	0.38 b	0.23 c	0.39 b	1.00 c
0 (unshaded)	0.40 b	0.23 c	0.32 c	0.95 c
1985				
63	0.53 a	0.32 a	0.51 a	1.36 a
55	0.45 b	0.27 b	0.41 b	1.13 b
40	0.39 c	0.22 c	0.36 bc	0 97 c
0 (unshaded)	0.38 c	0.21 c	0.30 c	0.89 c

[z]Means followed by the same letter are not significantly different according to Duncan's multiple range test (P = 0.05)

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Some Aspects of Cultural Management in Tomatoes at AVRDC

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Abstract

To evaluate the effect of cultural practices on yield of tomatoes, various studies were carried out at the Asian Vegetable Research and Development Center. Narrow spacing and high numbers of plants/hill reduced the number of fruits/plant. Given sufficient water and plant nutrients, transplanting shock had no significant effect on yield. The crop tolerated weeds for 28 d.a.t. without significant yield loss but the critical period of weed interference was between 28 and 42 d.a.t. Metribuzin gave the most satisfactory weed control among the herbicides tested. The yield of the crop was increased by 67.5% when plastic mulch was used. The yield was also increased by the use of methionine, an ethylene precursor, and Crotonyliden-Di-Urea (CDU), a slow-release fertilizer. An optimal furrow irrigation schedule for the crop was to apply irrigation three times, i.e. immediately, 30, and 45 d.a.t. A simple, inexpensive low-pressure drip irrigation system for use with the crop has been successfully developed to economize water use. A bed height of 30 cm was effective in protecting the crop from the detrimental effects of flooding during the summer season.

Introduction

Yields of tomatoes in the tropics are generally very low when compared with those in the temperate region. In 1985, the average yield was 4.5 t/ha in Thailand, 4.9 t/ha in Malaysia, 9.1 t/ha in the Philippines, 52.6 t/ha in Japan, and 50.0 t/ha in the United States (FAO, 1985). The yield differences between these countries are not only due to different environments, but also to differences in the cultural practices applied, and in the level of their application. While high production inputs such as weed control, irrigation and fertilization are used in temperate countries, low production inputs are practiced by farmers in tropical countries. Lack of information is one of the factors preventing the farmers in the tropics from using many beneficial cultural practices for tomato production.

Many studies have been carried out at the Asian Vegetable Research and Development Center (AVRDC) to improve the cultural management of this crop to increase yields, particularly in the lowland tropics.

Effect of Spacing and Number of Plants per Hill

One of the management practices which greatly influences tomato yield is population density and spacing. Various intrarow spacings with one or two plants/hill were tested during the autumn season using the determinate cultivar Tainan No. 2. Plant survival rate, marketable yield, fruit size, and fruit number are presented in Table 1. Although spacing and number of plants/hill had no effect on plant survival rate and fruit size, they affected yield/plant and fruit number significantly. Planting one plant/hill gave higher yield/plant and more fruits/plant than planting two plants/hill. A similar response was also obtained using wide spacings when compared with

Table 1. Yield and its attributes as affected by spacing and number of plants per hill.[z]

Spacing[y] (cm)	No. plant per hill	Plant survival rate (%)	Yield (kg/plant)	Yield (t/ha)	Fruit size (g/fruit)	Fruit number (no./plant)
30	1	88.9	1.9 cd	56.8	65.0	29.7 cd
30	2	92.9	0.9 f	56.0	62.0	14.6 e
40	1	94.9	2.4 c	56.0	65.1	36.5 bc
40	2	93.6	1.2 ef	56.8	57.9	21.0 de
50	1	88.3	2.9 b	51.5	67.0	44.2 ab
50	2	86.7	1.6 de	56.5	57.7	28.4 cd
60	1	89.6	3.5 a	51.2	70.0	50.7 a
60	2	89.6	1.8 d	53.9	64.3	28.0 cd

[z]Means within columns followed by different letters are significantly different at the 5% level by Duncan's multiple range test. [y]Interrow spacing was 1 m for all treatments

narrow spacings. Based on hectarage, however, yields did not differ whether the crop was planted one or two plants/hill with wide or narrow spacing, due to the population density difference. Taking into consideration the yield and number of plants involved, planting the crop at two plants/hill is not advantageous.

Seedling Nursery Methods

To avoid the transplanting shock associated with planting seedlings in flats or beds, they are usually raised in small pots, a costly and time-consuming procedure. In most leafy vegetables, like Chinese cabbage, transplanting shock can cause significant yield loss. An experiment was carried out to determine whether transplanting shock also affects the yield of tomato. The determinate line Tainan No. 2 was used, and the experiment was conducted in the autumn season.

Plants grown from seedlings raised in flats were the shortest and smallest, and had the smallest root size. There were significant differences in height, plant and root weight between the pot and slot treatments. Differences in yield among treatments, however, were not significant (Table 2). The yield averaged to 68.9 t/ha for the flat method, 71.3 t/ha for the slot method, and 73.0 t/ha for the pot method.

It was obvious that the roots of tomatoes grown from seedlings raised under the pot and slot methods developed more quickly than did the roots of plants grown from seedlings raised under the flat method. They would thus be able to exploit nutrients and soil moisture more effectively than could the roots of plants grown from seedlings raised using the flat method. Although there was no yield difference under the conditions of the present trial, where plant nutrients and soil moisture were not limiting, vigorous root development should be advantageous under conditions where soil is dry and infertile. Therefore, we conclude that transplanting shock has no significant effect on yield of tomato when the crop is grown in an environment where nutrient and water supplies are sufficient.

Table 2. Root fresh weight, plant height and fresh weight at 30 d.a.t., and yield of tomatoes as affected by seedling method.[z]

Seedling raising method	Root weight (g/plant)	Plant height (cm)	Plant weight (g/plant)	Yield (t/ha)
Flat	5.1 b	39.5 b	92.5 b	68.9
Pot	7.4 a	45.6 a	138.3 a	73.0
Slot[y]	7.3 a	45.0 a	137.5 a	71.3

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test. [y]Flats partitioned into slots (5.5 cm × 6.0 cm and 7 cm deep) with PVC strips

Effect of Weed Competition

Farmers in the tropics traditionally weed tomatoes by hand. This practice is becoming more expensive, due to the rising cost of labor. Studies on the critical period of weed competition, and in particular on the timing of manual weeding required to provide the best control with the least labor, can help farmers to utilize their labor economically and efficiently.

The typical weeds encountered were the broadleaf weeds *Amaranthus viridis*, *Chenopodium ficifolium*, *Portulaca oleracea* and the grass *Eleusine indica*. The critical period of weed competition for transplanted tomatoes, i.e. the period during which weeds must be removed or yield or growth would be reduced, was determined during the autumn season using two cultivars, i.e. Tainan No. 2 and TM 103. Treatments included weed infestation for 0, 14, 28, 42, 56, and 70 days after transplanting (d.a.t.) and absence of weeds for 0, 14, 28, 42, 56, and 70 d.a.t.

Yields of both cultivars were as high as the weed-free check when the plantings were kept weed-free for 42 d.a.t. (Table 3). Controlling weeds for longer periods did not increase yield. On the other hand, the yield of Tainan No. 2 was reduced by 29.9% and that of TM103 by 21.5%, when plots were kept weed-free for only 28 d.a.t.

Tomato yields were reduced significantly, compared with the weed-free check, when weed competition was longer than 42 d.a.t. for Tainan No. 2, and 28 d.a.t. for Tainan No. 3 (Table 3). Yield reduction was 39.1% and 39.6%, respectively, for Tainan No. 2 and TM103 when weeds were left to compete with the crop throughout the growing season.

The response in terms of number of fruits produced in relation to length of time to weed interference was similar to response measured by fruit yield as reported above (Table 3).

The yield data showed that tomato tolerated weed infestation for 28 d.a.t. (TM 103) and 42 d.a.t. (Tainan No. 2) without significant yield loss. On the other hand, the crop needed to be kept free of weeds for 42 d.a.t. to yield as high as the weed-free check. Therefore, the critical period of weed competition was between 28 and 42 d.a.t. This suggests that one or two weedings during this period is adequate to prevent yield loss. A study conducted earlier reported that the critical period was between 24 and 26 d.a.t. (Frusen, 1979). Weaver and Tan (1983), however,

Table 3. Effect of time of weed removal on yield and fruit developmen of two tomato cultivars.[z]

Duration of weed interference (DAT)	Yield (t/ha)		Number of fruits/plant	
	Tainan No. 2	TM 103	Tainan No. 2	TM 103
Weed-free				
0-14	18.4 d	65.4 ef	15.2 f	74.4 cde
0-28	26.0 bcd	70.1 cde	21.0 cde	82.8 bcd
0-42	32.2 ab	84.1 abc	24.0 a-d	94.2 ab
0-56	32.7 ab	78.5 a-d	24.9 a-d	89.4 abc
0-70	37.4 a	78.4 a-d	28.0 a	93.0 ab
0-harvest (weed-free check)	37.1 a	89.3 a	27.1 ab	99.6 a
Weed-infested				
0-14	35.9 a	85.2 ab	26.7 abc	96.6 ab
0-28	37.9 a	81.2 abc	27.2 ab	94.2 ab
0-42	30.0 abc	72.8 bcd	21.8 b-e	83.4 bcd
0-56	24.4 cd	69.4 cde	16.6 e	81.6 bcd
0-70	22.3 cd	57.2 ef	19.6 de	72.0 de
0-harvest (weedy check)	22.6 cd	54.0 f	17.4 e	63.6 e

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test

concluded that this period was between 28 and 35 d.a.t., and weeding once during this period was enough to avoid significant yield loss. Yield reduction, under the present study, was manifested by a reduction in the number of fruits per plant. This suggests that weed interference suppresses the development of the fruit; the longer the period of weed interference, the lower the number of fruits per plant.

Selection of Herbicides

In cases where labor is lacking or labor cost is high, hand weeding may not be possible, and chemical weed control can be a good alternative. Trials have been conducted at AVRDC to identify effective herbicides that can control weeds and are safe for the crop.

Eight herbicides, i.e. alachlor, diphenamid, oxyfluorfen, metribuzin, pendimethalin, trifluralin, oryzalin, and EL-5219 were evaluated for weed control in transplanted tomatoes. All herbicides were applied preemergence and before tomato transplanting. The rates of application varied from below the recommended rates to higher than the recommended rates. Trifluralin, oryzalin, EL5219, and pendimethalin caused serious crop injury, whereas alachlor resulted in moderate injury, especially with high application rates. The crop was not affected by metribuzin, diphenamid, and oxyfluorfen. Although diphenamid did not cause phytotoxicity to the crop, it was somewhat weak in control of both grass and broadleaf weeds (Table 4). Based on these findings, only metribuzin, oxyfluorfen, and alachlor were selected for further evaluation.

Further evaluation revealed that oxyfluorfen and alachlor caused crop injury, as indicated by a reduction of plant height starting from three weeks after transplanting, whereas metribuzin caused no height reduction (Table 5). Although oxyfluorfen had not caused crop injury in a previous trial, the severe phytotoxicity of oxyfluorfen in this case was attributed to heavy rain, encountered at 20 days after transplanting (d.a.t.). Rain splashing caused the top part of the tomato plant to be covered with soil particles already sprayed with oxyfluorfen. It has been shown that shoot exposure to oxyfluorfen is more injurious than root exposure (Fadayomi and Warren, 1977).

Table 4 Weed counts at 50 days after the application of various herbicides.[z]

Herbicide application rate (kg a.i./ha)	Crop injury[y]	Weed counts (no./m²) Grass	Weed counts (no./m²) Broadleaf	Herbicide application rate (kg a.i./ha)	Crop injury	Weed count (no./m²) Grass	Weed count (no./m²) Broadleaf
Weedy check	0.0 e	453.3 a	0 a	Metribuzin			
				0.50	0.0 e	73.3 c-f	0.0 c
Weed-free check	0.0 e	0.0 f	0.0 c	0.75	0.0 e	53.3 ef	0.0 c
Alachlor							
2.0	0.0 e	146.7 bcd	33.3 b				
4.0	3.3 bc	53.3 ef	0.0 c	Pendimethalin			
				0.75	1.3 cde	86.7 c-f	6.7 bc
Diphenamid				1.00	0.3 e	113.3 b-e	6.7 bc
3.0	0.0 e	153.3 bc	20.0 bc	1.25	3.0 bcd	60.0 def	0.0 c
6.0	0.0 e	186.7 b	13.3 bc	1.50	5.0 b	46.7 ef	0.0 c
Oxyfluorfen				Oryzalin			
0.24	1.0 de	33.3 ef	0.0 c	1.50	8.0 a	66.7 c-f	6.7 bc
0.29	0.3 e	33.3 ef	0.0 c	2.00	8.7 a	100.0 cde	6.7 bc
0.35	1.7 cde	46.7 ef	0.0 c	2.50	9.0 a	73.3 c-f	13.3 bc
EL-5219				Trifluralin			
2.00	9.0 a	60.0 def	0.0 c	2.00	8.7 a	60.0 def	0.0 c
3.00	9.3 a	40.0 ef	0.0 c	2.50	9.0 a	46.7 ef	0.0 c
4.00	10.0 a	40.0 ef	0.0 c	3.00	9.3 a	66.7 c-f	6.7 bc

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test. [y]For crop injury rating, 0 = no crop injury, 10 = complete crop kill.

Table 6 shows that weed infestation was reduced as the herbicide application rates increased. Oxyfluorfen and metribuzin provided good broadleaf weed control, while alachlor gave good control of grasses. Yield from oxyfluorfen treatments, as a result of severe crop injury, were the lowest of all treatments. The highest yield of 31.6 t/ha came from metribuzin treatment at 1.00 kg a.i./ha.

Table 5. Effect of herbicides on tomato plant height at different times after transplanting.[z]

Herbicide application rate (kg a.i./ha)	Height (cm^2)			
	2 w.a.t.[y]	3 w.a.t.	4 w.a.t.	5 w.a.t.
Weedy check	14.2 a	22.6 a	32.5 a	40.1 a
Weed-free check	13.0 a	20.6 ab	29.8 ab	35.0 abc
Alachlor				
1.00	14.4 a	19.1 b-d	24.8 cde	30.5 cd
2.00	12.4 a	16.8 c-e	22.3 de	28.1 de
4.00	13.4 a	15.9 de	21.1 ef	24.2 ef
Metribuzin				
0.25	14.2 a	20.3 ab	28.0 bc	35.6 abc
0.50	13.1 a	20.4 ab	26.2 bc	33.8 bc
0.75	14.1 a	20.1 abc	25.6 cd	32.8 cd
1.00	13.4 a	20.0 abc	28.0 bc	38.2 ab
Oxyfluorfen				
0.059	10.9 a	16.4 de	18.0 fg	20.4
0.118	11.1 a	15.7 de	16.3 gh	16.6 gh
0.176	11.3 a	16.0 de	17.7 fg	17.7 fg
0.235	12.7 a	17.2 b-e	17.3 fgh	18.9 gh
0.294	11.0 a	15.4 e	13.6 h	14.0 h
0.352	11.0 a	16.4 de	17.8 fg	15.9 gh

[z]Mean within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test. [y]Weeks after transplanting

Table 6. Effect of herbicides on weed fresh weight and on tomato yield.[z]

Herbicide application rate (kg a.i./ha)	Weed fresh weight (t/ha)		Yield (t/ha)
	Broadleaf	Grass	
Weedy check	3.8 bcd	26.6 a-d	6.1 cde
Weed-free check	0.0 d	0.0 f	28.2 a
Alachlor			
1.00	16.9 a	7.6 ef	11.2 c
2.00	6.8 b	6.7 ef	9.5 cd
4.00	6.6 bc	6.6 ef	10.0 cd
Metribuzin			
0.25	4.1 bcd	36.1 a	9.0 cd
0.50	1.4 cd	27.7 abc	18.7 b
0.75	0.2 d	23.0 bcd	19.3 b
1.00	0.3 d	18.9 cd	31.6 a
Oxyfluorfen			
0.059	0.6 d	32.8 ab	5.3 de
0.118	0.1 d	26.3 a-d	1.9 e
0.176	0.1 d	30.4 abc	2.7 e
0.235	0.0 d	20.0 cd	1.6 e
0.294	0.0 d	15.0 de	0.5 e
0.352	0.0 d	23.6 bcd	2.6 e

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test

Mulching

Mulch controls weeds, conserves soil water and provides a favorable root environment for plant growth. A field trial conducted at AVRDC during the autumn season revealed that yield of nonstaked tomato was increased 67.5% when the crop was mulched with black plastic and by 15% when it was mulched with rice straw (Table 7). The high yield of the plastic mulch treatment was in terms of a high number of fruits/plant. Plastic mulch stimulated root growth, as indicated by the highest root weight in Table 7. This helped the plants to exploit plant nutrients and soil moisture more effective than in the other treatment, resulting in high yields. This is in agreement with the results of other workers (Jones et al. 1977; Jones and Jones, 1978; Sweeney et al. 1987; Vandenberg and Tiessen, 1972). The high yields under mulch obtained in these earlier studies were due to increased numbers of clusters, flowers, fruit per plant, and earliness (Vandenberg and Tiessen, 1972), lower soil moisture fluctuation (Jones et al. 1977) increased nutrient uptake (Jones et al. 1977; Sweeney et al. 1987), and improved fruit size (Schalk, 1987).

Water Management

Tomato is sensitive to flooding. Heavy rainfall during the growing period can be detrimental to the plants, a common problem in the tropics where tomatoes are grown in the summer season. Trials were conducted with AVRDC line CL 9001, a determinate heat-tolerant line. The total rainfall for the growing season was 1220 mm. After one heavy rainfall, it was found that the top 15 cm of soil in high beds (30 and 40 cm)lost soil moisture quicker than the top soil in low beds (15 cm)(Table 8). This resulted in a high plant survival rate and a high yield from the high beds. The lower yield from the low beds was due to a lower fruit number per plant and smaller fruit size. Since there was no yield difference between beds 30 and 40 cm high, a bed height of 30 cm is considered optimal.

During the dry (autumn)season, farmers usually irrigate tomatoes by furrow irrigation, a method which may have a low water use efficiency. To economize on water use in this method, a study was carried out in autumn to determine the optimum irrigation schedule. The best irrigation schedule giving high yields was to irrigate the crop three times, i.e. immediately after transplanting, and 30 and 45 days after transplanting (Table 9). The yield from this treatment

Table 7. Effect of mulching on yield, parameters and dry root weight.[z]

Treatment	Yield (t/ha)	Fruit size (g/fruit)	Fruit number (no./plant)	Root dry weight (g/plant)
Black plastic mulch	38.9 a	44.7 a	52.3 a	11.7 a
Rice straw mulch	26.8 b	41.6 a	38.6 ab	8.5 b
Check	23.2 b	42.0 a	33.7 b	8.6 b

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test

Table 8. Effect of bed height on soil moisture content, yield parameters, and survival rate of tomato grown in summer.[z]

Bed height (cm)	Soil moisture[y] 1	Soil moisture[y] 5	Plant (%)	Yield (t/ha)	Fruit size (g/fruit)	Fruit no. (no./plant)
15	40.0 a	22.7 a	39.1 b	1.9 b	18.7 b	10.1 b
30	37.2 ab	15.7 b	96.4 a	11.4 a	25.9 a	18.9 a
45	36.3 b	15.6 b	97.8 a	13.2 a	28.0 a	19.9 a

[z]Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test. [y]Measured at 1 and 5 days after one heavy rainfall of 84.8 mm.

was as high as those of the treatments which received irrigation four to five times. High yield was due to a higher number of fruits/plant and was also found to be associated with small fruit size. By applying water at 0, 30, and 45 days after transplanting (d.a.t.) high fruit yield was obtained because the treatment covers the flowering and fruit development stages of the crop. There was no need to irrigate the crop after 45 d.a.t., since at this time the crop entered the fruit maturation stage and roots had grown extensively and could exploit soil water very effectively.

Table 9. Yield, fruit size and number following different furrow irrigation schedules.[z]

Irrigation application (d.a.t.)	Marketable fruit		
	Yield (t/ha)	Size (g/plant)	Number (no./plant)
0, 15	52.7 ed	58.9 a-d	54.8 fg
0, 30	66.7 abc	57.0 cd	73.0 b-e
0, 45	60.2 bcd	57.1 cd	65.0 c-f
0, 60	59.4 cd	62.8 a	57.6 efg
0, 15, 30	59.1 cd	59.1 a-d	62.9 def
0, 15, 45	58.0 cd	57.2 cd	63.5 c-f
0, 15, 60	62.1 bcd	62.4 ab	59.9 ef
0, 30, 45	79.7 a	54.6 d	91.8 a
0, 30, 60	67.9 abc	60.4 abc	70.3 b-f
0, 45, 60	71.4 abc	59.4 a-d	73.4 b-e
0, 15, 30, 45	71.4 abc	54.8 d	79.5 abc
0, 15, 30, 60	66.2 a-d	58.1 a-d	71.0 b-e
0, 15, 45, 60	77.3 a	57.8 bcd	82.7 ab
0, 15, 30, 45, 60	73.8 ab	58.3 a-d	79.0 a-d
0 (check)	42.0 e	61.8 abc	42.9 g

[z]Means within a column followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Low-pressure Drip Irrigation

To further economize water use, a low-pressure drip irrigation system was developed at AVRDC. The system consisted of a water tank with the maximum pressure head of 7 k Pa connected to PVC pipes, which served as laterals. The other end of the system was connected to a water hose, which was raised vertically higher than the level of water in the tank to prevent water from being discharged through the open end. Holes of 5.0 mm in diameter drilled along the laterals served as drippers. Pieces of low-absorbency sponge, 1.0 x 2.0 x 0.7 cm in size, were inserted into the holes to slow down the water discharge rate. The determinate tomato variety TM 103 was used, grown on 1.5 m-wide and 16 m-long beds. Throughout the growing season, the pressure in the water tank varied from 7 k Pa to about 1 k Pa depending on the water level in the tank, and it took from four minutes to 1.5 hrs to discharge the required amount of water. The precipitation for the whole growing period was 130 mm and the average evaporation was 491.8 mm. The result showed that yield from the drip irrigation was as high as that from the furrow irrigations. Drip irrigation saved as much as 66% of the water used in furrow irrigation (Table 10). Since wilting of plants was not observed and crop yield was as high as with furrow irrigation, it is concluded that the drip irrigation system works satisfactorily and delivers sufficient water for plant growth at different stages.

Effect of Methionine and CDU

An experiment was conducted during the autumn/winter of 1987/1988 to evaluate the effect of Crotonyliden-Di-Urea (CDU) on tomato yield, a slow-release fertilizer, and methionine, an

ethylene precursor. The study was carried out in a randomized complete block design with six replications during the cool dry season. Twenty-six-day-old seedlings of tomato cultivar TK No. 10 were transplanted onto beds measuring 1.5 m × 4 m on 21 October. Plants were planted in a single row and were spaced at 50 cm resulting in 8 plants/bed. Individual plots consisted of four beds. Treatments consisted of: a complete fertilizer at the rate of 210 kg N (90 kg as basal application, and 60 kg side-dressed at 3 and 6 w.a.t.), 210 kg P_2O_5 (135 kg as basal and 15 and 60 kg side-dressed at 3 and 6 w.a.t., respectively) plus 180 kg K_2O/ha (60 kg each as basal and side-dressed at 3 and 6 w.a.t.) of CDU at the same rate; and of 1,000 ppm methionine foliar sprays at the rate of 1,500 l/ha at 4 w.a.t. CDU and methionine gave higher yields than normal fertilizer. Higher yields were due to higher numbers of fruits/plant (Table 11). Fruit size was about the same for all treatments. The highest yield of 65.9 t/ha was obtained from the methionine treatment. Methionine may have initiated more flowers and hence more fruits/plant. The slow-release fertilizer CDU provided a steady supply of nutrients throughout the growing period, which may account for the high yield of this treatment.

Table 10. Yield and total amount of water applied, including rain, by different irrigation methods.

Irrigation method	Yield[z] (t/ha)	Amount of water applied (liters/bed)
Low pressure drip	110.3	3546
Furrow (3 times)	96.5	8496
Furrow (4 times)	100.1	10496

[z]Differences between the treatments are not significant.

Table 11. Tomato yield and its attributes following CDU and methionine application.[z]

Treatment	Yield (t/ha)	Fruit size (g/fruit)	Fruit no. (no./plant)
Normal fertilizer	55.1 c	83.5	52.4 c
CDU	59.2 b	82.5	57.5 b
Methionine	65.9 a	82.8	63.9 a

[z]Means within a column followed by different letters are significantly different at the 5% level by Duncan's multiple range test.

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Symposium Discussion

G.Y.H. Grubben: Is the application of metribuzin or other herbicides which kill broad leaf weeds dangerous, because they promote the development of *Cyperus rotundus*?
A. Sajjapongse: *Cyperus rotundus* is a poor competitor. It will not give serious infestation if there are other weeds in the plot. On the other hand, it will infest the plot seriously if there is no competition from either other weeds or crops. In the case where other weeds are eradicated by herbicide application and the crop is not affected by the herbicide, infestation from *Cyperus rotundus* is not serious because the weed will be suppressed by competition from the crop.

J.M. Soriano: Plastic mulch increased temperatures in the soil when tested in the Philippines. This was a negative factor. How did mulching promote yield in AVRDC's studies?
A. Sajjapongse: The plastic mulch used in our studies has two different sides, a black surface and a silver covered surface. In summer, the silver side is used to reflect light and heat and hence lowers the soil temperature. On the other hand, the black surface is used in the winter to absorb heat and increase the soil temperature. In addition, mulch increases nutrient uptake by the plant, provides good moisture supply and controls weeds, resulting in a better environment for plant growth. In your case, if you use black plastic mulch in summer, it will increase soil temperature as you mentioned and will have a detrimental effect on the plant. The silver side of the plastic mulch should be used so that it reduces soil temperature rather than increasing it.

N.S. Talekar: What are the possible reasons for better crop performance under mulch?
A. Sajjapongse: Mulch reduces the fluctuation of soil moisture content, reduces soil temperatures in summer and increases soil temperatures in winter. Mulch also controls weeds and enhances the uptake of nutrients such as N, Ca and Mg. These factors create a favorable environment for root growth.

A. Watanabe: (1) What are the application method, dosage, and timing for methionine? (2) Did you observe any specific plant development by application? (3) Do you have any idea how methionine works for higher production?
A. Sajjapongse: (1) Methionine, at 1,000 ppm concentration, is applied as a spray at the rate of 1500 liters/ha on 24 days after transplanting. (2) Yes, more flowers are initiated by the application. (3) As stated in answer (2), more flowers are initiated, and hence more fruits per plant are produced, resulting in higher yield.

40

Hydroponic Production Studies on Lowland Tomato in Malaysia: The Effect of Pruning System and CHPA Application on Yield

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Abstract

A production study was carried out on five selected determinate tomato lines obtained from the Asian Vegetable Research and Development Center (AVRDC). The plants were grown using a two-phase substrate soilless culture system at Universiti Pertanian Malaysia. A continuous recirculating nutrient flow was maintained throughout the study. Comparisons were made between the lines for productivity under single-stem and double-stem pruning systems and flower treatment with a synthetic auxin, CHPA.

The lines varied in the degree of response to the production treatments, but in general yields obtained from the double stem pruning system were superior to the single stem system. The application of CHPA to the flowers also resulted in increased yields generally due to the production of larger fruits and an increase in the fruit-set. Lines CL 5915-229 and CL 5915-223 were found to respond well to the double stem pruning system and the CHPA application and produced yields equivalent to 62 and 50 tonnes per hectare respectively.

Introduction

The yield of tomato grown in the lowlands locally has been generally low. Yields ranging from 16 to 22 t/ha have been reported for promising heat-tolerant lowland selections (Melor, 1986). Tomato yields are influenced by many factors among which the genotype, growing environment and cultural practices are the more important ones. The use of adapted high yielding material, provision of optimum growing environment and the adoption of suitable cultural practices are considered in this study.

In a preliminary study yields ranging from an equivalent of 18 to 43 t/ha were obtained from various AVRDC determinate-type lowland tomato selections (Lim, 1986, unpublished). Five of these selections were chosen for further evaluation of cultural practices.

The use of hydroponic culture system for the production of tomato can increase the crop yield. It has been reported that tomato grown in hydroponic units produced yields of 50 t/ha which is approximately four times the yield of tomato grown under field conditions (Wan and Lim, 1984). The hydroponic production system was able to provide near optimum growing conditions. Besides ensuring a good supply of available plant nutrients, the glass-enclosed growing units also provided protection from the weather and severe pest infestations. The use of hydroponics can be considered as an aspect of cultural practice that can increase yield.

Another cultural practice for consideration is the pruning system. There have been various reports on the advantage of multiple stems. Patil (1977)reported that single stemmed plants yielded more high-quality fruits than multiple stemmed plants. However, in a series of trials with determinate-type tomato, Zubeldia and Gasco (1977)found that tomato plants with double stems grown at a spacing of 1.2 by 0.5 m produced higher yields than single-stem plants.

The use of growth regulators to enhance fruit yields is not new. A synthetic auxin, CHPA (4-chloro-2-hydroxymethyl phenoxy acetic acid) has been recommended as a fruit-setting agent for tomato grown at low temperature and low light intensity. In Japan, the application of CHPA at 100 ppm was found to be optimum and applications from six days before to four days after anthesis resulted in 90% fruit-set (Kyowa. 1982. personal communication).

In this study, the response of some lowland tomato selections to the pruning system and auxin application under tropical conditions using hydroponic culture was investigated.

Materials and Methods

The experiment was conducted at Universiti Pertanian Malaysia using a two-phase substrate system of soilless culture (Lim and Wan. 1984). A split-plot arrangement within a randomized complete block design with four replications was used for the experiment. Five AVRDC determinate-type lowland tomato selections were grown in the main plots (cultivation troughs). The main plots were divided into four subplots for factorial combinations of the pruning system (single stem and double stems)and flower treatments (with and without the application of CHPA on the flowers). Plants were arranged in double rows with 0.65 m between rows and 0.50 m between plants in the row within each trough. Each row of cultivation troughs was separated by a one-meter wide path.

Pregerminated tomato seeds were planted into planting baskets within each trough. Pruning to allow one or two stems to develop was carried out as the lateral shoots appeared. In two-stemmed plants the first lateral was allowed to develop into a second stem. The application of CHPA was carried out on opened flowers. A rate of 100 mg CHPA/liter of solution was sprayed on newly opened flowers in the early part of the day.

During the growing period of the crop, the air temperature within the glasshouse recorded a mean daily minimum of 23.1°C + 1.1° and a mean daily maximum of 39°C + 4.2°. The temperature of the nutrient solution was automatically regulated to between 28° and 29°C using a heat exchanger unit located outside the glasshouse.

Harvesting commenced nine weeks after seeding and continued for eight weeks. Fruits ranging from yellowish to reddish green were considered ripe. Harvesting and weighing of the fruits were carried out every third day.

Results

Significant differences were observed among the various tomato lines for the various reproductive characters measured. With a few exceptions, significant differences due to the pruning system as well as the treatment of the flowers with CHPA were also observed for the various reproductive characters. However, in most of the characters there were interactions between tomato lines and the application of CHPA. The effect of pruning system was less influenced by the particular tomato lines. For each reproductive character the response to treatment of each line is given below.

Flowering

The number of flower trusses produced differed significantly among different lines, pruning systems and flower treatments. Although all lines produced more flower trusses with double-stem pruning, the level of increase varied with the line (Table 1). Plants on which flowers were sprayed with CHPA produced fewer flower trusses than those on which no application was carried out (11.3 and 13.0 trusses per plant, respectively).

The mean number of flowers per truss was also significantly affected by the various treatments. Plants not treated with CHPA produced more flowers per truss for each of the lines.

However, with the exception of line CL 1131-0-0 there was no difference due to the pruning system (Table 2).

Fruit-set

The proportion of flowers setting fruits differed significantly among the lines and between the various treatments (Table 3). A higher proportion of flowers formed fruits when the flowers were sprayed with CHPA. Some lines were more dependent on the application of CHPA than others for good fruit-set (e.g. CL 5915-136 and CL 5915-229). All lines set more fruits when the flowers were sprayed with CHPA. Plants having double stems showed an overall lower proportion of flowers forming fruits but this was largely the effect of the higher number of flowers produced (Table 4). Double-stemmed plants actually produced more fruits than single-stemmed plants.

The fruit weight was not influenced by the pruning system but was significantly increased by the CHPA treatment. Although the lines varied in the average size of fruits, the application of CHPA increased the average fruit weight in some cases to more than twice the size of that from untreated flowers, particularly for the lines with smaller fruits (Table 5).

Table 1. The effect of pruning on the number of flowering trusses produced per plant.

AVRDC line	Single stem	Double stem
CL 5915-136D4-1-0	9.3 b[z]	18.6 e
CL 5915-223D4-2-1	10.1 bc	15.4 d
CL 5915-229D4-1-3	9.2 b	17.6 e
CL 1131-0-0-13-0-6	6.8 a	15.8 de
CL 143-0-10-3-0-1-10	6.8 a	12.0 c

[z]Means followed by the same letter are not significantly different at P = 0.05.

Table 2. The effect of flower treatment and pruning on the number of flowers produced per truss.

AVRDC line	Flower treatment		Pruning	
	With CHPA	Without CHPA	Single stem	Double stem
CL 5915-136D4-1-0	5.7 a[z]	8.6 c	7.6 ab	6.8 a
CL 5915-223D4-2-1	6.6 b	11.1 d	8.8 cd	8.9 cd
CL 5915-229D3-1-3	5.4 a	8.4 c	6.7 a	7.1 a
CL 1131-0-0-13-0-6	6.2 ab	10.8 d	9.4 d	7.5 ab
CL 143-0-10-3-0-1-10	6.6 b	10.7 d	9.0 cd	8.3 bc

[z]Means within each pair of treatments (flower treatment or pruning) followed by the same letter are not significantly different at P = 0.05.

Table 3. The effect of flower treatment on the percentage of flowers that form fruits.

AVRDC line	Flower treatment	
	With CHPA	Without CHPA
CL 5915-136D4-1-0	70.8 d[z]	32.5 a
CL 5915-223D4-2-1	80.6 e	63.4 cd
CL 5915-229D4-1-3	80.0 e	45.8 b
CL 1131-0-0-13-0-6	81.9 e	61.8 c
CL 143-0-10-3-0-1-10	83.2 e	57.2 c

[z]Means followed by the same letter are not significantly different at P = 0.05.

Table 4. The effect of pruning on fruiting.

Pruning	Flowers/ plant (no.)	Fruit set (%)	Fruits/ plant (no.)
Single stem	70.2 a[z]	67.7 a	35.1 a
Double stem	123.2 b	63.4 b	54.2 b

[z]Means within each column followed by the same letter are not significantly different at P = 0.05.

Table 5. The effect of flower treatment on fruit weight (g).

AVRDC Line	Flower treatment	
	With CHPA	Without CHPA
CL 5915-136D4-1-0	29.5 b[z]	14.0 a
CL 5915-223D4-2-1	46.9 e	17.7 a
CL 5915-229D4-1-3	51.5 e	40.3 d
CL 1131-0-0-13-0-6	29.8 b	17.2 a
CL 143-0-10-3-0-1-10	35.3 c	14.2 a

[z]Means followed by the same letter are not significantly different at P = 0.05.

The increase in the number of flowering trusses with double-stem pruning and the better fruit-set and development obtained with the application of CHPA resulted in significant improvement of the overall yield (Table 6). With the exception of line CL 1131-0-0 all other lines produced two to three times the yield of single-stemmed plants not treated with CHPA.

Fruit Quality

The fruit of plants with blossom-end rot (BER), and fruit which is misshapen or poorly formed (MSF), are not marketable. The incidence of BER was found to be related to particular lines and to treatment with CHPA (Table 7). Lines CL 5915-136 and CL 1131-0-0 were totally free from BER while CL 143-0-10 had the highest incidence. Treatment with CHPA caused an increase in the incidence of BER in some lines (CL 5915-223, CL 5915-229 and CL 143-0-10). The increased fruit-set in these lines when CHPA was applied may have caused nutritional imbalance resulting in the condition.

The formation of misshapen fruit (MSF) was observed to be a varietal trait and was more frequent on lines with low untreated yields. CL 5915-229 had the lowest number of MSF, but lines CL 5915-136 and CL 143-0-10 had the highest. The application of CHPA to the flowers greatly reduced the proportion of such misshapen fruits.

Discussion

The effect of pruning and CHPA treatment on the flowers needs to be viewed together with that of fruit set, as both are interrelated. The plant produces flowers progressively upward and along the trusses. Fruit set begins a few days after flowering commences and continues throughout the flowering period. Plants that have poor fruit set compensate by producing more flowers. This was evident from the large number of flowers produced on each truss when CHPA was not applied, and constitutes a plant response to poor fruit set. CHPA stimulated fruit set and fruit set inhibited the formation of more flowers.

Double-stem pruning was found to be better than single-stem pruning. With two stems per plant there were more flowering trusses produced. This increased the fruiting potential and provided more sinks for the ample supply of carbohydrates. Fruit size was not restricted by the larger number of sinks, indicating that the source was more than adequate. Although single-stem pruning of tomato has been practiced in many temperate countries where tomato is grown under soilless culture, its advantage under local conditions needs to be evaluated. In cooler temperate climates the indeterminate type of tomato is grown and the stem is allowed to grow

Table 6. The effect of flower treatment on the fruit yield per plant (g).

AVRDC Line	Flower treatment	
	With CHPA	Without CHPA
CL 5915-136D4-1-0	1,119 c[z]	376 a
CL 5915-223D4-2-1	2,255 e	949 bc
CL 5915-229D4-1-3	2,471 e	1,354 c
CL 1131-0-0-13-0-6	1,354 c	953 bc
CL 143-0-10-3-0-1-10	1,472 d	674 ab

[z]Means followed by the same letter are not significantly different at P = 0.05.

Table 7. The effect of flower treatment on the incidence of blossom-end rot and misshapen fruits.

AVRDC Line	No. fruits with blossom-end rot[z]		Percentage of misshapen fruits	
	With CHPA	Without CHPA	With CHPA	Without CHPA
CL 5915-136D4-1-0	0.0 a[y]	0.0 a	1.89 a	58.64 c
CL 5915-223D4-2-1	6.0 b	0.5 a	2.88 a	26.50 b
CL 5915-229D4-1-3	13.5 c	0.0 a	2.08 a	6.74 a
CL 1131-0-0-13-0-6	0.0 a	0.0 a	3.20 a	27.15 b
CL 143-0-10-3-0-1-10	74.5 d	1.0 a	4.41 a	76.56 d

[z]Tests of significance based upon transformed data where $x = \sqrt{x + 0.5}$. [y]For each character, means followed by the same letter are not significantly different at P = 0.05.

and bear fruit over a long period of time (up to nine months). Under hot tropical conditions, the tomato plant senesces after four to five months. Locally grown tomato is also topped after reaching a height of about two meters in order to keep the plants manageable. Under such conditions, high yields must be obtained in as short a time as possible, i.e. within four months, and with a limited plant height. The double-stem pruning system provides a means to increase the fruiting capacity of the plant without the need to increase the number of plants in an already narrow plant spacing of 0.65 x 0.50 m, using soilless culture.

The application of CHPA resulted in increased fruit set and in the development of larger fruits. This, together with the increase in the number flowering trusses resulting from double-stem pruning, contributed to the yield increase. The use of soilless culture may have contributed also to yield increase because the nutrient supply was less likely to be a limiting factor, which is not the case under conventional land farming.

The effect of CHPA on fruit quality was considered beneficial in spite of the slight increase in the number of fruits affected by blossom-end rot (BER). The susceptibility to BER was restricted to certain lines. All the lines were grown using the same recirculating nutrient solution and any difference in BER incidence is unlikely to be due to differences in the nutrient supply status. It is also unlikely that CHPA treatment alone caused more BER. Among the lines, there were those that responded well to CHPA treatment that had no incidence of BER (lines CL 5915-136 and CL 1131-0-0). However, in two other lines, CL 5915-223 and CL 5915-229, there was an increase in fruits with BER. Line CL 143-0-10 had a much higher increase in BER incidence. In the affected lines the benefit from yield increase was greater than the loss caused by an increase in the number of affected fruits. The varietal susceptibility to BER is considered to be the more important factor.

The beneficial effect of CHPA on fruit quality was evident from the reduction in the proportion of misshapen fruits for all lines. The larger size of the fruits when CHPA was applied could also be considered as an improvement in fruit quality. Lines which normally have very small fruits produced fruits more than double the usual size. Fruit marketability could, therefore, be improved with the application of CHPA.

The highest yield, which was equivalent to 62 t/ha, was produced by variety CL 5915-229 when pruned to produce double stems and when flowers were treated with CHPA. This was followed by CL 5915-223 yielding an equivalent of 50 t/ha under the same treatments. Although no direct comparison with field trials has been made, the yields obtained were very much higher than those generally obtained locally. In addition, such yields were obtained over a shorter growing period of four months compared to the longer season of the indeterminate types that were grown locally (six months). The study has shown that determinate tomato lines are capable of high yields when managed under proper cultural conditions.

Conclusion

The AVRDC tomato lines grown under soilless cultivation were significantly affected by the pruning system and by treatment of the flowers with CHPA. Increasing the number of main stems to two allowed a larger number of flowering trusses to be produced. The application of CHPA increased the proportion of flowers setting fruits, increased the size of fruits, and also improved fruit quality. These two treatments (double-stem pruning and CHPA application)together resulted in an increased fruit yield of all the lines tested. Under these treatments, lines CL 5915-229 and CL 5915-223 gave the highest yields with good fruit size. The modification of cultural practices to include the double-stem pruning system together with the application of CHPA to the flowers can improve the yield of determinate type tomato.

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Symposium Discussion

Suwandi: (1) What was the temperature regime in your glasshouse? (2) Have you done an economic study? If so, how can it be applied to farmers in Malaysia?

E.S. Lim: (1) Air temperature within the glasshouse ranged from 22°C in the morning to over 40°C in the afternoon. Only natural ventilation through the windows was provided. However, the culture solution is maintained at a temperature of 28° to 30°C using external heat exchanger cooling units. (2) An economic study was conducted separately by Lim and Wan (1984)

Presently, studies to further reduce the cost of production and to simplify the system are being carried out before this method of production can be used by farmers.

R.L. Villareal: Why did you use determinate tomatoes instead of indeterminate ones in your greenhouse experiment?
E.S. Lim: Limitations on height imposed by the hydroponic culture system is one reason. Topping at a height of 1.5 meters is necessary for indeterminate types to prevent excessive vine growth. Determinate forms also have a shorter growing season and can produce multiple stems if unpruned.

-365-

41

Irrigation and Nitrogen Management for Bell Pepper (*Capsicum annuum* L.) in Tropical India

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Abstract

Studies conducted from 1982-83 to 1984-85 at the Indian Institute of Horticultural Research, Bangalore revealed that irrigation at 40% available soil moisture (ASM) resulted in maximum dry matter production, fruit yield, nutrient uptake and water use efficiency (WUE) in bell pepper although the difference between irrigations at 40 and 60% ASM was not significant. Very high or low-frequency of irrigation at 80 or 20% ASM had an adverse effect on productivity. It was also observed that scheduling irrigations when the soil matric potential at 15 cm depth reached -65 kPa resulted in higher yield and WUE than at -85 kPa; differences among irrigations scheduled at -25, -45 and -65 kPa were not significant. Imposing soil moisture stress of -85 kPa either up to first picking or thereafter significantly reduced the yield and WUE as compared to uniform irrigations at -45 and -65 kPa. Alternate and widely spaced furrow (100 cm) irrigation with 20 mm water/irrigation saved up to 40% water without any adverse effect on the productivity as compared to irrigating every furrow (50 cm spacing) with 40 mm water/irrigation. A quadratic relationship was observed between yield and ASM and between yield and evapotranspiration (ET) during all the years of study. Based on the pooled data, the ASM and ET which gave maximum yields were found to be 52% and 464 mm. These gave yield levels of 15.62 and 15.24 t/ha, respectively. N fertilization increased dry matter production, fruit yield, nutrient uptake and WUE, and 168 kg N/ha was found to be optimum for bell pepper.

Introduction

Bell pepper (*Capsicum annuum* L.) is an important vegetable cultivated in many parts of India. Soil moisture and N fertilizer are among the essential inputs controlling the productivity of bell pepper (Maynard et al. 1962; Albregts, 1971; Batal and Smittle, 1981; Beese et al. 1982; Srinivas and Prabhakar, 1982). The increasing demand for limited water supplies in arid and semiarid regions coupled with escalating costs and finite supplies of N fertilizer calls for their judicious use without impairing productivity. Scheduling irrigations at an optimum soil moisture regime is an important step in this direction. Since the extent of root development, leaf area and evaporative conditions during the entire growth period of the crop would not be the same, the magnitude of plant water deficit and its subsequent effect on growth would also vary. It would be important, therefore, to investigate the optimum moisture requirement of bell pepper at different phases of growth by subjecting the crop to different soil moisture stresses during each growth phase. There is also a need to devise simple but effective ways of applying water so that wastage is minimized in surface irrigation. Water management of bell peppers has received practically no attention in India.

An understanding of N nutrition of bell pepper is clearly required to ensure that crop yields are not restricted by a deficit N supply and to avoid depressed yields, the detrimental effects

of excess leaching and denitrification. Therefore, a series of field experiments were conducted to find out the optimum soil moisture regime, water requirement, critical stages for soil moisture stress, method and volume of irrigation and N requirement of bell pepper.

Materials and Methods

The field experiments were carried out for three years from 1982 to 1985 at the Indian Institute of Horticultural Research, Hessaraghatta, Bangalore (altitude 868 m; latitude 13°-58'N) in tropical South India on sandy clay loam soils (Udic Haplustalf) of low fertility (organic C, 0.46%; total N, 0.05%; available P, 9.6 kg/ha; available K, 132 kg/ha; pH 6.8). The soil had the capacity to hold an average of 108 mm available water in the top 75cm profile measured between 30 and 1500 kPa. The water table was deeper than 190 cm during the cropping season in each of the three years and hence groundwater contribution to the root zone was considered negligible. The environmental conditions prevailing during the three cropping seasons when the experiment was conducted are shown in Table 1.

Table 1. Mean monthly weather data recorded during cropping season.

Month Year	Air temperature (°C) Maximum	Minimum	Mean relative humidity (%)	Pan evaporation[2] (mm/day)	Total rainfall (mm)
		1982-83			
October, 1982	31.0	17.8	64.5	6.0	14.8
November, 1982	28.0	18.4	71.8	4.8	65.0
December, 1982	26.4	15.6	63.4	5.4	0.0
January, 1983	28.2	14.8	57.4	6.4	0.0
February, 1983	32.3	19.0	48.2	7.2	0.0
March, 1983	34.6	21.0	48.8	8.4	0.0
		1983-84			
October, 1983	28.1	19.2	73.7	4.4	77.6
November, 1983	27.8	16.3	66.6	5.0	2.0
December, 1983	25.4	17.2	71.0	4.1	51.2
January, 1984	26.7	16.7	62.9	4.9	0.0
February, 1984	27.3	17.7	62.5	5.3	24.0
March, 1984	30.8	18.7	51.0	7.2	37.4
		1984-1985			
October, 1984	27.5	19.0	69.0	5.3	126.2
November, 1984	27.6	17.4	67.0	5.4	24.4
December, 1984	27.6	15.3	61.0	5.8	0.0
January, 1985	26.7	15.2	62.8	6.1	0.0
February, 1985	30.1	15.0	47.3	7.0	0.0
March, 1985	33.0	18.3	47.4	7.8	0.3

[2]United States Weather Bureau Class-A

Experiment 1

The experiment aimed to establish the optimum soil moisture regime and N requirement of bell pepper. The treatments consisted of all combinations of irrigations at four available soil moisture (ASM) regimes (80, 60, 40 and 20% ASM in the top 30 cm soil layer which was equivalent to -29, -50, -70, and -93 kPa) and four levels of applied N (0, 60, 120 and 180 kg/ha). Plots were arranged in a randomized block design with three replications. Soil moisture was

monitored gravimetrically to schedule irrigations. Two soil samples were taken per plot from the top 30 cm soil layer to determine the timing for irrigation. Furrow irrigation was used. The amount of irrigation depended on the total moisture deficit in the root zone depth of 75 cm.

A sample of five bell pepper plants in each replicated plot was randomly collected at the time of final harvest for determining the dry matter and nutrient concentration in leaves and stems. Dry weights of fruits harvested during each picking from five randomly tagged plants in each plot were used to estimate dry matter distribution and nutrient concentration in fruits. Ground composite samples were used for determining N, P and K concentrations according to methods described by Jackson (1967). Ca and Mg concentrations were determined by atomic absorption spectrophotometer. Uptake of all the nutrients was calculated using data on their concentrations and dry matter yield.

Experiment 2

The experiment was designed to find out the optimum soil matric potential and critical stages for soil moisture stress in bell pepper. Irrigations were scheduled when the soil matric potential at 15 cm depth reached -25, -45, -65 and -85 kPa throughout the crop growth and when plants were stressed to -85 kPa either up to first picking (about 70 days after transplanting) or after first picking (70 to 135 days) with the other period being continuously irrigated at -25 kPa (no stress). The treatments were arranged in a randomized block design with four replications. Jet-fill tensiometers were installed at 15 cm depth to monitor soil matric potential and schedule irrigations.

Experiment 3

This experiment was carried out to find out a better method of application and the optimum volume of water per irrigation for bell pepper. The treatments consisted of alternate and widely spaced (100 cm) furrow irrigation with 40, 30 and 20 mm water/irrigation, along with a control where every furrow (50 cm spacing) irrigation was practiced with 40 mm water irrigation. Furrows were opened at every 50-cm distance space which could hold about 40 mm water; and hence it was included as the control treatment. The treatments were replicated four times in a randomized block design. When the soil matric potential at 15 cm depth reached -45 kPa as measured by a jet-fill tensiometer, irrigations were scheduled. In the widely spaced furrow irrigation treatment, furrows were opened every 100 cm and two rows of seedlings were planted on the raised bed to maintain a spacing of 50 cm between rows.

In all three experiments, half of the N as urea and a uniform level of 25.2 kg P (single super phosphate) and 49.6 kg K/ha (KCl) were applied prior to transplanting, and the remaining half of the N was side-dressed 30 days later. In the second and third experiments, a uniform level of 120 kg N/ha was applied in two equal splits. Five-week-old healthy seedlings of bell pepper cv. California Wonder were transplanted every 30 cm in rows 50 cm apart on 14 October 1982, 2 November 1983, and 19 October 1984. The plot size was 14.4 m^2 (4 m × 3.6 m). Fully matured green fruits were harvested at regular intervals from an area of 9 m^2 and the total marketable fruit yield was computed. Harvests began on average 70 days after transplanting (d.a.t.) and were completed by 135 d.a.t. in all three years.

In all the experiments, differential irrigation treatments were initiated after four common furrow irrigations of 40 mm each were applied for transplanting and establishment. Soil moisture was monitored gravimetrically and by measuring the changes in water content with time in the root zone down to 75 cm depth and the amount of irrigation or rainwater added. The actual evapotranspiration (ET) of the crop was estimated by the procedure given by Dastane (1967). It was assumed that drainage or upward flow from groundwater did not cause significant error in the estimate of ET. Water use efficiency (WUE) was calculated by dividing the marketable yield by ET.

To establish the relationship between yield and ASM and yield and ET, regression equations were fitted for individual years as well as pooled data, and yield-maximizing ASM and ET were estimated. Response equations for N were fitted as described by Munson and Doll (1959) to study input output relationships.

Results and Discussion

Effect of Irrigation and N Fertilization

Dry matter production. Irrigation at different soil moisture regimes had significant influence on dry matter production in bell pepper except during 1982-83 (Table 2). Nevertheless, similar trends were observed during all the three years of study. Intermediate irrigation frequency or 40% ASM generally produced maximum dry matter, closely followed by irrigation at 60% ASM. Irrigation at 80% or 20% ASM resulted in reduced dry matter production. Bell pepper growth is favored by moderate moisture, while either frequent irrigations (Sadykov and Mikhael, 1981) or large soil moisture deficits (Sirjacobs and Dada, 1983) have been shown to affect adversely growth and dry matter production. The N fertilization increased dry matter production and affected partitioning of plant dry matter into leaves, stems and fruits at rates up to 180 kg N/ha. The difference between 120 and 180 kg N/ha was not significant except in the stems during 1983-84. These results were expected because of low initial N status (total N 0.05%) of the soil in the experimental field. There was no significant interaction between soil moisture and N on dry matter production.

Table 2. Dry matter production and distribution in bell pepper on final harvest date as affected by soil moisture regimes and N fertilization.

Treatments	1982-83				1983-84				1984-85			
	Leaf	Stem	Fruit	Total	Leaf	Stem	Fruit	Total	Leaf	Stem	Fruit	Total
	(g/plant)				(g/plant)				(g/plant)			
Available soil moisture												
80% ASM	3.16	8.03	10.71	21.90	3.60	7.84	10.00	21.44	3.08	7.45	11.82	22.35
60% ASM	3.65	7.55	12.48	23.68	3.96	7.61	11.59	23.16	3.21	7.96	13.02	24.19
40% ASM	4.30	7.85	12.44	24.59	4.11	7.70	11.88	23.69	3.45	8.14	13.19	24.78
20% ASM	4.18	7.19	10.64	22.01	3.80	7.13	9.70	20.63	3.00	7.14	11.22	21.36
LSD (P = 0.05)	0.51	NS	NS	NS	0.40	0.74	1.48	2.33	NS	0.57	0.97	0.99
N levels (kg/ha)												
0	2.22	4.94	6.67	13.83	2.41	4.53	6.11	13.05	1.96	5.19	6.57	13.72
60	3.50	7.02	11.41	21.93	3.70	7.67	10.68	22.05	3.21	7.08	12.71	23.00
120	4.61	9.05	13.33	26.99	4.51	8.37	12.96	25.84	3.77	9.00	14.89	27.00
180	4.95	9.60	14.86	29.41	4.85	9.77	13.42	28.04	3.80	9.42	15.08	28.96
LSD (P = 0.05)	0.51	0.87	1.90	2.62	0.40	0.74	1.48	2.33	0.48	0.57	0.97	0.99

NS: Not significant

Fruit yield and its components. Bell pepper yield, the number of fruits/plant and average fruit weight were significantly influenced by irrigation at different soil moisture regimes during two out of three years and a similar trend was noticed in the third year (Table 3). Maximum yield occurred at an irrigation at 40% ASM, closely followed by irrigation at 60% ASM. Too wet a condition (80% ASM) or too dry a condition (20% ASM) significantly reduced yield. Vuelvas (1982) obtained the highest bell pepper yields with irrigations scheduled at 30% to 40% ASM, and others have also found that excessive irrigation always reduces pepper productivity

(Lepori and Gennari, 1979). The differences in yield among irrigation treatments could be traced to significant variations in yield components like fruits/plant and average fruit weight (Table 3).

The N fertilization increased the fruit yield up to 180 kg/ha although the difference between application rates of 120 and 180 kg/ha was not significant. The strong response to N was expected because of low initial N status of the soil in the experimental field. The differences in yield among N levels were the reflections of significant differences in fruits/plant and the average fruit weight. There was no interaction between soil moisture and N as indicated by fruit yield and its components.

Response functions fitted to the yield data of individual years and their mean indicated a quadratic nature of the response to N by bell pepper (Table 4) with a very high coefficient of determination (R^2). The optimum N level was found to vary between 158 and 187 kg/ha in different years. Based on pooled data, 168 kg N/ha was found to be optimum and resulted in yields of 18 t/ha. The N use efficiency with optimum N was found to vary between 97 to 117 kg with an average of 107 kg fruits/kg N.

Nutrient uptake. Irrigation regimes significantly affected nutrient uptake by bell pepper (Table 5). Irrigation at 40% ASM generally resulted in maximum nutrient uptake except in the case of K which was highest with irrigation at 60% ASM. High or low frequency of irrigation at 80 or 20% ASM reduced the nutrient uptake by bell pepper. Soil moisture affected nutrient uptake through its influence on biomass production and nutrient availability in the soil. Soil moisture status affects nitrification of soil organic matter and a decline in N uptake could be

Table 3. Fruit yield and its components in bell pepper as affected by soil moisture regimes and N fertilization

Treatments	Fruit yield (t/ha)			Fruits/plant (No.)			Average fruit weight (g)		
	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85
Available soil moisture									
80% ASM	13.57	12.74	13.65	7.3	6.4	6.6	28.0	29.3	31.3
60% ASM	15.10	14.62	15.92	8.3	7.4	7.5	28.6	30.1	33.6
40% ASM	15.37	14.83	15.96	8.5	7.0	7.7	27.5	30.6	34.0
20% ASM	13.09	12.07	12.74	7.6	6.8	6.3	26.6	28.4	30.5
LSD (P = 0.05)	NS*	2.16	1.96	NS	1.0	0.9	NS	1.7	1.5
N Levels (kg/ha)									
0	8.58	6.85	7.83	5.6	4.2	3.8	23.5	21.3	22.2
60	14.00	13.13	14.74	7.7	7.4	7.4	28.3	30.3	31.0
120	16.40	16.66	17.80	8.8	8.0	8.3	29.1	33.1	37.7
180	18.15	17.61	18.29	9.6	8.0	8.6	29.7	33.7	38.5
LSD (P = 0.05)	2.48	2.16	1.96	1.1	1.0	0.9	1.8	1.7	1.5

*NS: Not significant

Table 4. Fitted response functions of bell pepper to N for fruit yield

Year	Response function	R^2	Optimum N (kg/ha)	Fruit yield at optimum N (t/ha)	N use efficiency at optimum N (kg fruits/kg N)
1982-83	$Y = 8.07 + 0.09779 N - 0.000255 N^2$	0.99	187	18.07	97
1983-84	$Y = 6.87 + 0.12606 N - 0.000369 N^2$	0.99	167	17.63	106
1984-85	$Y = 7.82 + 0.13230 N - 0.000411 N^2$	1.00	158	18.46	117
Pooled	$Y = 7.80 + 0.11867 N - 0.000345 N^2$	0.99	168	18.00	107

Cost of N: Rs 5.11/kg; Sale price of bell pepper fruits: Rs 2,000/t (US$1.00 = Rs 13.03)

Table 5. Nutrient uptake by bell pepper as affected by soil moisture regimes and N fertilization.

Treatment	N			P			K			Ca			Mg		
	1982-83	1983-84	1984-85	1982-82	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85
Available soil moisture															
80% ASM	41.4	39.0	37.5	11.6	11.61	1.6	65.2	65.0	50.0	16.8	16.2	15.8	14.5	14.2	13.6
60% ASM	46.5	44.2	41.7	11.9	11.6	11.8	68.6	68.0	67.7	18.2	17.0	16.4	15.0	16.3	15.5
40% ASM	47.4	45.6	43.7	11.1	11.7	11.6	64.6	64.8	65.0	20.0	18.2	16.9	19.6	17.8	17.4
20% ASM	43.7	39.7	38.3	10.2	9.5	9.6	54.8	55.8	56.5	18.3	14.5	14.5	17.5	16.1	15.1
LSD (P = 0.05)	5.4	4.8	3.4	1.4	1.4	1.6	7.1	8.1	7.3	2.3	2.1	2.0	1.8	1.7	1.9
N levels (kg/ha)															
0	23.9	22.9	20.6	7.7	7.5	7.7	42.7	40.3	40.8	9.9	9.0	9.2	10.6	9.4	8.8
60	41.4	42.1	39.3	10.9	11.0	11.3	63.1	63.1	65.6	16.0	16.9	15.6	14.5	14.7	15.2
120	53.6	50.4	49.9	12.7	12.1	12.8	73.3	71.0	73.7	22.8	20.2	18.4	19.7	19.5	18.2
180	60.2	55.0	51.2	13.6	13.1	12.9	74.0	72.4	73.0	24.7	22.2	20.0	22.3	21.3	19.2
LSD (P = 0.05)	5.4	4.8	3.4	1.4	1.4	1.6	7.1	8.1	7.3	2.3	2.1	2.0	1.8	1.7	1.9

expected with increased moisture stress (Colman and Lazenby, 1975). Since P moves towards roots by diffusion, and K, Ca and Mg by both diffusion and mass flow (Barber, 1966; Pill and Lambeth, 1980), their uptake is governed largely by soil moisture status. The differences in nutrient uptake observed in the present studies may, therefore, be attributed to treatment effects on both these processes.

The N fertilization increased nutrient uptake during all three years up to 180 kg/ha although the difference between application rates of 120 and 180 kg N/ha was not significant in most cases. These differences in nutrient uptake mostly followed the differences in dry matter production. The interaction effect between soil moisture regimes and N was not significant.

Water use. Irrigation treatments had a conspicuous effect on the water use of bell pepper (Table 6). Decreasing frequency of irrigation reduced ET, perhaps because of a combination of both reduced surface soil evaporation with lower irrigation frequency and greater plant water deficits in low ASM treatments, which then resulted in greater stomatal resistance and reduced transpiration. WUE, however, increased with irrigation at decreasing soil moisture up to 40% ASM as a result of a marked decline in ET coupled with a significant increase in fruit yield. The N application increased ET, probably because higher leaf areas increased transpiration losses of water. As the increase in ET was smaller than the yield increases, WUE increased considerably with N fertilization up to 120 kg/ha.

The regression equation between crop response (fruit yield) and ASM indicated a quadratic nature of the response with high R^2 value (Table 7) in all three years as well as in pooled data. Russo (1983) also observed a quadratic relationship between yield and soil water potential in bell pepper. The yield-maximizing ASM was around 51 to 52% with the yield levels varying between 15.03 and 16.25 t/ha in different years. The pooled data indicated the highest obtainable yield of 15.62 t/ha with irrigation at 52% ASM.

There was also a very close relationship between yield and water use (ET) and the nature of response was found to be quadratic (Table 8). The maximum obtainable yield of 14.69 to

Table 6. Water use of bell pepper as affected by soil moisture regimes and N fertilization.

Treatment	Irrigation water applied (mm)			Evapotranspiration (mm)			Water use efficiency (kg fruit/m³ of water)		
	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85
Available soil moisture									
80% ASM	542	513	562	578	543	577	2.35	2.35	2.37
60% ASM	432	418	469	456	462	480	3.31	3.17	3.20
40% ASM	398	386	438	429	442	450	3.58	3.36	3.55
20% ASM	328	323	347	365	327	356	3.59	3.69	3.58
N levels (kg/ha)									
0	425	410	454	434	402	422	1.98	1.71	1.86
60	425	410	454	474	428	446	2.95	3.07	3.59
120	425	410	454	448	469	488	3.66	3.55	3.65
180	425	410	454	471	476	508	3.85	3.70	3.60

Table 7. Relationship of yield to available soil moisture (ASM) in bell pepper.

Year	Regression equation	R^2	Yield maximizing ASM (%)	Highest obtainable yield (t/ha)
1982-83	$Y = 9.23 + 0.24414\ ASM - 0.00238\ ASM^2$	0.98	51	15.49
1983-84	$Y = 7.30 + 0.29982\ ASM - 0.00291\ ASM^2$	0.99	52	15.03
1984-85	$Y = 7.14 + 0.35040\ ASM - 0.00337\ ASM^2$	0.98	52	16.25
Pooled	$Y = 7.89 + 0.29881\ ASM - 0.00289\ ASM^2$	0.98	52	15.62

Table 8. Relationship of yield to evapotranspiration (ET) in bell pepper.

Year	Regression equation	R^2	Yield-maximizing ET (%)	Highest obtainable yield (t/ha)
1982-83	$Y = -26.88 + 0.1778\ ET\ 0.000187\ ET^2$	0.99	475	15.39
1983-84	$Y = -24.94 + 0.1794\ ET\ 0.000203\ ET^2$	0.99	442	14.69
1984-85	$Y = -35.14 + 0.2149\ ET\ 0.000226\ ET^2$	0.99	475	15.95
Pooled	$Y = -28.27 + 0.1875\ ET\ 0.000202\ ET^2$	0.99	464	15.24

15.95 t/ha was found to be associated with 442 to 475 mm of water use in different years. The pooled data indicated a yield-maximizing water use of 464 mm, which could produce 15.24 t/ha.

Effect of Different Soil Matric Potentials

Irrigation at different soil matric potentials had a significant effect on fruit yield of bell pepper except during 1982-83 (Table 9). Irrigating the crop when the soil matric potential reached -65 kPa resulted in the highest fruit yield which was at par with the yield obtained with irrigation at -25 and -45 kPa but significantly higher than that obtained at -85 kPa. Sirjacobs and Dada (1983) obtained best yields with tensions between 15 and 25 kPa under a plastic greenhouse while Tedeschi and Zebri (1984) observed a big reduction in yield when soil moisture stress was higher than 100 kPa. Imposing a stress of -85 kPa either until first picking or thereafter significantly reduced the yield as compared to those irrigated continuously at -45 or -65 kPa. It may be further noted that the greatest reduction in yield occurred when there was high moisture stress after first picking, which confirms the findings of Nelson (1962) and Vuelvas (1982).

Decreasing frequency of irrigation at lower soil matric potential reduced ET. WUE increased with irrigation at decreasing soil matric potentials mainly because of a large decrease in ET coupled with some increase in yield. Stress, either up to first picking or thereafter, also reduced WUE as reflected in larger decreases in yield.

Effect of Method and Volume of Irrigation

Method and volume of irrigation had no significant effect on fruit yield of bell pepper in any of the three years (Table 10). Both alternate and widely spaced furrow irrigation systems with different quantities of water recorded similar yields as when every furrow was irrigated. The number of irrigations required was also the same in different treatments viz. 21, 19 and 20 during 1982-83, 83-84 and 84-84 respectively. However, the amount of irrigation water used

Table 9. Fruit yield and water use of bell pepper as affected by moisture stress at different stages.

Treatment		Fruit yield (t/ha)			Evapotranspiration (mm)			Water use efficiency (kg fruit/m³ of water)		
		1982-83	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85
Soil matric potential (kPa)										
Up to 1 picking	After 1 picking									
-25	-25	15.89	15.53	14.68	581	533	556	2.73	2.91	2.64
-45	-45	20.58	17.26	16.48	491	452	479	4.13	3.82	3.44
-65	-65	18.16	17.42	16.58	437	418	452	4.16	4.17	3.67
-85	-85	15.83	14.13	13.24	366	342	346	4.33	4.13	3.83
-85	-25	18.72	14.59	13.66	418	389	426	4.48	3.75	3.21
-25	-85	17.85	14.16	13.30	399	380	407	4.47	3.73	3.27
LSD (P = 0.05)		NS[z]	2.41	2.12	–[y]	–	–	–	–	–

[z]NS: Not significant. [y]No statistical analysis was conducted.

Table 10. Fruit yield and water use of bell pepper as affected by method and volume of irrigation.

Treatment	Fruit yield (t/ha)			Irrigation water used (mm)			Water use efficiency (kg fruit/m^3 of water)		
	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85	1982-83	1983-84	1984-85
Every furrow with 40 mm	17.21	17.78	15.63	840	760	800	2.05	2.34	1.95
Alternate furrow with 40 mm	15.84	16.91	15.06	840	760	800	1.89	2.22	1.88
Alternate furrow with 30 mm	17.29	17.82	15.54	670	610	640	2.58	2.92	2.43
Alternate furrow with 20 mm	15.18	16.88	14.95	500	460	480	3.04	3.67	3.11
Widely spaced furrow with 40 mm	14.76	17.24	15.15	840	760	800	1.76	2.27	1.89
Widely spaced furrow with 30 mm	15.48	16.47	14.61	670	610	640	2.31	2.70	2.29
Widely spaced furrow with 20 mm	13.92	16.52	14.54	500	460	480	2.78	3.59	3.03
LSD (p = 0.05)	NS[1]	NS	NS	-[2]	-	-	-	-	-

[1]NS Not significant [2]No statistical analysis was conducted

and WUE varied greatly among different methods and volumes of irrigation. Alternate and widely spaced furrow irrigation with 20 mm water per irrigation required about 40% less irrigation water as compared to irrigating every furrow with 40 mm water. These treatments also had maximum WUE, mainly because lower irrigation water use resulted in no significant reduction in fruit yield. Lal et al. (1975) also reported maximum water use efficiency under alternate furrow irrigation.

These findings show clearly that alternate furrow irrigation and widely spaced furrow irrigation with 20 mm water per irrigation can produce yields of bell pepper as high as when every furrow is irrigated, with about 40% saving in irrigation water. The magnitude of water savings using these methods, without any reduction in yield levels, should find application in many of the semiarid regions of India especially on soils with good lateral movement of water. Since most vegetable crops in India will continue to be irrigated by conventional furrow irrigation systems, alternate and widely spaced furrow irrigation have potential application value which could result in substantial savings of irrigation water with higher WUE. Moreover, these systems also have the in-built advantage of reducing over-irrigation which is generally practiced by most of the vegetable farmers in India.

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Symposium Discussion

A. Sajjapongse: Since you did not have high nitrogen rates (higher than 180 kg N/ha) to cause yield reduction due to N toxicity, it was not valid that you fit the N-yield response into quadratic equation.

D.M. Hegde: It is no' necessary that we observe yield reduction due to N toxicity as long as the equation gives a good fit with a significam regression coefficient.

Managing Nitrogen Fertilization of Tomatoes Using Nitrate Quick Tests

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Abstract

Nitrogen (N) is one of the most difficult fertilizer nutrients to manage properly because of the role that micro-organisms and weather play in determining N availability. Because of the unpredictability of these factors, a quick, field-administered test for N sufficiency in plant tissues during crop development would be useful. Nitrate levels in tomato and pepper petioles are sensitive indicators of the N status of these crops, and fairly simple sap nitrate tests are sufficiently sensitive to indicate whether N fertilization is needed. Field-grown fresh-market tomatoes yielding 35 t/ha contained petiole sap NO_3-N concentrations of 625 mg/liter at flowering, 696 mg/liter when the plants had small fruit, and 539 mg/liter when the plants had large fruit. Lower sap NO_3-N levels may be associated with maximum yields when N is supplied frequently than when it is split-applied. Sap nitrate levels vary substantially from plant to plant even under well-controlled conditions. Reliable indications of plant N status can be obtained by observing trends in petiole sap nitrate concentrations in 15 to 20 plants on a weekly basis. The cost and time required to conduct sap nitrate test on the somewhat large number of plants dictated by the high sample variability can be kept low by analyzing composite sap samples. Greenhouse tomatoes fertilized with solutions progressively higher in NO_3-N concentrations produced maximum marketable yields of 3.2 kg/plant by adjusting external N concentration to maintain about 1000 μg/ml in petiole sap.

Introduction

Nitrogen (N) is one of the most important fertilizer nutrients to manage properly in vegetable production. Because much of the N absorption of many vegetable crops occurs during the last three to four weeks before harvest (Lorenz and Bartz, 1968), yield-reducing N deficiencies can develop rapidly during this period. Growers may overfertilize to reduce the risk of N deficiency developing in their crops, but this can lead to other problems. Besides wasting costly fertilizer, excess N availability causes poor stand establishment, reduced growth, and undesirably high nitrate levels in vegetables and drainage water (Scaife and Stevens, 1977). In tomatoes, excess nitrogen can cause delayed fruit-set, slow ripening, and an increase in fruit defects (Coltman, 1988; Lorenz and Bartz, 1968).

Exact nitrogen requirements of crops are difficult to predict before planting. Both N demand by crops and N supply to crops are sensitive to environmental influences over which growers have little or no control, including light intensity, temperature, and rainfall. These factors can cause significant changes in crop N status and consequently can influence crop yields and the recovery of applied N unpredictably. Low efficiency of N recovery from applied fertilizers (about 50% for field and row crops) is the rule rather than the exception (Maynard and Lorenz, 1979).

Plant tissue analysis is a useful tool for determining whether N supply to a crop is keeping pace with N demand. While conventional tissue testing procedures are capable of accurately

identifying tissue from plants where N deficiencies or excesses have occurred, farmers rarely know the results of conventional tissue tests in time to allow them to respond to N deficiencies or excesses before those conditions cause irreversible yield or supplementary fertilizer N losses. Field-administered tissue tests of N sufficiency in vegetable crops could improve N fertilization practices by allowing farmers to provide only as much N as is currently needed to support maximum yields.

For many vegetable crops, the NO_3-N concentration in plant tissue is a very sensitive indicator of plant N status (Scaife and Stevens, 1977). Nitrate N concentrations in tomato leaf blade tissue increased six- to seven-fold as NO_3-N fertilization concentrations were increased from levels that produced only 75% of maximum shoot dry weight to levels that supported maximum shoot growth (Gomez-Lepe and Ulrich, 1974). Because NO_3-N levels in many vegetable crops change greatly when N deficiencies develop, only semiquantitative accuracy is required of NO_3-N tissue tests to detect N deficiencies. Rapid field tests for NO_3-N in crop tissues have been available since the 1920s (Scaife and Stevens, 1977). However, previously available procedures generally were unsuitable for routine use by farmers for reasons of convenience, reliability, simplicity, or safety. Several years ago scientists in England and New Zealand began to evaluate a convenient NO_3-N test strip made by Merck (Darmstadt, Fed. Rep. of Germany) as an analytical tool for determining the N status of vegetable crops (Scaife and Stevens, 1983; Prasad and Spiers, 1984). The test strip consists of a thin plastic strip with a paper square on one end that produces an azo dye when contacted by solutions containing NO_3-N. No external reagents are required, and a NO_3-N determination can be made within two minutes at a cost of about US$0.25. The accuracy of the test strip analysis was deemed satisfactory for use in monitoring crop NO_3-N status on a routine basis (Prasad and Spiers, 1984).

These sap NO_3-N test strips have been tested for the past three years in evaluating the N status of tomatoes and peppers in Hawaii. The objectives of the three studies conducted were to determine the minimum levels of NO_3-N in petiole sap associated with maximum yields (i.e. 'critical NO_3 levels'), and to assess the usefulness of quick NO_3 tests for monitoring and adjusting N fertilization rates. The results of these tests are summarized below.

Materials and Methods

Determination of Critical NO_3-N Levels in Field-grown Fresh-market Tomatoes (Experiment 1)

A well draining Oxisol was prepared for this experiment by cropping twice with maize with no added fertilizer to remove residual nutrients. The soil was then tested and amended with dolomitic limestone, triple superphosphate, potassium sulfate, and zinc sulfate to bring the availability in the soil of Ca, Mg, P, K, Zn, and S to recommended nonlimiting levels. Treatments consisted of 11 rates of N as 50% calcium nitrate-N: 50% potassium nitrate-N (0-365 kg N/ha in 36.5 kg increments) using a completely randomized design. Four-week-old transplants of the semideterminate tomato cultivar Celebrity were set in rows 107 cm apart with 60 cm between plants in a row. A plot consisted of five 4.9 m rows. Data were collected from the 21 interior plants. All plants were staked and pruned to two main stems. Weekly fertilization through the irrigation lines was simulated by applying a small volume of solution containing nitrate N to the base of each plant each week. Irrigation water was applied to maintain 5 to 20 kPa soil moisture tension as measured by tensiometers in the root zone. One thirteenth of the total amount of N was applied weekly. A large proportion of plants in the 110, 220, and 257 kg/ha plots succumbed to bacterial wilt, and data from these plots were omitted from subsequent analyses.

Petiole sap nitrate concentrations (mg NO_3-N/liter) in recently fully expanded leaves were determined biweekly using Merckoquant nitrate test strips. Petiole sap was extracted by rolling and pressing a pen barrel toward the cut end of the petiole, which was placed in contact with the reactive paper square on the end of the test strip. The time required for color development

to the highest level on the color chart accompanying the strips was recorded. The following laboratory-derived relationship between the aqueous NO_3-N concentration (mg/liter) and the time t (in seconds) required for full color development of the test strip was used to estimate petiole sap NO_3-N concentrations: $\ln NO_3\text{-}N = 10.68/(\ln t)^{0.513}$. Quadratic functions relating final marketable yields and sap NO_3-N concentrations at 4, 6, and 8 weeks after transplanting were evaluated to determine sap NO_3-N concentrations associated with 75, 90, and 100% of maximum yield.

Determination of Critical Sap NO_3-N Levels in Greenhouse-grown Fresh-market Tomatoes (Experiment 2)

Ninety-eight Celebrity tomato plants were grown from seed in 25 cm diameter plastic pots that contained 0.013 m^3 of a 2 peat : 1 perlite : 6 vermiculite (by volume) mixture amended with 4.8 kg dolomite/m^3, 1.4 kg gypsum/m^3, and 0.44 kg P/m^3 as triple superphosphate. Slow release micronutrients and 0.13 kg K per m^3 were incorporated as 1.1 kg Micromax/m^3 and Osmocote K_2SO_4, respectively (Sierra Chemical, Milpitas, California). Treatments consisted of five N levels (20, 40, 80, 160, and 240 μg NO_3-N/ml) with 14 replicates in a completely randomized experimental design. Nitrogen was proportioned into each of the five irrigation systems from stock solutions containing 60% KNO_3-N: 40% $Ca(NO_3)_2$-N (by weight). Pots were irrigated to excess three times a day to keep concentrations of NO_3-N in the root zone stable. Plants were staked but not pruned.

Validation of a Proposed N Fertilizer Management Scheme for Greenhouse Tomatoes Based on NO_3-N Quick Tests (Experiment 3)

Maximum yields in Experiment 2 were found to be associated with relatively stable or slowly decreasing levels of petiole sap NO_3-N. Day-to-day variability in sap NO_3-N levels was high, indicating that sap NO_3-N testing needs to be relatively frequent, e.g., weekly, to identify significant trends. Based on these results, the following approach for managing NO_3-N fertilization of greenhouse tomatoes was suggested: a) sample 5 to 15 plants weekly, and b) increase N fertilization concentrations by 50% when sap NO_3-N readings lower than desirable levels have been obtained for two or more consecutive samplings. The purpose of this study was to test this approach to NO_3-N management of greenhouse tomatoes.

Plants of Caruso, an indeterminate, fresh-market tomato cultivar, were raised under cultural conditions similar to those in Experiment 2. Plants were pruned to single stems and trained on strings. Treatments consisted of five sap NO_3-N target levels (200, 400, 600, 900, and 1200 mg NO_3-N/liter) in seven replications. The five sap NO_3-N target-level treatments were fertilized initially with five NO_3-N fertilization concentrations (4, 6, 9, 13, and 20 mg/liter, respectively) in the irrigation systems as in Experiment 2. Sap NO_3-N concentrations in the petioles of young, fully expanded leaves were determined weekly at 1100 HR beginning four weeks after planting as described in Experiment 2. According to the proposed N management guidelines, the NO_3-N fertilization concentration for a treatment was increased 50% whenever the average petiole sap NO_3-N level for a treatment was found below the target sap NO_3-N level for that treatment for two consecutive weeks. One exception to these guidelines was made. Because an immediate response to the first subtarget-level readings was desirable to control the rapid decline in sap NO_3-N levels found in Experiment 2 during the first four to six weeks after planting, N fertilization concentrations were immediately increased 50% when petiole sap NO_3-N levels first dropped below target levels.

Results and Discussion

Experiment 1

Fresh-market field tomatoes (cv. Celebrity) produced a maximum yield of about 35 t/ha when applied with N at the rate of about 220 kg/ha (Figure 1). Sap NO_3-N readings associated

with various levels of maximum yield are presented in Table 1. These sap NO_3-N levels are somewhat lower than previously reported for field-grown tomatoes by Prasad and Spiers (1985). The attainment of maximum yields in the experiment by plants with these lower sap NO_3-N levels may be related to the more continuous supply of N by the weekly applications compared to the peaks of N availability provided by the conventional split applications of N fertilizer used by Prasad and Spiers (1985). Thus higher levels of sap NO_3-N may be associated with maximum yields under split-application N management, but these higher levels may not be required to support maximum yields.

Experiment 2

Maximum marketable yields of greenhouse-grown Celebrity tomatoes of about 3.3 kg/plant were obtained in all treatments with N feed concentrations of 40 μg NO_3-N/ml or higher (Table 2). Although a sharp increase in tomato yields resulted from increasing N feed concentrations from 20 to 40 μg NO_3-N/ml, tissue levels of total N increased only marginally between these treatments, and all tissue N concentrations were within a range considered normal, except P, which may have been marginally deficient.

In contrast to total N concentrations, sap NO_3-N concentrations were very different in the N-deficient 20 μg NO_3-N/ml treatment compared to the maximally yielding 40 μg NO_3-N/ml treatment (Figure 2). Petiole sap NO_3-N levels of the 20 μg NO_3-N/ml treatment plants dropped rapidly to less than 200 ppm as the plants produced fruit, whereas in the adequately fed 40 μg NO_3-N/ml treatment between 500 and 750 ppm of NO_3-N was present in petiole sap. When the plants were fed more than they required for maximum yields (80, 160, 240 μg

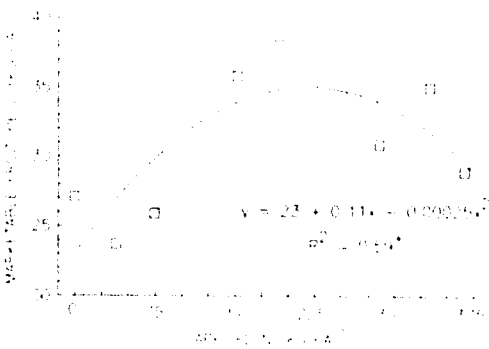

Figure 1. Marketable yields of Celebrity tomatoes in response to applied N in Experiment 1 (Coltman, 1987a).

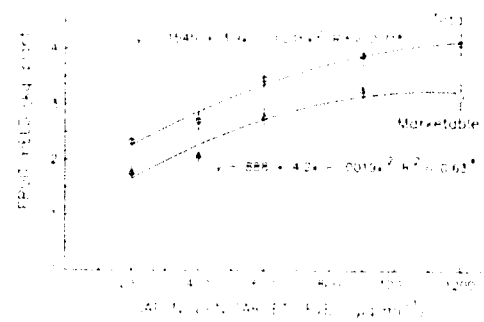

Figure 2. Sap NO_3-N levels in tomato petioles from plants grown at five N levels in Experiment 2. Vertical bars represent standard errors of the mean (Coltman, 1987b).

Table 1. Sap NO_3-N concentrations in petioles of field-grown Celebrity tomato at various times after transplanting for plants producing various percentages of maximum yields.

Weeks after transplanting	Phenology	Yield level (% of maximum)		
		75%	90%	100%
		mg NO_3-N/ml		
4	Flowering	464 or 787[z]	517 or 733	625
6	Fruit 2 to 5 cm dia.	411 or 980	478 or 915	696
8	Fruit 5 to 9 cm dia.	28 or 1051	167 or 912	539

Source: Coltman, 1987a. [z]Reductions in yield were associated with sap NO_3-N levels being both too low or too high.

NO_3-N/ml), petiole sap NO_3-N levels were considerably higher. Thus, N-starved, N-adequate and N-excessive plants could easily be identified by examining sap NO_3-N levels, but not by measuring total N concentrations in the tissue.

Levels of NO_3-N in some crops have been shown to fluctuate during the day. If this were true for the crop to be evaluated using sap NO_3-N tests, it would be important to standardize the time of day for sampling. Although there was a tendency for sap NO_3-N levels to be highest around midday in these experiments (data not shown), this effect was not statistically significant. Nevertheless, it is probably a worthwhile precaution to sample at the same time every day (Scaife and Stevens, 1983).

Other aspects of sap sampling methodology also were compared in Experiment 2. Scaife and Stevens (1983) reported that petiole sap NO_3-N concentrations varied greatly among cabbage plants under field conditions. Because coefficients of variation approached 40%, they suggested that at least 20 plants should be tested to obtain a trustworthy average concentration value. Coefficients of variation for sap NO_3-N concentrations among plants in the greenhouse studies were large (30%) but somewhat lower than those reported by Scaife and Stevens (Table 3). This is understandable since better control of N supplies can be achieved under greenhouse conditions than in the field. Estimated petiole sap NO_3-N values did not differ when sap was carefully rolled out of the cut end of the petiole with a pen barrel as opposed to being crudely extracted from comparable petiole segments using a garlic press, despite the noticeably higher chlorophyll content of sap extracted using the latter method. By analyzing a composite sap sample from three petioles at a time, comparable means and only slightly wider confidence intervals were achieved with five sap tests of 15 plants than when each of the 15 plants was tested individually. To get an equivalent level of confidence as with individual plant analyses,

Table 2. Fruit yields and nutrient composition of recently mature whole-leaf samples taken during late fruit production from Celebrity tomato plants.[z]

Liquid feed rate	Yield (kg/plant)		Leaf nutrient concentration (%)				
(µg NO_3-N/ml)	Total	Marketable	N	P	K	Ca	Mg
20	1.5	1.4	2.6	0.31	3.3	4.4	0.8
40	3.8	3.3	2.8	0.21	4.7	3.1	0.6
60	3.4	3.0	3.0	0.21	4.9	2.7	0.4
160	3.8	3.4	3.4	0.21	4.8	3.5	0.5
240	3.8	3.4	3.5	0.18	5.6	3.0	0.4
Normal levels[z]	–	–	2.5-4.0	0.3-0.6	3.0-4.0	0.5-2.0	0.6-1.0
LSD 5%	1.7	1.6	-	-	-	-	

Source: Coltman, 1987b. [z]Geraldson et al. 1973.

Table 3. Average coefficients of variation (C.V.), sample number, and 95% confidence intervals (C.I.) for NO_3-N in sap extracted from individual or pooled tomato petioles either by rolling with a pen barrel ('roll' method) or by crushing in a garlic press ('press' method) on five dates

Sample	Sap extraction method	$\bar{x}$[z] (µg NO_3-N/ml)	CV(%)	Sample no.	95% C.I.
Individual petioles					
	Roll	2251	30	15	± 17%
	Press	2117	30	15	± 17%
Composite sample from 3 petioles					
	Roll	2022	20	5	± 22%
	Press	1893	19	5	± 22%

[z]There were no significant differences between kind of sap sample and sap extraction methods.

about seven composite samples from 21 plants would have been required. Thus, the use of composite sap samples allowed about a 50% saving in time and cost over sampling plants individually.

Experiment 3

Adherence to the proposed method of managing N feed concentrations based on quick test results was quite effective in maintaining on-target petiole sap NO_3-N levels (Figure 3), and resulted in only four to five adjustments in N feed concentration over a 27-week crop cycle. Total fruit yields responded positively to increasing petiole sap NO_3-N concentrations up to the highest target level in the experiment (1200 μg NO_3-N/ml), but marketable fruit yields were maintained in the 900 to 1100 μg NO_3-N/ml range (Figure 4). This approach to managing sap NO_3-N concentrations directly to achieve maximum yields appears feasible and effective.

Other crops growing under other cultural conditions may have different optimum patterns of sap NO_3-N. Leafy vegetable crops require high N availability to produce optimum yields and quality. However high levels of nitrates in some of these crops at harvest are undesirable because they may lead to problems during processing and storage, and because consumption of high levels of nitrates is hazardous to human health (Maynard et al. 1976). By monitoring sap NO_3-N levels during crop development, growers may be able to actively tailor their N fertilization programs to maximize crop yields and quality.

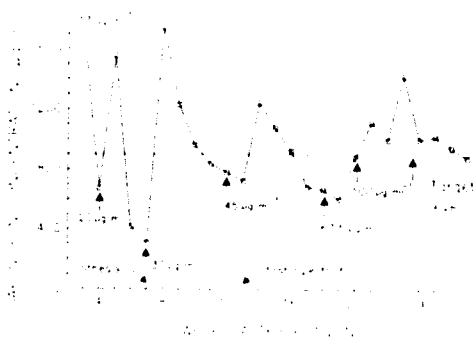

Figure 3. Petiole sap NO_3-N concentrations over time in a maximally yielding treatment with NO_3-N fertilization concentrations managed to maintain 900 μg NO_3-N/ml in petiole sap.[2] Vertical arrows indicate when NO_3-N fertilization concentrations were increased 50% to the indicated levels.[3] Data are representative of patterns exhibited in treatments with other sap NO_3-N target levels (Coltman, 1988).

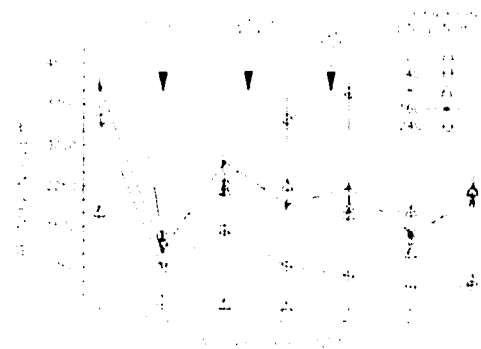

Figure 4. Total and marketable fruit yields of Caruso tomatoes with NO_3-N fertilization concentrations managed to maintain specific petiole sap NO_3-N levels.

Practical Recommendations

Inadequate or excessive N fertilization can prevent greenhouse and field tomatoes from yielding optimally. The sap nitrate quick test can be used effectively to monitor crop NO_3-N status. Because the results of the test are known rapidly, an iterative approach to N fertilizer management of the crop is feasible. These experiments suggest that critical sap NO_3-N levels for field and greenhouse tomatoes are approximately 650 and 1000 mg/liter respectively, and are not particularly dependent on crop age. These sap NO_3-N concentrations correspond to full

color development on the quick test strips in about 10 and 14 seconds, respectively, after contact with petiole sap. The higher critical levels of the greenhouse crops is probably due in part to their culture in a high quality artificial medium. Growers wishing to adopt N fertilization management based on sap NO_3-N monitoring should extract and test petiole sap of young, fully expanded leaves from 15 to 20 plants weekly beginning at about four weeks after planting. A single test of a composite sap sample from the plants should be adequate when sampling is as frequent as weekly.

If full color development of the test strip after contact with the sap sample takes longer than 14 seconds for soil grown tomatoes, a modest amount of fertilizer should be applied, e.g. 40 kg N/ha. Greenhouse growers concerned principally with liquid N feed concentrations in artificial media can follow the procedure outlined in Experiment 3, where an optimal sap NO_3-N target level of 1000 mg/liter was indicated by a 10 second sap reading. Improvement in crop N status should be indicated by higher sap NO_3-N readings within two weeks of adding fertilizer carrying nitrate N. Longer periods may be required if urea for ammonium fertilizer is used and nitrification rates are low. Additional applications of fertilizer should be given at two to three week intervals until target sap NO_3-N levels are obtained. Depending on the duration of the harvest period, maintenance of 650 or 1000 mg/liter sap NO_3-N target levels in field and greenhouse crops, respectively, may or may not be necessary after harvest begins.

These recommendations should be viewed as starting points for new N fertilization programs based on sap testing. Growers should be encouraged to fine tune a methodology for their specific crops and conditions by experimenting with higher or lower sap NO_3-N target levels, and with supplemental fertilization amounts, forms and frequencies of response to sub/target level readings. Because progressive vegetable growers usually welcome opportunities to try variations in cultural practices that hold promise for improving their profitability, extension of sap testing-based N fertilization methodology may find ready acceptance by these kinds of growers.

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Symposium Discussion

G. Grubben: Could the quick test with soil samples be more accurate or practicable? Are there good prospects for application in tropical lowlands with high rainfall, by illiterate small farmers? Is much training needed for extension officers?

R.R. Coltman: I believe quick-testing the plant sap is a more accurate and reliable procedure because it is measuring the current balance between crop N demand and soil N supply, not just the absolute magnitude of one of these important quantities. The procedure is particularly well suited to high rainfall areas, where leaching losses of N can be significant and difficult to predict. Because the only skills required to apply the test are knowing how to measure elapsed time and compare numbers on a chart, a high level of literacy is not required.

W.J. Ho: Is your NO_3-N test for plant N status still reliable when NH_4^+-N is applied as fertilizer?

R.R. Coltman: I have not investigated this. In reasonably warm, well drained soils, rates of nitrification are high enough so that much of the plant uptake of N is in the NO_3-N form. If conditions are such that significant NH_4-N is being absorbed by plants, lower sap nitrate levels will be associated with maximum yields. Routine monitoring of sap nitrate levels could provide farmers and researchers sufficient data to begin fine tuning on their own more general recommendations to their local practices and conditions.

E.S. Lim: Can you explain whether the quick test for nitrate will be influenced by clarity of the plant sap? What is the effect of milky sap (latex) or sap containing resins or gums, or even pigments?

R.R. Coltman: My data has shown that the clarity of the sap did not affect the nitrate determination. If the excess sap is shaken off the paper square after saturating it, very little green color remains, and it does not confuse the determination of the purple end point.

N.S. Talekar: Is the nitrate strip specific to NO_3? Do other ions interfere with this test, especially other N compounds?

R.R. Coltman: The nitrate test strip is specific for nitrite and nitrate forms of N. Levels of interference of other ions found in plant sap are not significant.

S.J. Tsou: Local farmers tend to overfertilize the crops. What action would you suggest if the sap NO_3 level is too high? At what stage will this too high level hurt the yield?

R.R. Coltman: First of all, my recommended approach of routine sap nitrate monitoring accompanied by incremental fertilization should not lead to serious excesses of N. Once excess N accumulates in the soil, little can be done except to leach the nitrate out of the soil. I have not examined the effects of episodic N excesses, but I suspect the yields are likely to be affected

only if N excesses are maintained over extended periods of growth. Excesses or deficiencies in early growth appear to have the least effect on yields.

R.L. Villareal: Would you know if a similar quick test is being developed for other elements?
R.R. Coltman: Quick test strips are available for potassium and calcium, and a number of heavy metal elements, in addition to nitrate. No quick-test strip is available for phosphorus. The suitability of the K and Ca strips for plant sap analysis is undetermined as of yet, but they are clearly not as convenient as the nitrate test because dilution of the sap is required. I still feel procedures can be developed for their practical use.

Country Reports

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43

Tomato and Pepper Production and Research Status in Australia

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Abstract

A total of 100,000 tonnes of fresh-market tomatoes are produced from 4,000 hectares in three major districts in tropical Australia. The same regions produce 12,000 tonnes of fresh-market peppers from 900 hectares of land area. Cultivation of staked tomato crops in Bundaberg, as opposed to ground crops at other centers, results in higher average yields. Pepper yields, however, are similar in all regions. A large increase in Bundaberg tomato production since 1982 has caused real prices to fall. This followed the reduction in international sugar prices, the dislocation of the established sugarcane industry in that region, and a consequent shift to increased vegetable production. High summer temperatures are the major climatic limitation to production. Cropping from November to March-May is therefore impractical although in Bundaberg late harvests may extend to January. Winter temperatures in this district are sufficiently low to prevent cropping from early August to November. Bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) is the most damaging disease of peppers. Bacterial speck (*Pseudomonas tomato*) and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) of tomato can inflict severe damage on Bundaberg crops, but are sporadic in other districts. The most serious disease losses of tomato are due to potato Y virus (PVY) and Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici* Race 3). The latter is responsible for yield losses of up to 60% and has contributed to a substantial reduction in Bowen's tomato production. Breeding programs have developed tomato cultivars with concentrated maturity and bacterial wilt resistance. Advanced tomato breeding lines with PVY and Fusarium wilt Race 3 resistance are now available. A pepper program is incorporating resistance to Race 1 of bacterial leafspot, conferred by three genes as well as highly effective PVY resistance. Cultivation of both tomato and pepper crops using plastic mulch and trickle irrigation has improved water use efficiency and yield performance in all regions. Future expansion of tomato and pepper industries in tropical Australia is critically dependent on access to export markets.

Tomato

Current Crop Situation

Fresh-market tomatoes are produced at three centers in tropical Australia (Figure 1). The greatest production is at Bowen, Queensland (20° S) where 35,000 tonnes are grown on 2,300 hectares. Carnarvon, Western Australia (24° S) supplies 6,000 tonnes from 150 hectares, and a minor quantity of 160 tonnes is produced around Darwin in the Northern Territory. While this accounts for all significant centers in tropical Australia, a balanced view of total production should include that from subtropical Bundaberg, Queensland (24° S) which now produces 59,000 tonnes from 1,600 hectares. Statistics for total yield, hectares under production, yield per hectare and economic value are presented in Table 1.

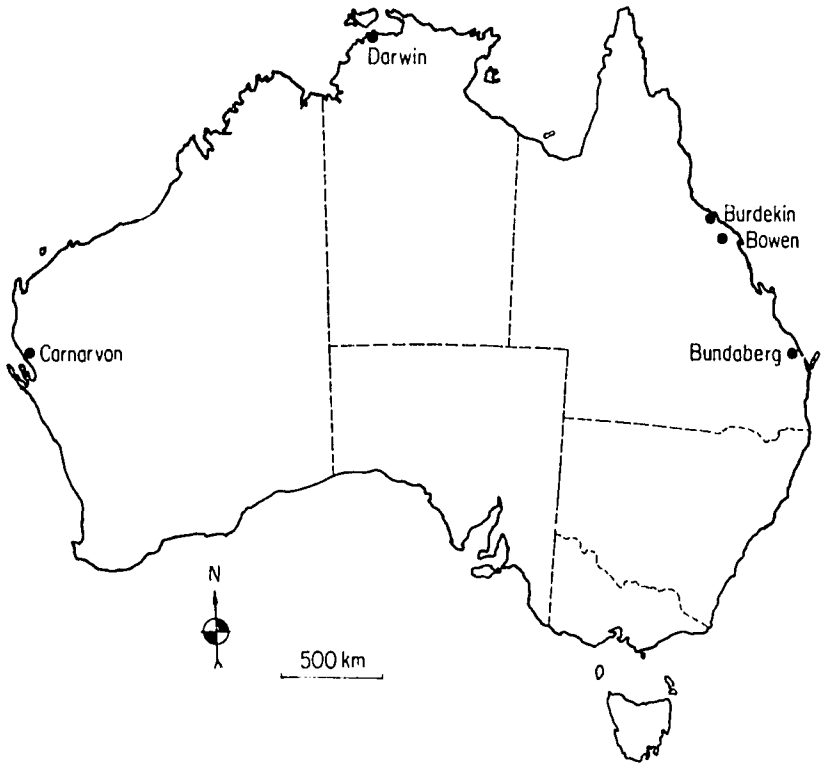

Figure 1. Growing areas of tomato and pepper in tropical Australia.

Table 1. Production statistics and gross value for tropical tomato production 1985/86.

Location	Production (t)	Hectares	Average yield (t/ha)	Gross value of production (US$ million)
Bowen	37,000	2,300	16.1	21.7
Bundaberg	59,000	1,600	36.9	35.0
Carnarvon	6,000	160	37.5	3.2

Queensland is the major supplier of winter tomatoes to east coast states. Historically, Bowen has shipped a very large proportion, in excess of 80% of the State's production, between May and November. In recent years, however, its production has declined, whereas that from Bundaberg has increased significantly. This trend reflects a major change in the local Bundaberg economy. Reductions in international sugar prices since 1982 have dislocated the sugarcane industry in that region and encouraged a diversification into vegetable production. Tomato production has therefore risen.

In 1985/86 the total value of the tomato industry in Queensland was $US76.1 million, of which $US34.8 million was grown in Bundaberg and $US21.9 million in Bowen. The remainder derived from smaller centers in subtropical districts of the State. The tomato industry represents approximately 40% of all horticultural production in Queensland. Apparent per capita consumption of tomato in Australia has risen from 13.0 kg/year in 1958/59 to a current level of 18.6 kg/year. This trend towards increasing consumption has plateaued and it is unlikely that any viable expansion of the industry can be sustained by domestic demand.

Climatic data. Both Bowen and Carnarvon are located in the dry tropics and have a marked seasonal pattern of rainfall. Typically, 75% of annual rainfall in Bowen is distributed between December and March, and only 11% is recorded in the production period of May to November with a total rainfall of 1,018 mm. Carnarvon has summer rainfall (30%) and another peak in May to June (40%) with a total rainfall of 231 mm. Bundaberg also has a summer rainfall peak, but a relatively greater proportion of the total of 1,145 mm falls through winter. High summer temperatures from November to March are a primary determinant of cropping periods. In Bowen and Carnarvon, maximum daily temperatures of 31°C or more and high nightly minimums above 22°C are normal, adversely affecting fruit-set and quality. A requirement for lower temperatures and a preference for dry growing conditions therefore determines a cropping period of May to November in these centers. At Bundaberg, both maximum and minimum temperatures are marginally lower and may allow extended cropping to January. Winter minimum temperatures from June to August are generally sufficiently low to reduce pollination and fruit-set, with a consequent production gap from early August to late October. Both tropical centers therefore enjoy a climatic advantage over Bundaberg in this period. Mean monthly maximum and minimum temperatures are presented in Figures 2 and 3 respectively.

Cropping systems. Tomatoes are grown both as ground and staked crops. For various reasons, different regions have adopted cropping systems appropriate to local conditions. Apart from a small proportion of staked crops in Carnarvon, production in the Australian tropics is based on the ground. By contrast, Bundaberg production is largely trellis-grown. Traditionally, crops are grown on open beds and furrow irrigated. Basal fertilizer is incorporated preplanting and side-dressing is applied after flowering. Weed control is achieved by one well timed cultivation and judicious use of herbicides such as Pebulate, Metribuzin and Paraquat.

In recent years, trickle irrigation has become widespread. It is often installed in conjunction with plastic mulch, which provides good weed control. Although expensive, this technology allows greater flexibility in the frequency of irrigation, facilitates nutrient application, increases water use efficiency, and provides access to a wider range of soil types. More effective exploitation of soil moisture enhances yields. Despite these many advantages, its higher cost may reduce gross margins, particularly for ground crops. Trickle irrigation is almost universal in Queensland, but for economic reasons, the adoption of plastic mulch is tentative.

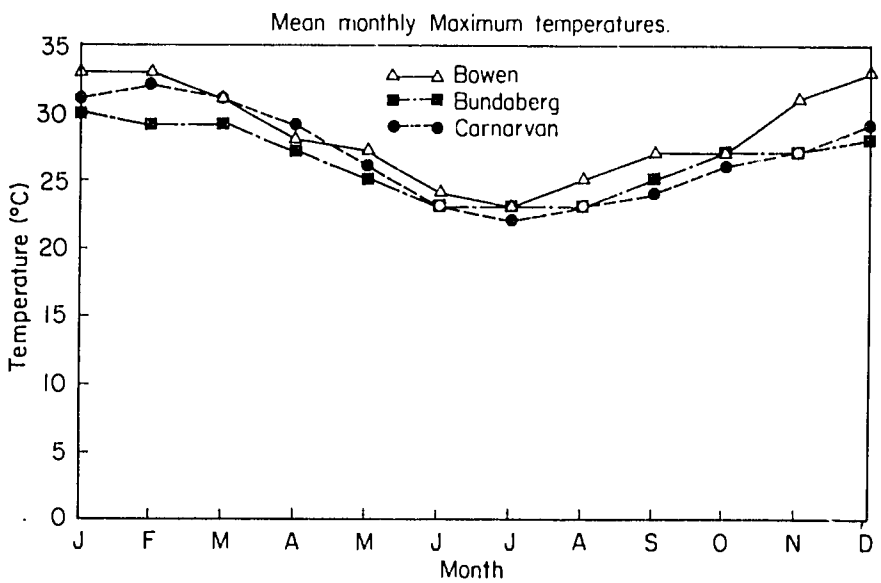

Figure 2. Mean monthly maximum temperatures.

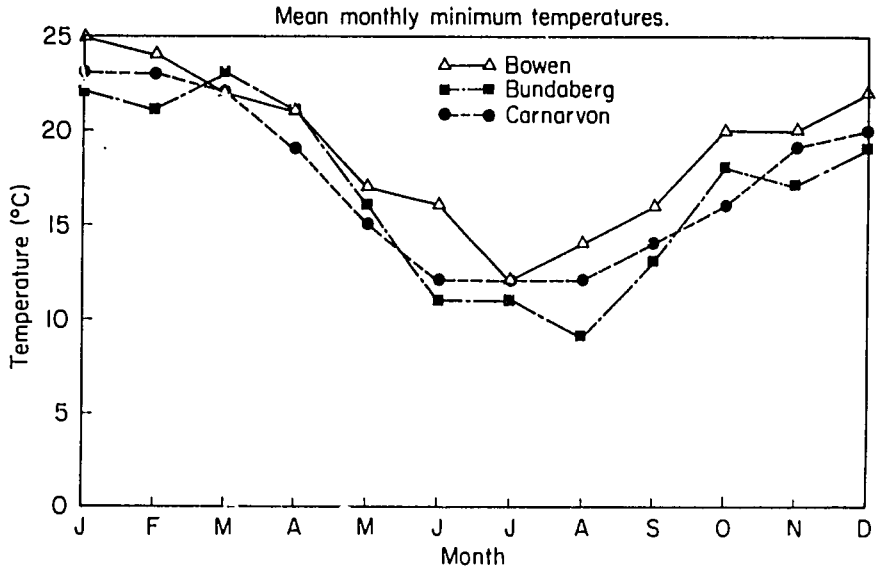

Figure 3. Mean monthly minimum temperatures.

Fruit is harvested by teams of pickers and processed directly in individual growers' packing sheds. In Bundaberg, semiripe fruit is harvested from trellis crops at three-day intervals, graded for size, cooled and consigned to market. Up to 90% of fruit is harvested in this manner. At other production centers, ground crops are harvested mature green, sized and ripened by trickle ethylene injection. Crops harvested in this way may be picked up to three times, but often fewer harvests are taken because of the damage sustained by plants and the associated loss of fruit quality. The major difficulty with this system is the harvest of immature fruit by inexperienced pickers, resulting in unacceptable fruit quality.

Marketing. Fruit is sold through agents at wholesale markets in Brisbane, Sydney, Newcastle and Melbourne on the east coast, and Perth in Western Australia. Ten-kilogram cartons are uniform for size, grade and color. There is an increasing trend to standardization, so that pallets contain only one size grade and color. A recent development is direct selling to retailers where wholesale markets are bypassed entirely. Quarantine regulations require disinfestation of Queensland fruit for fruit fly before marketing in the southern states. Fruit must be certified by an authorized Government officer at the point of harvest.

Cultivars. The most widely grown open-pollinated cultivars are Contender and Floradade. The latter is favored by some growers for trellis crops, but it has been superseded by Contender and a range of F_1 hybrids for ground crops. Seed of these open-pollinated lines is produced by a statutory authority of the Queensland Government (the Committee of Direction of Fruit Marketing) at reasonable cost to the industry. A range of F_1 hybrids marketed by seed companies is available. The most widely grown of these hybrids are Sunny, Duke, Red Chief and Cherokee. F_1 hybrids are suited to winter production where they show superior performance to open-pollinated lines.

Foreign trade. Export of fresh-market tomatoes has been limited to markets in New Zealand, Pacific Island countries, Papua New Guinea and Singapore. Some increases in trade have occurred recently, particularly to New Zealand; however, export markets have been poorly understood by Australian growers and the prospects of large increases in export volumes are, in the short

term, poor. In the last few years significant quantities of Queensland tomatoes have been airfreighted to New Zealand in the winter months. Quarantine restrictions against the entry of fruitfly have created some difficulties in accessing that market. In 1986/87 1,292 tonnes of fruit valued at US$ 1.25 million, and 307 tonnes of processed product worth US$ 0.38 million, were exported.

Constraints

The overriding environmental limitation in the Australian dry tropics is water. Established production centers depend on irrigation supplied by local aquifers. In Carnarvon stringent regulation of available water resources effectively limits the area under cultivation. In Bowen aquifers have been critically depleted following an eight-year period of abnormally low summer rainfall. Water quality has been declining and reserves are now so low that severe restrictions will certainly be imposed in 1988 unless some relief is obtained. Paradoxically, there is a vast supply of water available from the Burdekin River Dam, 100 km to the north, which will ultimately provide irrigation of 45,000 hectares of new country, at least 8,000 hectares of which are excellent horticultural soils. It is possible that a relocation of the industry will occur in the medium term if chronic water supply problems continue. Although there remain serious marketing problems, water shortages should not ultimately be seen as a check to expansion.

All tomato production centers have a range of pest and disease problems for which controls are generally available. Those which are usually associated with humid weather conditions are incited by *Alternaria solani*, *Pseudomonas tomato* and *Xanthomonas campestris* pv. *vesicatoria*. The most serious endemic disease is Fusarium wilt incited by *F. oxysporum* f. sp. *lycopersici* Race 3. The organism was identified in 1979 and has rapidly infested most of the soils in the Bowen small crops area. It is unknown elsewhere in Australia. Yield losses up to 60% on certain farms have forced growers to produce other crops, fallow land, or cultivate new land. The expense of such management strategies, the decline in productivity, and poor quality of affected fruit, have inflicted severe financial losses. A resistant cultivar has been developed with excellent agronomic characteristics and this will be released in 1988. It is anticipated that a large increase in production will follow. Bacterial wilt (*Pseudomonas solanacearum*) of tomato is an emerging problem in Bundaberg. Less than 5% of the cultivated area is infested but more intensive tomato production is likely to exacerbate the disease. Several locally developed cultivars such as the open-pollinated Scorpio and Redlander and Summertaste (F_1) demonstrate good resistance but this is ineffective at temperatures above 32°C.

From an industry perspective the most serious limitation to tomato production is that imposed by domestic markets. For much of the year an oversupply of fruit ensures that prices are less than, or only marginally above, the cost of production. Historically, growers have relied upon a short period of a few weeks when climatic advantages allowed them a competition-free period. This is no longer the case, as producers in other districts extend their normal production season and increase the total volume of fruit supplied to the market. Bundaberg producers, in particular, have contributed to this surplus, thereby depressing market prices. There is undoubtedly an export niche for growers who are prepared to research the requirements of foreign markets and who can find solutions to transport and marketing difficulties. At present these are formidable and it is unlikely that a large increase in export volumes will be achieved in the near future.

Research and Development

Varietal development is confined to public institutions, principally State Departments of Agriculture. These bodies have traditionally evaluated breeding lines from local programs and F_1 hybrids imported by seed companies. There is currently no varietal development work by private seed companies whose activities are limited to importing and selling F_1 hybrids derived from programs of international seed companies. The Queensland Department of Primary Industries is the only institution in Australia which conducts an active tomato breeding program

for tropical production. A state program generates breeding lines adapted to specific regional requirements, and much of the program's resources have been devoted to the unique needs of the industry in Bowen.

The most significant development project has now produced a cultivar resistant to *Fusarium oxysporum* Race 3, due for release in 1988. This pathogen has been responsible for severe yield reductions in 60% of soils in the Bowen small crop district and is directly responsible for declining production in recent years. Genetic resistance to Race 3 was located in PI 414773 of *Lycopersicon pennellii* and has been transferred to *L. esculentum* through a backcross program (McGrath et al. 1987). Genetic analysis of PI 414773 identified one dominant gene, $I\text{-}3$, regulating resistance to Race 3, and two independent dominant genes for Race 2 resistance, one of which is the well known $I\text{-}2$ locus. The other locus is, as yet, unidentified. The first commercial release of the resistant material is strongly determinate, concentrated in maturity, large-fruited and firm fruited.

Resistance to potato Y virus (PVY) is a requirement for production in Queensland. Immunity has been found in PI 247087 of *L. hirsutum* and a conventional backcross breeding program to transfer resistance is underway (Thomas et al. 1988). Analysis of breeding populations has suggested that a major recessive gene, plus genes of minor effect, control resistance. These studies are not unequivocal, however, since segregation is abnormal and heritability is low. Difficulties in recovering resistant segregates have delayed progress with this program. A continuing program of development for bacterial wilt has been in place for some years. A series of inbred and F_1 cultivars has allowed improved production on affected soils. Because of limited requirements for these cultivars, this program has been reduced in priority.

The Queensland Department of Primary Industries is committed to the development of superior quality of fresh-market tomatoes grown in Australia. Some efforts have been devoted by workers in various institutions to identify agronomic, nutritional and postharvest factors which contribute to the poor flavor of commercial tomatoes. However, it is clear that there are large genetic differences for flavor among genotypes, much of which is related to levels of soluble solids. High-sugar breeding lines have been imported by workers in CSIRO and the New South Wales Department of Agriculture. Preliminary evaluation of this material suggests that although genotype by environment interactions can be large, sufficient genetic gain in total soluble solids is possible to warrant active breeding.

The introduction of trickle irrigation and plastic mulch technology in 1980 led to a reappraisal of agronomic practices for tomato production. At the time, research was directed towards the effects of population density, fertilizer application, and irrigation frequency on yield performance under this regime. Research is now concerned with rapid assessment of plant nutrient status in the field so that deficiencies may be quickly corrected by fertilizer injection. It must be mentioned that data obtained so far have not validated the claims of enthusiastic proponents of the technique and the effectiveness of such crop management has yet to be demonstrated.

Problems of poor postharvest quality are generally believed to be low but observations in the major Australian wholesale markets indicate large variation in the quality of fruit. A long-term project seeks to identify losses that occur in the marketing chain, the quality of fruit presented at market, the adequacy of packaging, areas of inefficiency, and the overall suitability of the marketing system. By minimizing inefficiencies it is hoped that significant increases in profit can be achieved.

Future Needs

The greatest difficulty facing the tomato industry in Australia is the imbalance of supply and demand on domestic markets. The industry needs an effective mechanism for clearance of inferior quality fruit coupled with greater market demand. Access to foreign markets is feasible only if growers can improve their marketing skills and arrange regular transport services. In the absence of some managed means of regulating market forces the industry will be restructured harshly by economic forces.

Pepper

Current Crop Situation

The major pepper production areas in tropical Australia are Carnarvon, W.A., Bowen, Burdekin and Bundaberg districts, Queensland. Table 2 presents production statistics for pepper production in each region.

Table 2. Production statistics and gross value for tropical peppers 1985/86.

Location	Production (t)	Hectares	Average yield (t/ha)	Gross value of production (US$ million)
Bowen				
Bell types	4,990	350	14.3	3.3
Burdekin				
Bell types	5,200	380	13.7	3.4
Bowen/Burdekin				
Chili types	360	20	18.0	0.2
Bundaberg				
Bell types	2,704	195	13.9	1.8

Carnarvon is a small center, producing approximately 1,200 tonnes. Bundaberg has been expanding in recent years but is significantly less important than the dry tropics district of Bowen and Burdekin. Total production in tropical Australia is approximately 12,000 tonnes. Major production is based broadly in the same areas which produce tomatoes, with the exception of the Burdekin district which has no tomato industry. The total value of the Queensland state production in 1985/86 was $US11.5 million, which is considerably lower than the value of the tomato industry. Peppers are therefore less important to the State's economy as a whole but the crop is regionally significant in the sparsely populated dry tropics, where 60% of the State's crop is grown.

Climatic data. The climatic data for the production areas are presented above. Seasonal harvest times are well defined for Carnarvon and Bowen/Burdekin; the cropping period here is from May to November, with peak production in September. Continuous production is possible in Bundaberg, which does not receive such hot, moist summers. Volume of production is substantially reduced, however, in the cool July-August period. The frequency of rainfall in Bundaberg is responsible for a greater incidence of foliar diseases and postharvest quality problems than in drier northern locations.

Cropping systems. The majority of pepper crops in Bowen and Bundaberg are grown using trickle irrigation and plastic mulch. The use of containerized seedlings in conjunction with this cropping system allows rapid establishment and high productivity. Some large growers trickle irrigate crops daily and inject nitrogen two to three times weekly. This is most appropriate for early planted crops which are harvested repeatedly over four to five months, slashed and ratooned. Crops planted later are not normally ratooned, as their subsequent yield potential is low.

Burdekin district cropping accounts for 5,200 tonnes, nearly all of which is produced by conventional furrow irrigation. There has been no adoption of plastic mulch here and bare-rooted seedlings are planted. A complex of cultural and economic factors underlies this difference between the Burdekin and Bowen districts, not the least of which is the abundance of irrigation water and less stringent requirements for water use efficiency in the Burdekin. Fruit is harvested by teams of pickers and processed directly in growers' packing facilities. Some large growers use harvesting aids which follow pickers through the crop, allowing them to unload fruit directly

without excessive handling procedures. Impressive gains in cost effectiveness are possible with this system.

Marketing. Bell peppers are marketed on domestic markets as green or colored fruit in 6.5 kg cartons. A premium is normally paid for red fruit. Most Queensland peppers are sold in fresh-market outlets in Brisbane, Sydney and Melbourne. In 1987 the percentage of the crop sold at each center was approximately 40%, 39% and 9%, respectively. Disinfestation treatments for fruitfly apply to movement of fruit to Melbourne.

Data available for the Brisbane wholesale market indicate that throughput increased 16% in the five-year period to 1985, and that in nominal terms prices have decreased 21%. However, forecasting models have now indicated a slow increase in production and it is believed that domestic oversupply problems will not eventuate in the near future. There is a small market for processed sweet peppers. However the great majority of produce is sold as fresh-market sweet peppers. A very small quantity of chillis is grown and marketed; these are regarded as a specialized enterprise for small growers.

Cultivars. A range of open-pollinated and F_1 hybrid sweet pepper cultivars is grown in all production centers. Green Giant is the most widely grown open-pollinated cultivar, but there is a well developed market for F_1 hybrids. The most important of these at present is Bell Tower, but small quantities of Cordoba, Domino, David and Espadon are grown. Bell Tower is favored for its uniformity, stability of production, attractive shape and size, and freedom from defects. Long Red Cayenne is the most widely grown chilli cultivar. Seed is supplied entirely from seed companies.

Foreign trade. Foreign trade is quite small. In 1986–87 export of processed peppers from Australia amounted to 3,340 tonnes, valued at $US2.0 million. Figures for fresh produce were not available, however the quantities involved were small. The markets were New Zealand and Southeast Asia. There are some export opportunities in Hong Kong, Singapore and Malaysia, apparently in response to temporary shortages, where Australia can airfreight produce in small quantities. This potential is largely unexploited, since it requires specialized marketing knowledge and skills.

Constraints

In tropical areas of Australia there are relatively few disease limitations to pepper production. The most serious is bacterial leafspot (*Xanthomonas campestris* pv. *vesicatoria*) which is sporadic in occurrence and often associated with rainfall. Because control is sometimes difficult to achieve, significant losses can be sustained. On balance, however, bacterial leafspot causes only minor levels of damage to total crop production, principally because drier climatic conditions prevail during crop growth. Control of potato virus Y is effective because of resistant cultivars. Yolo spot is frequently damaging on susceptible cultivars. It is seen in all districts and leads to marketing problems. The condition is a physiological disorder which tends to express itself at unpredictable times. Green fruit develops small circular dark brown areas which persist as the fruit ripens. The most resistant cultivars appear to be F_1 hybrids with closely related pedigrees.

The most important agronomic practice to have influenced productivity in recent years is the use of plastic mulch with trickle irrigation technology. Although this system is widespread in a number of areas, significant production still occurs on furrow-irrigated open beds. Gains in productivity would certainly follow adoption of the newer technology.

There is a need for improved plant productivity in bell peppers. It appears that much of the material generated by European breeding programs is now showing gains over older open-pollinated cultivars. Resistance to bacterial leafspot (*X. campestris* pv. *vesicatoria*), PVY, and Yolo spot, are necessary for bell peppers cultivated in the Australian tropics.

As with the tomato industry, bell pepper cultivation is constrained by a small internal market in Australia, as a result of small population and low consumption rates. Australians are certainly

familiar with peppers and consume them fresh and cooked, but cultural factors determine that only small quantities are required.

Research and Development

Varietal development constitutes the only current research program in tropical Australia. This is centered on a breeding project which seeks to incorporate various resistance genes to bacterial leafspot (*X. campestris* pv. *vesicatoria*) and potato virus Y. Only race 1 of *X. campestris* pv. *vesicatoria* is found in Queensland and presumably in Western Australia (this has not been confirmed). Genes *BS2*, *BS3* and *BS4* control race 1; the first two confer a hypersensitive reaction, whereas the latter is best evaluated by quantitative estimates of disease severity. BS3 controls only race 1 but *BS2* and *BS4* control races 1, 2 and 3 (Hibberd, 1985; Hibberd et al. 1987). Because race 1 mutates to race 3, both BS2 and BS4 are being introduced into programs to provide more durable resistance. Additionally, all programs are incorporating good resistance to potato virus Y. Disease resistance genes are incorporated into well adapted genotypes.

The cultivar Redlands Sweet Sue was released in 1985 with partial resistance to bacterial spot. A routine assessment of commercial cultivars in the various regions is regularly conducted to determine district requirements.

Future Needs

The pepper industry is relatively undeveloped in Australia. At present there appears to be only a small increase in annual production, and oversupply is not an acute problem. In the future, access to Southeast Asian markets may provide some opportunity for expansion and better knowledge of these markets will be essential.

It is clear that the continuing support of local breeding programs for disease resistance is necessary. Research into pepper agronomy has been seriously neglected, particularly that concerned with population density and fertigation requirements. By maintaining access to the best F_1 hybrids from international seed companies, growers will continue to benefit from improved plant productivity which is the basis of higher yields.

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Thomas, J.E. and McGrath, D.J. 1988. Inheritance of resistance to potato virus Y in tomato. Aust. J. Agric. Res. 39:475-479.

Appendix 1: Researchers active in tomato and pepper improvement programs.

Tomato

Dr. D.O. Huett	New South Wales Department of Agriculture, Tropical Fruit Research Station, Alstonville, NSW 2477
Dr. V.Q. Nguyen	New South Wales Department of Agriculture, Horticultural Research and Advisory Station, Gosford, NSW 2250
Mr. W.J. Ashcroft	Victorian Department of Agriculture and Rural Affairs, Institute for Irrigation and Salinity Research, Tatura, Vic. 3616
Mr. J.A. Barnes	Queensland Department of Primary Industries, Bundaberg Research Station, MS108 Ashfield Road, Bundaberg, Qld. 4670
Mr. M. Herrington	Queensland Department of Primary Industries, Redlands Horticultural Research Station, P.O. Box 327, Cleveland, Qld. 4163
Mr. D.J. McGrath	Queensland Department of Primary Industries, Bowen Horticultural Research Station, P.O. Box 538, Bowen, Qld. 4805
Dr. W.B. McGlasson	CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113

Pepper

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44

Tomato and Pepper Production in Brazil

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Abstract

About two million tons of tomato are produced in Brazil annually on approximately 50,000 ha in three major production areas with distinct climatic conditions. The two leading Brazilian fresh-market cultivars are Angela and Santa Clara. The major processing cultivars are Rio Grande, Petomech, Roma, and the local cultivars are IPA-5 and IPA-6. Among the most important diseases and pests are tomato spotted wilt virus, bacterial diseases, late blight, and tomato leafminer. Almost 100,000 tons of peppers are produced yearly in Brazil. Many different *Capsicum* species are grown as hot peppers. Bacterial spot and Phytophthora rot are the most serious pepper diseases.

Tomato

Current Crop Situation

Tomato is the most important vegetable crop in Brazil, ranking 14th in economic value among agricultural crops (Table 1). The area grown to tomatoes in Brazil is about 50,000 ha, with a yearly production of approximately two million tons. It is noteworthy that yield is increasing steadily (Figure 1).

Major production areas. The three main production areas in Brazil are the São Paulo State plateau, the western portion of the State of São Paulo, and the valley of the São Francisco River (States of Pernambuco and Bahia).

Table 1 Economic value of tomatoes among agricultural crops in Brazil (1986).

Crops	Value US$
Coffee	2,071,250,000
Maize	1,429,320,000
Sugarcane	1,395,720,000
Soybean	1,390,248,000
Rice	1,191,905,000
Wheat	933,450,000
Cassava	748,929,000
Dry bean	621,144,000
Citrus	553,956,000
Cotton	531,367,000
Banana	360,860,000
Cacao	360,633,000
White potato	318,853,000
Tomato	261,902,000

Source: IBGE, 1987.

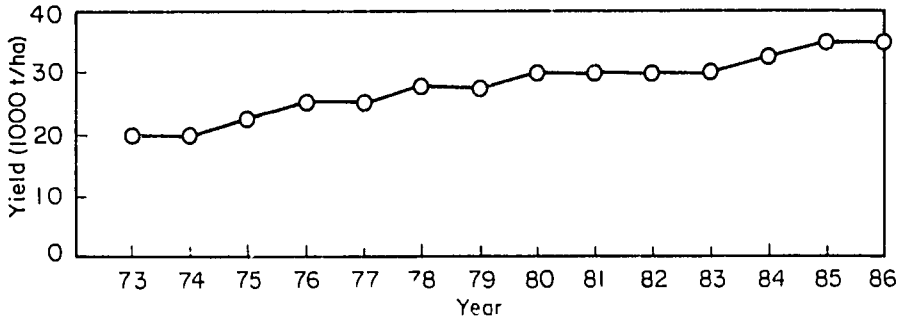

Figure 1. Increase of tomato yield in Brazil, (1973-86). Source: Anuário Estatistico do Brasil. Instituto Brasileiro de Geografia e Estatistica – 1986.

The São Paulo State plateau (Figure 2) comprises an area with an altitude of between 600 and 900 m. The climate can be classified as Cwa or Cfa according to Koppen and Geiger (1930) and is typical for tropical highland, with hot humid summers, and cool dry winters. A considerable share of Brazil's fresh-market tomatoes are produced in the region of Campinas year-round. In April, there is usually some shortage due to tomato spotted wilt virus, which severely damages the crop sown during December-January. Shortages in December are due to excessive rainfall. Supplies in July-August can be affected by frosts that may occur in this region.

Processing tomatoes are grown mostly in the western districts of the State of São Paulo, in the region of Presidente Prudente near Aracatuba, which is located 500 km inland from the Atlantic shore. The climate is tropical (Aw, according to Koppen) with a rainy season from October through March, and a dry season from May through August, and with a water deficit of 91 mm from July through September. In spite of the relatively low altitude (400 m), this climate is not typical "lowland", due to the continentality.

In the valley of the São Francisco River, in the states of Pernambuco and Bahia, near Petrolina in northeastern Brazil (Figure 3), conditions for growing tomato are ideal. Approximately 12,000 ha of processing tomato are grown here. The climate is typically semiarid (Bs according to Koppen's classification). The increasing occurrence of diseases and pests on processing tomato crops in western São Paulo and climatic irregularities in the last few years are responsible for the relocation of tomato growing to the semiarid regions of northeastern Brazil.

Cultivars. With the introduction half a century ago of the cultivar Santa Cruz (presumably a natural hybrid between Rei Humberto and Chacareiro or Redondo Japonês), with oblong, very firm, bilocular, 60-90 g fruit and indeterminate growth habit, market preferences were established for fresh-market varieties and have remained unchanged so far. The original cultivar Santa Cruz underwent mass selection during several decades, resulting in improved selections such as Kada, CAC, Yokota, etc.

In the 1970s, the Instituto Agronômico de Campinas released the cultivar Angela (derived from the cross between Santa Cruz and PI 126410), with resistance to PVY, Fusarium, Stemphylium and also to blossom-end rot. This cultivar has indeterminate growth habit, produces bior trilocular oblong shaped fruits of 100-120 g weight with uniform red skin color, and yields up to 60 t/ha. Today, the cv. Angela and its derivatives (Angela Zabon, Angela Hiper and Angela Gigante I-5,100) predominate among fresh-market tomato cultivars, occupying 70% to 80% of the total acreage of fresh-market tomatoes in Brazil (Nagai and Costa, 1969; Nagai, 1979). More recently, the Instituto Agronômico de Campinas released the cv. IAC Santa Clara, obtained from the cross between Angela and Duke, an F_1 hybrid from Petoseed Co. This cultivar is large-fruited (170-200 g), with resistance to race 1 and 2 of Fusarium, and has basically the same commercial quality as Angela (Nagai, 1985).

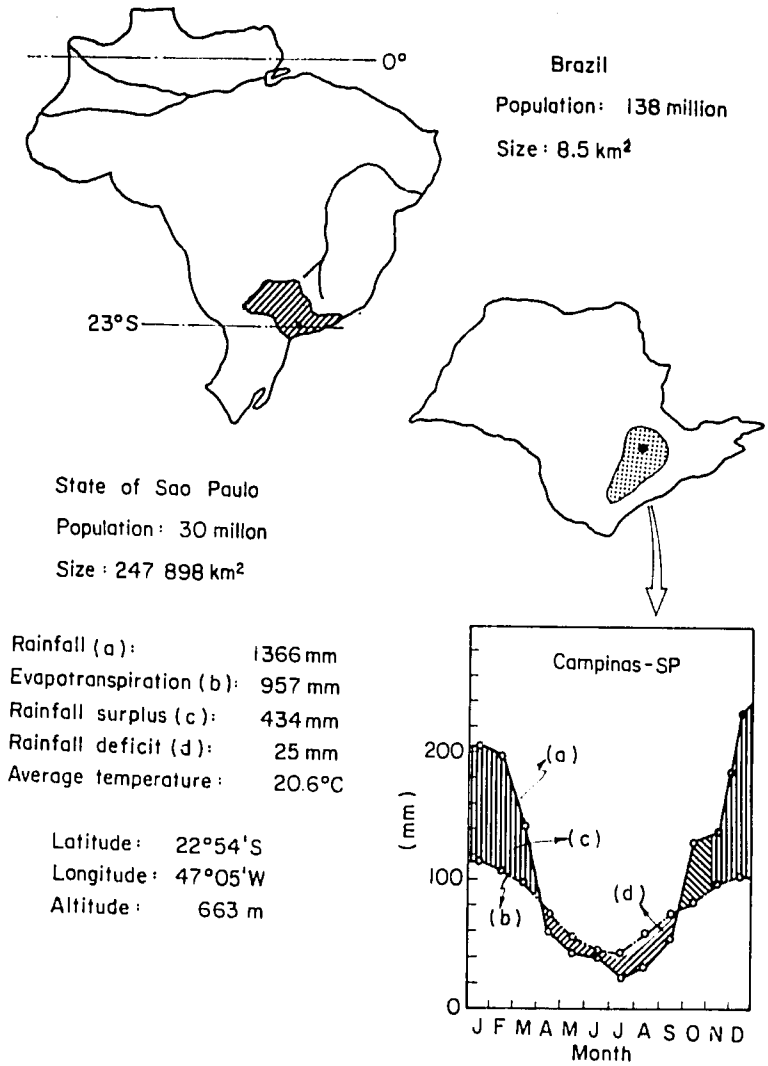

Figure 2. Location and agroclimatological data of the main fresh market/region tomato region in the State of São Paulo, Brazil.

Multilocular round-fruited types share a restricted market (less than 5% as compared to the Santa Cruz type). The more common cultivars are Oishi (derived from Manalucie), Sunny, Duke, Ogata-Fukuju, Carmel, etc.

Until the late 1960's, the indeterminate Santa Cruz types were grown for processing in the state of São Paulo. In the 1970's, with the increasing importance of processing tomatoes, there was a switch toward determinate processing cultivars imported from the USA or Europe. Nowadays, all processing cultivars grown in Brazil are small and firm-fruited. The most common pear-shaped cultivars grown are: Roma VF, Royal Chico, Rossol, Europeel and the cv. IPA-3 (from Rossol × M-128), a cultivar released by the Instituto de Pesquisas Agronômicas de Pernambuco (Melo, 1985). The most common square-round cultivars are: Rio Grande, Rio Fuego, Petomech, Euromech, Peto-86, UC-82B and the Brazilian cultivars IPA-5 (IPA-3 × Cal-J) and IPA-6 (IPA-3 × Rio Grande).

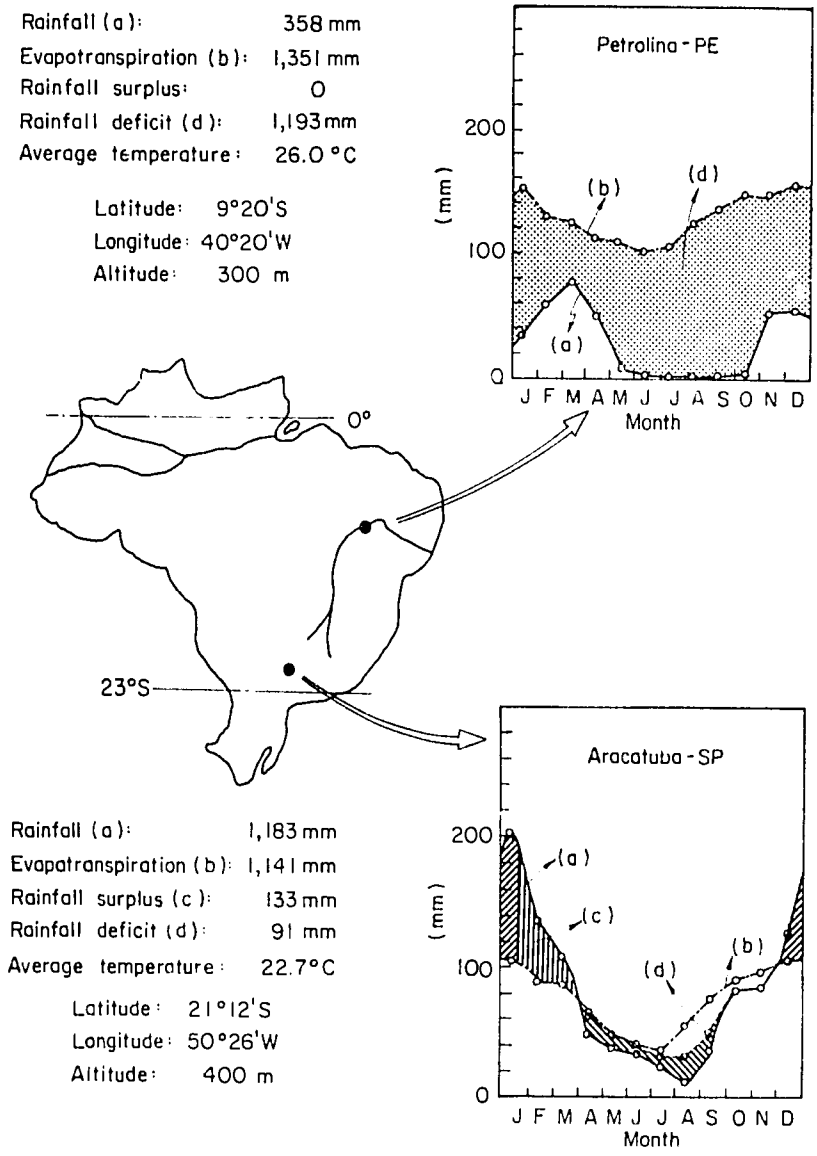

Figure 3. Location and agroclimatological data of the two main processing tomato regions in Brazil.

Cropping systems and common cultural practices. Cropping systems vary among the three main production regions. The more commonly applied cultural practices are summarized in Table 2.

Marketing. Commercialization of fresh-market tomato takes place according to supply and demand in wholesale outlets available in every state, such as CEASA (Central de Abastecimentos) and CEAGESP (Companhia de Entrepostos e Armazens Gerais de São Paulo). From the farmer's field, the products are usually transported by farmers themselves, or by a cooperative's truck, to the market. From the markets, distribution is via retailers or supermarket organizations to consumers. In the last ten years, seasonal changes in price and volume have become less important due to the opening up of new production areas and to general improvement in marketing, including better communication among retailers, new roads, and so on.

Table 2. Cropping systems and cultural practices more commonly applied to tomato crops in the three main producing areas of Brazil.

Practices	São Paulo		São Francisco river valley
	Plateau	Western region	
	Fresh market tomato	Processing tomato	Processing tomato
Cultivated area (ha)	7,000-8,000	10,000	10,000
Production (t) Yield (t/ha)	370,000 50-60	350,000 30-40	200,000-350,000 20-35
Producing counties (harvest season, months of the year)	Apiai (1-4) Elias Fausto (4-9) Ibiuna (11-5) Indaiatuba (5-11) Rib. Branco (12-4)	Aracatuba, Presidente Prudente, and Novo Horizonte (4-8)	Petrolina and neighboring
Cultivars	Angela 70% Santa Clara 25% Kada, etc. 5%	Pear-shaped: Roma VF, IPA-5, Europeel. Squares or square-rounds: Petomech, Rio Grande, Rio Fuego, Euromech, Peto-86	Rossol, Rio Grande, UC-82B, Petomech, IPA-4, IPA-5, IPA-6, Roma VF
Sowing	Paper cups (6 × 8 cm) or flat seeder	Direct-seeded with tractor	Direct-seeded or transplanted
Spacing	1.0-1.2 m × 0.6-0.7m, 2 plants/hill	Varies with cultivar and soil type. Single or double rows. 40 cm spacing between hills	Single rows 1.0 × 0.5 m, 2 plants/hill
Staking	Bamboo poles	No staking	No staking
Cultural practices	Tying, pruning, manual weeding (one laborer takes care of 4 000 plants)	Mechanical weeding. Thinning Thinning to a 40 cm spacing between hills	Moulding up to promote adventitious roots
Irrigation	Furrow or sprinkler once a week or more, according necessity	500-600 mm water per crop; 4-5 day intervals between intervals between applications	500 mm per crop sprinklers: weekly 43 mm
Fertilizer (kg/ha)	N 180,P 540, K360, B 22.5, B 2.5. Lime and organic fertilizers	N 40, P 300-400, K 80, B 1.7	N 25, P 60, K 60
Fertilization (side-dressings)	After 2nd cluster 10 to 15 g of 12-5-12 every 10 days later	N 40 kg/ha after thinning plus N 20 kg/ha 10 days later	N 80 kg/ha as urea, ca. 30 days after transplanting transplanting
Pest and diseases and control	Fungicides and insecticides according to occurrence of diseases and pests	N 40 kg/ha after thinning plus N 20 kg/ha 10 days later	Main problems: leafmiers, mites, nematodes
Harvest and packing	Manual harvest. Fruits are classified according to size, degree of maturity and uniformity. Wooden containers either 25 kg capacity	Manual harvest, two or three times. Fruits are handled in plastic boxes or in bulk	Manual harvest, two or three times. Handling in plastic boxes

Processing tomatoes are produced under a contract between farmer and processor, whereby mutual advantage is assured, and whereby seeds, transportation and technical assistance are provided by the processor. The contract also establishes the basic price for the crop. Prices are established yearly by representative farmers and representative processors, under mediation by the State Secretary of Agriculture.

Utilization. Approximately 40% of the total production of tomatoes in Brazil consists of processing tomatoes. Of these, 90% are processed as paste or purée and the remainder as juice, ketchup and so on. Fresh-market tomatoes, which comprise 60% of the total production, are usually consumed in salads or as homemade sauces and pastes.

Cost of production. In São Paulo, one hectare of staked tomatoes costs about US$5,000 to produce and one hectare of processing tomato about US$2,400, compared to US$1,200 in northeastern Brazil. Labor accounts for 21% of fresh-market tomato costs and 11% of processing tomato costs in São Paulo State. Seeds make up some 20% of the total cost.

Seed supply. Tomato seeds for the fresh-market and for processing are produced in Brazil or outside the country by both national and international seed companies. There are a few local and foreign companies in Brazil. Many produce up to 70% of their commercial seed stocks abroad and import them. Seeds of the Brazilian cultivars such as Angela, Angela Hiper, and IAC Santa Clara are produced mostly in Chile, where more favorable climatic conditions for seed yield and, especially, seed health, are available. Some seeds of processing tomato are produced in northeastern Brazil.

Foreign trade. In years when cold impairs Argentinian production and there are abundant supplies in Brazil, fresh tomatoes are exported to the Buenos Aires market. Fresh fruit exports are not, however, constant, and amounts vary widely from year to year (3,000 to 8,000 t). Processed products, such as paste or juice, are exported on a limited scale.

Constraints

Diseases and pests. The most important constraints to tomato production in the lowlands are diseases and pests. Most cultivars grown are highly susceptible to bacterial diseases caused by *Xanthomonas campestris* pv. *vesicatoria*, *Pseudomonas syringae* pv. *tomato* and *Corynebacterium michiganense* pv. *michiganense*; and to fungal diseases caused by *Phytophthora infestans*, *Alternaria solani*, *Septoria lycopersici*, *Verticillium albo-atrum*, and *Rhizoctonia solani*; and viruses, especially tomato spotted wilt virus in the warm season. PVY used to be important in the past, but has been controlled by the use of the resistant variety Angela. Other viruses such as TMV and CMV are not important in Brazil.

The tomato leafminer (*Scrobipalpula absoluta*), potato tuberworm (*Phthorimaea operculella*), vegetable leafminer (*Liriomyza* sp.), aphids and thrips are the major insects that cause considerable damage (Franca et al. 1984).

The above pests and diseases are most serious in the State of São Paulo, where the variable climate provides favorable conditions for their proliferation. In semiarid northeastern Brazil (the São Francisco river valley) disease incidence is lower, but the major problems are rootknot nematodes (*Meloidogyne* spp.), mites (especially *Aculops lycopersici*), and leafminers. In the Amazon area, bacterial wilt (*Pseudomonas solanacearum*) is the most serious disease.

Crop management and costs. The main problems are: inefficient and uneconomical fertilizer application; irrational use of pesticides with respect to cost and residues; and inefficient irrigation systems and drainage which fail to prevent soil salinisation. The high cost of production is a constraint in certain regions, particularly São Paulo.

Research and Development

Varietal development. The main objective of tomato breeding programs in Brazil has been the introgression of disease and pest resistance. As a result, new tomato cultivars for both fresh-market and processing have been released with resistance to PVY, Fusarium, Verticillium, Stemphylium, bacterial canker and rootknot nematodes (Maluf, 1985). Breeding is currently aimed at obtaining cultivars resistant to tomato spotted wilt virus and tomato leafminers, the limiting factors to tomato production both in São Paulo and in northeastern Brazil (Nagai et al. 1985; Lourencão et al. 1984). Institutions working on tomato and pepper improvement in Brazil are listed in the Appendix.

Pepper

Current Crop Situation

Production and consumption status and economic importance. Sweet pepper is the fifth most important vegetable crop in central-southern Brazil, after tomatoes, potatoes, onions and carrots. Annual production is about 120 t in an area covering 4,000 to 6,000 ha. Yield of sweet pepper varies from 18 to 35 t/ha.

Reliable production and consumption statistics data are not available, except for the volume marketed by the Companhia de Entrepostos e Armazens Gerais de São Paulo (CEAGESP), which was 3,564 t in 1986 (CEAGESP, 1986). Hot peppers are important in north and northeastern Brazil, where consumption is probably higher than elsewhere due to dietary habits. In spite of an increase in hot pepper production in the last few years in response to increased processing for dry fruit, powder and sauces, the precise national statistics are not available.

Climatic conditions are favorable for sweet and hot peppers throughout Brazil and at any time of the year. However sweet pepper production is concentrated in central-southern Brazil, where it is widely scattered throughout the vegetable 'green belt' around the cities. Because of the high incidence of bacterial spot (*X. campestris* pv. *vesicatoria*), the wet season generally does not favor the planting of peppers.

Cultivars. The Brazilian fresh market requires predominantly conical, dark, shining green sweet pepper fruits with maximum development. Average fruit weight is 90-100 g, 14-16 cm in length and 6-8 cm in width. Flesh must be thick because of the need to transport it in wooden boxes.

The most widely grown sweet pepper cultivars in central and southern Brazil are the PVY-resistant Agronômico 10 G and its derivatives, Magda (Agronômico 10 × São Carlos) and Margareth (Agronômico 10 × Avelar) (Nagai, 1983). In central-southern Brazil, no cultivar can be grown if it is susceptible to PVY (Nagai, 1984). However, in north and northeastern Brazil, where temperatures are too high (up to 30°C) for aphid proliferation, the PVY-susceptible blocky type fruit cultivars, such as Yolo Wonder and All Big, can be grown. Several pungent pepper species are grown in Brazil. Some of them are local cultivars such as *Capsicum baccatum* (Dedo-de-mosa, Chifre-de-veado, Chapeu-de-frade, Sertãozinho, Cambuci); *C. frutescens* (Malagueta); *C. chinense* (Murici, Pimenta-de-bode, Pimenta de cheiro); *C. praetermissum* (Cumari, Passarinho); and some rare *C. annuum* hot peppers.

Cultural practices. Seeding of sweet pepper is done in paper cups or in seedling flats. Spacing is usually 1.0-1.2 × 0.4-0.5 m, with one or two plants per hole (17,000 to 19,000 plants per ha). Plants are staked with bamboo (1.30 m high). Fertilization is rather heavy in side-dressing: 60 to 240 kg N/ha, 180 to 300 kg P/ha; 120 to 240 kg K/ha, lime 2 t/ha. Irrigation is applied 20 to 25 mm every five days (sprinkler or furrow system). Chemical disease and pest control is carried out as needed. Harvest starts 90 to 110 days after sowing, and continues for three

or four months. The average yield is 30 to 40 t/ha. Fruits are classified by size and color (red or green). Solanaceous and cucurbitaceous crops are avoided as preceding or succeeding crops for peppers.

Marketing. Marketing takes place primarily via wholesale markets in large urban areas, and prices are established according to daily supply and demand. Seasonal fluctuations are not drastic throughout the year, thanks to the large number of production areas and regular supply. About 70% of the marketed volume comes from inside the state, the remaining 30% coming from neighboring states, allowing for more stable supplies in months when local production is difficult because of heavy rains and cool temperatures.

Utilization. Almost all sweet peppers are consumed raw in salads, or cooked. At peak production times, more than 30% of the crop is sold as red, fully mature fruit, though farmers prefer to harvest green fruits in order to increase yields per plant. Sweet pepper processing has only just begun in Brazil. The use of hot sauces is relatively limited in Brazil. The production of paprika powder has started recently.

Constraints

Diseases. Bacterial spot caused by *Xanthomonas campestris* pv. *vesicatoria* is the major disease in Brazil, especially in the hot and humid regions. Phytophthora rot (*Phytophthora capsici*) can be limiting to pepper production at certain times and at certain locations. Tomato spotted wilt virus can be serious (30%-40% incidence) during the summer season. Tomato curly top virus and tobacco rattle virus may affect plantings in the winter season. PVY is under control since the introduction of the resistant varieties. TMV and CMV are not important on solanaceous and cucurbitaceous crops in Brazil.

Pests. Mites (*Tetranychus urticae* and *Polyphagotarsonemus latus*) are the most important pests of both hot and sweet pepper. Recently, the Instituto Agronômico de Campinas selected one mildly pungent pepper (*C. baccatum*, IAC Ubatuba — a Chapeu-de-frade type) which is resistant to spider mites (Nagai and Lourencão, 1987). Aphids (*Myzus persicae* and *Macrosiphum euphorbiae*), beetles (*Diabrotica speciosa*), and caterpillars (*Agrotis ipsilon*) can affect pepper plants and fruits to some extent. Leafminers are not important.

Research and Development

Varietal development. Pepper breeding research in Brazil has focused on the development of PVY-resistant cultivars (Nagai, 1968, 1971, 1983). Nowadays, only PVY-resistant cultivars are planted in central-southern Brazil. In mid-1986, 15 years after the release of the PVY-resistant Agronômico 10 G, a new PVY strain appeared that was able to infect this cultivar and its derivatives (Nagai, 1987). Germplasm resistant to this new strain of PVY has already been identified. Resistance to *Phytophthora capsici* and to *Xanthomonas campestris* pv. *vesicatoria* has already been incorporated into commercial cultivars and will be available to farmers in the near future (Nagai and Sugimori, 1986). The development of cultivars suitable for export and for processing will be the key to the future development of peppers in Brazil. The institutions working on pepper improvement in Brazil are listed in the Appendix.

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Appendix: Institutions working on tomato and pepper improvement in Brazil.

Tomato

Instituto Agronômico de Campinas (H. Nagai)
Caixa Postal, 28
13100 - Campinas, SP.

Centro Nacional de Pesqauisas de Hortalicas
Empresa Brasileira de Pesquisas Agropecuárias
Caixa Postal, 0.7.0218
70359 - Brasilia, DF.

Pepper

Instituto Agronômico de Campinas
Caixa Postal, 28
13100 - Campinas, SP.

Universidade Federal de Vicosa
(Prof. Vicente W. Casali)
36570 - Vicosa, MG.

Private companies:

Agroceres, S.E.
Caixa Postal, 58
32500 Betim, MG.

Agroceres, S.A. (Dr. Paulo Della Vechia)
Caixa Postal, 427
12900 - Braganca Paulista, SP.

Asgrow Do Brasil Sementes Ltda.
(Dr. P.C.T. de Melo)
Caixa Postal, 1564
13100 - Campinas, SP.

Bioplanta, Technologia de Plantas Ltda.
(Dr. W.J. Maluf)
Caixa Postal, 1141
13140 - Paulinia, SP.

Escola Superior de Agricultura 'Luiz de Queiroz' (Prof. Cyro Paulino da Costa)
Caixa Postal, 83
13400 - Piracicaba, SP.

Centro Nacional de Pesquisas de Hortalicas
Empresa Brasileira de Pesquisas Agropecuárias
Caixa Postal, 07.0218
70359 - Brasilia, DF.

Private companies:

Agroceres, S.A.
Caixa Postal, 58
32500 - Betim, MG.

Agroflora, S.A.
Caixa Postal, 427
12900 - Braganca Paulista, SP.

Symposium Discussion

A.M. Hibberd: Please comment on the inheritance of PVY resistance in PI 126410 tomato.
H. Nagai: One single recessive gene, which we designated as rt rt. (Nagai and Costa 1969. Bragantia 28:219-226).

J.E. Thomas: Does the tomato variety Santa Clara have resistance to potato virus Y?
H. Nagai: No. One of the reasons is that PVY is no longer a prevalent pathogen in the tomato and pepper growing areas, where only PVY resistant tomato cultivars (Angela) and pepper cultivars (Agronômico) have been used for the last 15 years.

E.C. Tigchelaar: What are the screening procedures you have used for PVY and tomato spotted wilt virus on tomato?
H. Nagai: For virus PVY, mechanical inoculation of y^w, y^l and y^m strains, separately. For spotted wilt, (1) field test in summer under natural infection; (2) mechanical inoculation with a severe strain, and (3) Exposure to *Portulaca* infected with TSWV and thrips in a net house.

R.L. Villareal: Do you have an active breeding program for the control of bacterial wilt of tomatoes?
H. Nagai: Bacterial wilt is serious only in northern Brazil. In that region breeding for resistance has been conducted using AVRDC materials.

J.Y. Yoon: (1) Sunscald does not seem to be an important constraint of sweet pepper production in Brazil. Can you give the possible reason(s) for this? (2) Is the mite-resistant pepper line available to breeders outside Brazil?
H. Nagai: (1) Sunscald probably is not so important in São Paulo production areas because of the rainy summers. (2) Yes. IAC Ubatuba will the material to be distributed through the proposed INTHOPENET.

45

Tomato Production in Cambodia and Screening for Tomato Leaf Curl Disease Tolerance

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Abstract

Dry season tomatoes are commonly grown in Cambodia without irrigation or fertilizers. Tomatoes are transplanted into deep silt soils adjacent the Mekong River or on islands in the river. Major problems for growers include infestations of *Heliothis armigera* and a high incidence of tomato leaf curl disease. This disease is probably caused by a strain of tobacco leaf curl virus (TLCV). Tomato variety trials conducted from 1984-87 were severely affected by the disease; results from these trials illustrate more leaf curl tolerance in several AVRDC lines compared to some standard varieties.

Tomato Production and Research

Cambodia (or "Kampuchea" in the Khmer language) is a relatively small country of 180,000 km^2 lying between 11-15 degrees North latitude and bounded by Thailand on the west and Vietnam on the east. The country's population has probably now regained its 1972 level of about 7,000,000 (Whitaker, 1973) after having been reduced by perhaps 20% as a result of the civil war and suffering which followed (1972-79). Population density is low (40/km^2) compared with either Thailand (104/km^2) or Vietnam (189/km^2). As a result of the recent losses and continued hostilities, only about 1.5-1.7 million hectares of rice lands have been brought back into cultivation (1987-88 compared with the prewar cultivated area of 2.5 million hectares (Tichit, 1981).

Cambodia has a tropical monsoon climate characterized by a six-month period of almost absolute drought (November-May) followed by rains which are increasingly regular and heavy as the season progresses (June-October). The annual mean temperature is 27°C with a low thermic amplitude of only 3.6°C; mean annual precipitation is 1.37 meters with considerable year-to-year variation. The Mekong River, which flows through the heart of Cambodia and renews the fertility of the adjacent alluvial soils, rises slowly and regularly from June to October, reaching its maximum flood stage between 15 September and 15 October. Cambodian vegetable growers have adapted their cultural practices to take maximum advantage of the fertilizing silts and soil moisture provided by the Mekong's receding floodwaters.

Cambodia is presently attempting a reconstruction and recovery from the devastation of the last decade during which the agricultural research infrastructure was destroyed and during

[1]The most conservative source estimates 750,000 "deaths in excess of normal" during the Democratic Kampuchea (Khmer Rouge) regime from 1975-78 (Vickery, 1984). Added to estimates of 500,000 deaths during the war (1972-75), this is about 18% of the mid-1972 population estimate.

which most of the country's agricultural technicians and scientists died or were executed. Reconstruction of agricultural research facilities is slowly progressing. Presently, four research stations are active and conducting trials; two of these were built and developed (including training of Cambodian management) by Western-based non-governmental organizations (NGO's).

No research facility for vegetable crops existed before the war. Thus the Kbal Koh Vegetable Crops Research Station was built and staff was trained with assistance from a foreign NGO[2] from 1984-87. Variety adaptation trials and short-term training programs have been carried out successfully by Cambodian technicians at this station. Results from some of the tomato trials are discussed later in this paper.

Vegetables have played an important part in the Cambodian diet since the days of the ancient Khmer empire 700 years ago, so much so that Chou Ta-Kuan, a Chinese visitor to Angkor in the 13th century, commented on the availability of eggplants, onions, watermelons, cucumbers, mustard, and aquatic vegetables in the capital (D'Arcy Paul, 1967). Tomatoes (*Lycopersicon esculentum* Mill.) are highly valued for their use in sour soups and are one of the major dry-season vegetable crops grown in the country. Although it is difficult to estimate the total area planted to tomatoes, perhaps 100 hectares are grown in Kandal District to supply the Phnom Penh Markets.

Soils and Production Zones

Tomatoes and other vegetable crops are grown primarily on the deep alluvial silt and silt loam soils on the banks of the Mekong River or on islands in the river (Figure 1). These are the best soils in the country as they receive annual fertilizing silt deposits from the receding Mekong floodwaters. Commercial fertilizers are seldom used for tomato production on these soils. Soil pH is near neutral.

Another important quality of the island and Mekong river bank soils is their high water-holding capacity. Growers take full advantage of this by transplanting soon after floodwaters recede and following the receding waters with sequential plantings. In this way tomatoes or other vegetable crops can be produced in the dry season with little or no supplemental irrigation.

Another zone sometimes used for tomato production is the rear slope of the river bank (Figure 1). This is an area of finer alluvial deposits where soils are more compact and range from silt loams to clays. This zone is usually flooded for only one to three months during the year. Although dry season tomato production on these soils is marginal, it has been shown that traditional techniques can be very productive with adequate irrigation and fertilization (Tat Eng Lay

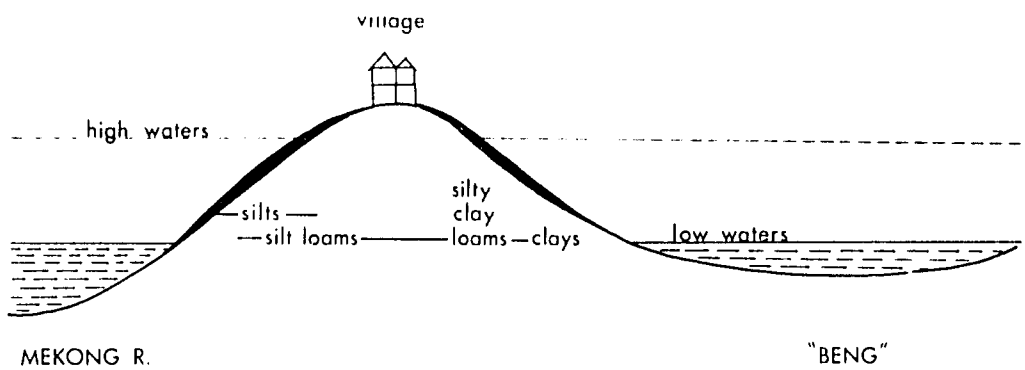

Figure 1. Topography and seasonal flooding pattern of the main vegetable/cash cropping zones of the Mekong River banks. Soil texture becomes increasingly fine away from the river and toward the inland depressions or 'bengs' (not to scale, adapted from Delvert, 1961).

[2]The senior author's work and construction of the Kbal Koh Research Station was supported by Church World Service, the relief and development agency of the US National Council of Churches, New York.

et al. 1987, unpublished.). It should be emphasized, however, that returns from tomato production alone may not justify the expense of pumping water to these fields. This zone may also be planted to maize or mungbeans at the beginning of the rains in May-June. The total production area for various crops (including maize, tobacco, fruit, vegetables, etc.) in both zones mentioned above was estimated to be 200,000 ha in the 1950s (Delvert, 1961); the Ministry of Agriculture estimated total vegetable production to be around 25,000 ha in 1984-1985.

Cultural Practices

While the Mekong floodwaters still cover the production fields in October, tomatoes are seeded in raised beds around the villages on the high ground of the bank summit (Figure 1). Three to four weeks after seeding, plants are pulled from the seedbeds (usually in bare-root condition) and transplanted in the recently exposed moist soil of the islands or river banks. In order to protect the plants from the drying sun and November winds, tomatoes are usually transplanted into the bottom of 15-20 cm holes so that the tops of the plants lie just below the edges of the holes. The holes are filled in as the plants grow out of them. Some growers use cut banana bracts for shading instead of planting in holes.

Most growers plant a local variety which, although it does not have a particular name, is appreciated for its sour tastes for soups. The fruits of this old determinate variety are large and flattened with strong ribbing at the calyx end (Figure 2). This variety is commonly planted as an intercrop with pumpkin, eggplant or white glutinous maize. Plantings are usually in combination with one or more of these; intercrops with leaf lettuce have also been observed.

Fertilizer is seldom used on tomatoes; however, some growers place urea or 0.5 kg of rotted cow manure in the planting holes before transplanting. Grower spacings vary from 0.7 to 1.5 m between rows and 0.5 to 0.8 m between plants. These wide spacings probably allow individual plants to exploit the water holding capacity of the deep silts without much inter-plant competition. As mentioned earlier, plants grown on the silt soils survive only on soil moisture; furrow irrigation of tomatoes is practically unknown.

Figure 2. Typical fruits of local Cambodian tomato variety.

As can be seen from the above description, tomato culture in Cambodia is generally not intensive. Staking and pruning are seldom practiced; however, weeding is common and most tomato fields are kept weed-free. Although tomato yields are generally low (around 5-15 t/ha), the best Cambodian growers demonstrate how wise exploitation of climate and soils can result in good yields[3] without extensive use of purchased inputs.

Production Problems

The most serious problem affecting tomato growers (and producers of other vegetables) is insect damage. For tomato growers, the principal pest is the fruitworm *Heliothis armigera*, although damage from *Spodoptera litura* also occurs. The *Heliothis* larvae are usually observed in January after the first fruits have appeared, but may also attack later in the season. If farmers treat the fields at all, it is usually too late, after the larvae have already entered the fruits. In the absence of affordable, effective insecticides, many farmers usually pick and destroy infested fruits and attempt to hand pick the larvae they see. Fruitworm populations appear to vary from year to year and extensive damage is observed only in some years. More research and information is needed for the management of this pest in Cambodia.

The most frequently observed disease on tomatoes is tomato leaf curl disease. Although a virus disease with similar symptoms has already been described (Marady, 1972), the disease has not been previously reported in Cambodia. Symptoms of this disease are severe leaf curling, yellowing and reduction of leaf size particularly in the top part of the plant. Plants are often stunted; severely infected plants bear only very small fruit or no fruit (Figure 3). Although a causal agent has not yet been identified, it is thought to be the same as that which produces identical symptoms on tomatoes in Thailand and which is a strain of the whitefly-transmitted tobacco leaf curl virus (TLCV), a member of the geminivirus group (Honda et al. 1986; Osaki and Inouye, 1981). Although it is difficult to estimate losses caused by this disease, incidences of 5-10% have been observed during the dry season on Mekong River islands and adjacent bank

Figure 3. Commercial tomato variety showing severe tomato leaf curl disease symptoms.

[3]Tat Eng Lay estimated yields of 33 t/ha in some farmers' fields in Kien Svay district, 1986.

soils of Kien Svay district, southeast of Phnom Penh (1984-87). Incidences of 80-100% were observed on the poorer alluvial soils in fields located further from the river which are usually planted later. Leaf curl disease incidence also appears to vary greatly from year to year. Even though farmers are not aware that this disease is whitefly-transmitted, they may have inadvertently developed cultural practices which avoid whitefly infestations. Farmers attempt to plant as early as possible to obtain the highest prices in the market; in this way the major build-up of whitefly populations later in the season might be avoided. In addition, plantings on the islands are exposed to winds in the early dry season which could perhaps help disperse vector populations. This may explain the lower incidence of the disease in the earlier island plantings compared to the later, more inland plantings. Also, the island plantings usually have a constant supply of soil moisture, permitting rapid early growth and a good yield in spite of the presence of the disease. Slower-growing crops on poorer soils further inland are attacked at an earlier, more susceptible growth stage, resulting in very low yields.

Recommendations for the control of the disease have recently been drafted at the Kbal Koh Vegetable Crops Research Station, but there is at present no extension service to communicate this information to farmers, primarily because of the dearth of trained technicians. With the human and material resources currently available the Ministry of Agriculture is unable to establish an extension service. This problem should be partly remedied in the future, considering the first class of 27 agronomy students from Chamcar Dong Agricultural University will graduate in early 1990 and 110 students who finish one- and two-year courses at Prek Leap Agricultural Lycee in 1988-89 with specialization in agronomy. As a result of a recommendation by the Ministry of Agriculture, all students must undergo field work and receive practical training at research stations (including the vegetable crops station) before obtaining their degrees.

Church World Service hopes to assist in the development of in-country training for vegetable crops with the help of international centers, scientists and other interested parties actively involved in vegetable research.

Screening for Tomato Leaf Curl Tolerance

Three years (1984-87) of tomato variety trials have been conducted in Cambodia. Severe infections of leaf curl disease were observed in the last two of these trials and it was possible to compare disease incidence among the varieties and breeding lines tested. Results from these trials are presented below.

Materials and Methods

Stad Chas Trial, 1984-85

This trial was planted on a clay alluvial soil adjacent to Beng Kok in Phnom Penh. Twelve AVRDC lines, six commercial varieties, and the local variety were seeded on 13 November and transplanted on 11 December, 1984. Traditional spacings of 1 m between rows and 0.7 m between plants were used in a randomized complete block design with two replications and seven plants per plot.

Kbal Koh Trial, 1985-86

Trials were conducted at the site of the new vegetable crops research station in 1985. This station, located on an alluvial silty clay loam soil, lies between the village of Kbal Koh and National Route No. 1, 16 km southeast of Phnom Penh. The site is a gently descending rear slope of an old Mekong River levee, about 300 m from an isolated branch of the river.

Eleven AVRDC lines, five commercial varieties, and the local variety were planted in a randomized complete block design with four replications. Tomatoes were seeded on 25 November

and transplanted on 18 December 1985. Plots consisted of beds 3.75 m long and 1.5 m wide with 60-70 cm between double rows and 50-55 cm between plants in the rows; 0.3-0.4 kg of rotted cow manure plus 72, 32, and 60 kg/ha of N, P, and K, respectively (480 kg/ha of 15-15-15) were mixed into the planting holes before transplanting. Plots were furrow irrigated.

The plants showing obvious leaf curl symptoms were counted at 46 days after transplanting. Both the total incidence [(number of plants with leaf curl symptoms divided by the total plants per plot) × 100] and the incidence of severely infected plants [(number of dead plants or severely stunted plants, yielding no fruits or only small unmarketable fruits divided by the total plants per plot) × 100] were recorded. Virus incidence data were analyzed as a completely randomized design because of missing plots in the trial; arcsin-transformed percentage data were used in all statistical analyses.

Kbal Koh Trial, 1986-87

Nine AVRDC lines (including the best six from the previous trial), five commercial varieties, and the local variety were planted in a randomized complete block design with four replications. Tomatoes were seeded on 6 November and transplanted on 28-29 December, 1986. Plots consisted of beds 3 m long and 1.2 m wide with 60 cm between double rows and 40 cm between plants in the rows; the center 2 m (10 plants) of each plot was harvested to determine yields. Nine t/ha of rotted cow manure plus 45, 20, and 37 kg/ha of N, P, and K, respectively, (300 kg/ha of 15-15-15) were mixed into planting holes before transplanting. A side-dressing of 30, 13, and 25 kg/ha of N, P, and K, (200 kg/ha 15-15-15) was applied when first fruits were 3-4 cm in diameter. Plots were furrow irrigated weekly or as needed.

The disease incidence in each plot was recorded after the first fruits had appeared. All statistical analyses of percentages (leaf curl incidence) were performed on arcsin-transformed data. A planned linear contrast was used to compare average incidence of all AVRDC lines with those of the local and commercial varieties.

Results and Discussion

In the Stad Chas trial virus incidence was generally low; the AVRDC plots appeared to be disease-free. Leaf curl disease was observed in some plants, however, in the commercial varieties tested: 50% of varieties Rutgers 39 VF and Roma VF were visibly infected. In addition, infected plants were observed in plots of Heinz 1350 and the local variety. Yields ranged from 7 to 22 t/ha for AVRDC lines and from 3 to 14 t/ha for the commercial varieties tested. All but two of the AVRDC lines were retained for retesting in 1985-86.

The Kbal Koh 1985/1986 trial was so severely affected by leaf curl disease that it could not be harvested; however, infections were fairly uniform and virus incidences among the varieties could be compared (Table 1). Probably one reason for the severe infection was the relatively poor early growth due to uneven irrigation. Slower-growing plants could be infected earlier than more vigorous plants which had access to adequate soil moisture.

Although both the total incidence of infected plants and the incidence of severely infected plants were recorded and analyzed, only the total incidence data are reported here. These data were less variable (c.v. = 18%) and differences among varieties were easier to detect. The disease affected 38-90% of the plants among the varieties and breeding lines tested. The only statistically detectable differences were between Marglobe, with the highest incidence in the trial (90%), and the two AVRDC lines with the lowest incidences (38% for CL 1131-0-0-43-8-1 and 51% for CL 5915-229D4-1-3). The local variety had a very high incidence (81%) along with some of the AVRDC lines (69-78%).

The average incidence for all AVRDC lines was 63% compared with 71% for the others. In addition, the line with the lowest incidence (CL 1131-0-0-43-8-1) was among the highest yielding of varieties and breeding lines tested in the 1984-85 trial at Stad Chas.

Table 1. Incidence of tomato leaf curl disease in 1985-1986 Tomato Variety Trial, Kbal Koh, Cambodia.[z]

Variety or breeding line	Seed source	Leaf curl incidence (%)[y] (original means)	Leaf curl incidence (transformed means)
CL 1131-0-0-43-8-1	AVRDC	38 a[x]	38
CL 5915-229D4-1-3	AVRDC	51 a	46
CL 5915-206D4-2-5-0	AVRDC	55 ab	48
CL 5915-136D4-1-0	AVRDC	61 ab	51
Tropical	Petoseed	61 ab	51
Floradade	Niagara Seed	61 ab	51
CL 5915-153D4-3-3	AVRDC	62 ab	52
CL 143-0-10-3-0-1-10	AVRDC	63 ab	52
Pacesetter 502	Asgrow Seed	67 ab	55
Pritchard	Arco Seed	68 ab	56
CL 1131-0-0-65-13-0-1	AVRDC	69 ab	56
CL 5915-206D4-2-2-0	AVRDC	71 ab	57
CL 5915-93D4-1-0	AVRDC	71 ab	57
CL 5915-223D4-2-1	AVRDC	71 ab	57
CL 1131-0-0-7-0-9	AVRDC	78 ab	62
Local variety	Kien Svay district	81 ab	64
Marglobe	Mayo Seed	90 b	72
c.v.			18%

[z]Data are means of four replications. [y]Total incidence [(number of plants with leaf curl symptoms divided by the total plants per plot) × 100]. [x]Arcsin-transformed data were analyzed by Duncan's multiple range test; means not followed by the same letter are significantly different (p = 0.05).

From the 1986/1987 Kbal Koh trial, moderate yields (8-32 t/ha, Table 2) were obtained in spite of the high incidence of leaf curl disease. The trial was not so severely affected by the disease as in the previous year's trial. This may be due to the earlier planting date and better furrow irrigation. Statistically significant yield differences could not be detected among varieties because of the variability within and among replications caused by the disease (c.v. for marketable yield = 52%) (Table 2). The average of yields for all AVRDC lines (24.8 t/ha), however, was significantly higher than the average of yields from the other varieties tested (15.4 t/ha) when compared by linear contrast (p = 0.01).

Drastic yield reductions caused by the disease were easily observed in the field for some varieties (Marmande, Floradade, Paradiesom: incidences 84%, 91%, and 94%, respectively). In these plots, many of the plants were severely stunted and died prematurely. This effect of the disease on yields is illustrated by the highly significant negative correlation (r = -0.73) between disease incidence and marketable yield (p = 0.01). In this case at least 53% (r^2) of the variability in marketable yield can be ascribed to the effects of leaf curl incidence.

The linear contrast between the mean disease incidence for AVRDC lines (49%) and the other varieties (78%) was highly significant (p = 0.01) indicating leaf curl disease tolerance in some AVRDC materials compared to varieties bred in the West. In addition, there were also some significant differences (p = 0.05) for virus incidence among the AVRDC varieties themselves (see DMRT, Table 2).

The large amount of year-to-year variability for disease incidence among varieties in these tests can be seen by comparing the results in Tables 1 and 2. Note the changes in relative rankings of Floradade and the local variety in the two trials. In spite of this variability, some AVRDC lines had relatively low incidence in both of the last two years' trials (i.e. CL 1131-0-0-43-8-1 and CL 5915-229D4-1-3).

The results of the trials indicate that AVRDC lines have more tolerance to tomato leaf curl disease than the temperate-bred commercial varieties tested, and that there are differences in

Table 2. Yields and incidence of tomato leaf curl disease in 1986-1987 Tomato Variety Trial, Kbal Koh, Cambodia.[z]

Variety or breeding line	Seed source	Leaf curl incidence (%)[y] (original means)	Leaf curl incidence (transformed means)	Marketable yield (t/ha)	Average fruit size (g)
PT 3027 (F1)	AVRDC	27 a[x]	31	32.4	42
CL 5915-153D4-3-3	AVRDC	34 ab	36	23.1	30
CL 1131-0-0-43-8-1	AVRDC	36 ab	37	27.5	27
Local variety	Cambodia	48 abc	44	30.7	55
CL 5915-136D4-1-0	AVRDC	50 abc	45	22.8	24
PT 913 (F1)	AVRDC	50 abc	45	18.1	28
CL 5915-229D4-1-3	AVRDC	52 abc	46	25.8	35
PT 870 (F1)	AVRDC	52 abc	46	26.1	37
CL 143-0-10-3-0-1-10	AVRDC	65 bcd	54	25.5	28
Pacesetter 502	Asgrow Seed	68 bcd	56	15.0	46
CL 1131-0-0-65-13-0-1	AVRDC	72 bcde	58	22.3	25
VF 134	Chia Tai Seed	82 cde	65	10.0	47
Marmande	Sutton's Seeds	84 cde	66	17.8	68
Floradade	Niagara Seed	91 de	72	8.0	60
Paradicsom	Hungary	94 e	76	11.2	41
LSD (p = 0.05)				NS	14
c.v.			35%	52%	24%

[z]Data are means of four replications. [y]Leaf curl virus incidence = Number of plants with obvious symptoms divided by the total number of plants per plot × 100 [x]Arcsine-transformed data analyzed by Duncan's multiple range test; means not followed by the same letter are significantly different (p = 0.05)

tolerance among the AVRDC lines themselves. The same trend of leaf curl tolerance in AVRDC materials compared with commercial varieties was also observed in tomato variety trials from southeastern Bangladesh in 1979-80 where high yields were obtained from several AVRDC lines in spite of severe infections in that location (Rowell, 1980). The tolerance exhibited in these materials should be very useful in years with mild to moderate infections.

As there has been no selection for leaf curl resistance at AVRDC, the origin of field tolerance in these lines is not clear. A clue may lie in the fact that some of the AVRDC lines were produced using the Hawaiian line Anahu as a grandparent. Anahu and its derivatives have been found to be tolerant to similar leaf curl virus diseases such as the tomato yellow leaf curl in Egypt and the Sudan (Yassin and Abu Salih, 1972; H.M. Munger, personal communication). The tolerant varieties from AVRDC may be recommended in the future after further testing in farmers' fields.

The Kbal Koh Vegetable Crops Research Station has made the following management recommendations to Cambodian growers to reduce the tomato leaf curl disease:

1. Sow tomatoes as early as possible in October (infections appear to increase as the growing season progresses). Provide good drainage and protect seedbeds from rain for early plantings.
2. Provide adequate water and fertility to encourage vigorous early growth. Straw mulch helps conserve soil moisture and may help to reduce whitefly populations (Cohen and Melamed-Madjar, 1978; Nitzany et al. 1964). Early tomato plantings on islands in the Mekong appear to escape severe damage from the virus perhaps because of the ideal soil texture and growing conditions.
3. Protect transplants in the seedbed and in early growth stages from the whitefly vector. Seedbeds could be protected with coverings of nylon screening or perhaps cotton netting

(as is used for tobacco seedbeds); both materials are available in Phnom Penh markets. While use of systemic insecticides may be helpful, they are not recommended because of limited availability and high cost.

4. Destroy annual and perennial weeds around field borders, ditches, and fences; keep fields weed-free.
5. Destroy old crops immediately after the last harvest. Encourage neighbors to destroy old field or garden plantings which could act as virus reservoirs.
6. Remove and destroy newly infected plants.

Acknowledgments

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Symposium Discussion

T.A. Thomas: Has any effort been made to collect the local germplasm of various vegetable crops from Cambodia before it is lost forever?

A.B. Rowell: No effort has been made to systematically collect local germplasm in Cambodia. I do not expect this material to be 'lost forever' since most Cambodian farmers are still using local varieties.

R.L. Villareal: (1) I am amazed by the low concentration of research workers in Cambodia. Are there plans to change this situation? (2) Are there restrictions to movement around Cambodia?
A.B. Rowell: (1) Advanced training should alleviate the shortage of agricultural research workers. The agricultural university at Chamcar Dong reopened in 1985. Although there is no training in agricultural research at this university, students are required to work for a year in one of the research stations before receiving their degrees. Cambodia is also sending agricultural workers to IRRI for rice production training in the Philippines and hopes to send students for advanced degree training in the future. (2) There are many travel restrictions. Travel in several provinces of the central region is possible with government permission. Travel to remote and insecure provinces is not possible at this time for foreigners.

A. Yu: What is the source of tomato line PT 3027?
A.B. Rowell: PT 3027, an F_1 hybrid, comes from AVRDC.

416

46

Production of Tomato and Pepper in China

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Abstract

The tomato, *Lycopersicon esculentum*, grown for its high nutritive and commercial value, is one of the most popular vegetables in China. It is exported as juices, pastes and whole fruit. The total hectarage of table tomatoes is 210,000 ha and that of processing tomatoes is 10,000 ha. The average yields throughout the country range from 22.5 to 60.0 t/ha. Tomatoes in China are primarily grown on trellises. Flat bed cultivation is practiced in northern China while high raised beds are popular in the provinces south of the Yangtze River. Throughout the country, tomatoes are usually transplanted. The areas along the Yangtze River have a single spring/summer crop, while two crops per year are produced in Guangdong, Hainan, southern Fujian, Taiwan, parts of Yunan, Guizhou and Sichuan. Diseases are the major constraints of tomato production causing fluctuation in production and yield. Early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), Septoria leaf spot (*Septoria lycopersici*), TMV and CMV are important throughout the country whereas bacterial wilt (*Pseudomonas solanacearum*) is important in central-south, south and southwest China. The most damaging insect pests of tomato are aphids and corn-earworm. Breeding programs focus on resistance to major diseases (bacterial wilt, TMV, CMV and Septoria leaf spot), fruit cracking and on postharvest constraints. Increasing the soluble solids and lycopene content is the breeding priority for processing tomato. Various national institutes are involved in tomato breeding in China.

The introduction and cultivation of hot and sweet peppers in China dates back to the 14th century. Sweet pepper is an important ingredient in the Chinese cuisine. Pepper is also valued for its medicinal property. The total planting area of pepper is about 60,000 ha. At an average yield of 28 t/ha, the total annual production is 1.68 million t. Production is concentrated in areas near the big cities of eastern, northern and northeastern China. Only one crop is usually grown. However in northern China, pepper cultivation often extends beyond summer. It is possible to grow two crops per year using plastic or net houses and heated glass houses. Planting density and cultivation methods are location specific. High raised beds are necessary in the south while flat-bed formation is practiced in the north. More than 20 popular pepper cultivars are grown in China. Most are local varieties, with great diversity in color, shape, maturity, pungency, sweetness, environmental adaptability and disease resistance. Diseases and insufficient supply of quality seeds are the major production constraints. The major diseases are viruses (TMV, CMV, PVX and PVY), anthracnose (*Colletotrichum* sp.), Verticillium wilt (*Verticillium albo-atrum*), bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), soft rot (*Erwinia carotovora*), Phytophthora rot and sun scald. The major insect pests are aphids, corn earworm and spidermites. Breeding programs emphasize improvement of quality, yield and disease resistance.

Tomato

The tomato, *Lycopersicon esculentum*, is one of the most popular vegetables in China. It is cooked as vegetable dish in the Chinese cuisine. It was also important as a fresh fruit throughout

China before apples, pears, peaches and oranges became widely available. Farmers can increase their cash income by growing tomatoes in their small private lots and selling them directly at the local markets. The government policy encourages the exports of processed tomato products such as juices, pastes, and whole fruit and has been promoting the expansion of the existing tomato acreage. The total annual area planted to tomatoes in China is about 220,000 ha of which 10,000 hectares are for processing. This figure does not include the tomato plantings scattered in the suburban and rural areas of the small cities. The average yields in the country range from 22.5 to 60.0 t/ha, depending upon location, season and varieties. Large-sized tomatoes, 150-270 g/fruit are preferred. More than 50 local and introduced tomato cultivars are currently under cultivation throughout China (Anon. 1987). Growing of tomatoes on trellises is the primary cultural practice in China. Small, dense trellises of 40-50 cm height are used for growing early and determinate cultivars, usually planted at 60,000 plants/ha, whereas trellises over 1.5 meters are used for the indeterminate, medium- to late-maturing varieties. Only about 3,000 ha of processing tomatoes are cultivated without trellis in the relatively dry areas of Xinjiang and parts of Heilongjiang. Flat-bed cultivation is practiced in the northern part of China, while high raised beds are popular for tomato growing in the provinces south of the Yangtze River. Planting density ranges from 30,000 to 90,000 plants/ha. Except in a few locations in southern China, where tomatoes may occasionally be intercropped with wax gourd or tall corn to avoid direct sunlight, tomatoes are planted mostly by transplant throughout the country.

A single spring/summer tomato crop, sown around January and harvested from May through November, is usually produced in the areas along the Yangtze River including Shanghai, Jiangsu, Hubei and other provinces (Figure 1). Two crops per year, usually sown between August and September and harvested from November through March, can be grown in Guangdong, Hainan, southern Fujian, Taiwan, and parts of Yunan, Guizhou and Sichuan. Tomatoes planted in parts of northeast and northwest China are sown in February and harvested from mid July to late September. Plastic film mulch has to be used to protect the crop from cold temperatures and for stretching the harvest time into November (Figure 2).

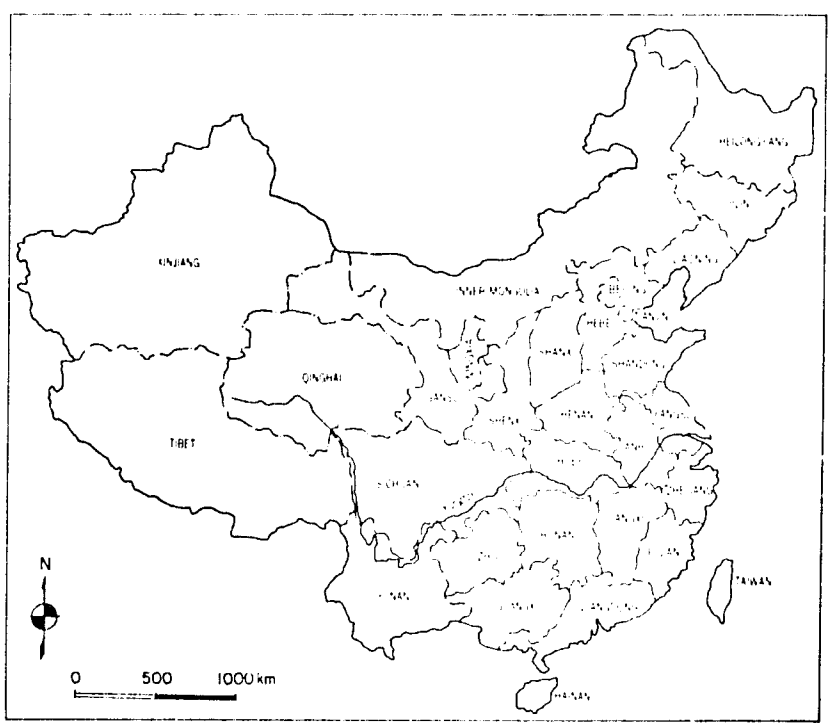


Figure 1. Map of China.

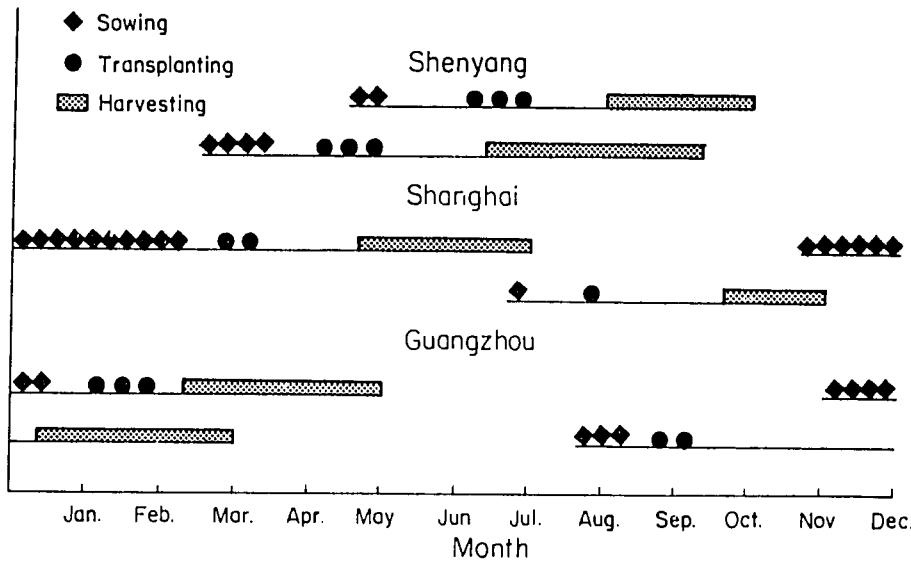


Figure 2. Tomato cultivation seasons in Shenyang, Shanghai and Guangzhou.

The primary tomato production constraints are diseases such as early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), Septoria leaf blight (*Septoria lycopersici*), TMV and CMV throughout the country and bacterial wilt, *Pseudomonas solanacearum*, in central-south, south and southwest China. Fruit rots caused by *Phytophthora* sp. and physiological disorders are also common. The most damaging insects are aphids and corn earworm. Insufficient supply of good quality seeds is another constraint.

Improvement of yield and quality and resistance to diseases such as bacterial wilt, TMV, CMV and Septoria leaf blight are the major breeding objectives. Significant improvement in tomato production has been achieved through the use of both open-pollinated and F_1 hybrids that are resistant to TMV and bacterial wilt (Table 1). Currently resistance to cracking is emphasized. Increase of lycopene and soluble solids content is an additional breeding objective for the processing tomato. Although the seeds are supplied to farmers by the state-operated seed companies, in cooperation with the agricultural research institutions, the requirement for tomato seeds for national production goals can not be met adequately.

The agencies involved in tomato improvement programs, including breeding for disease resistance, high yield, and improved quality, are listed in Appendix 1.

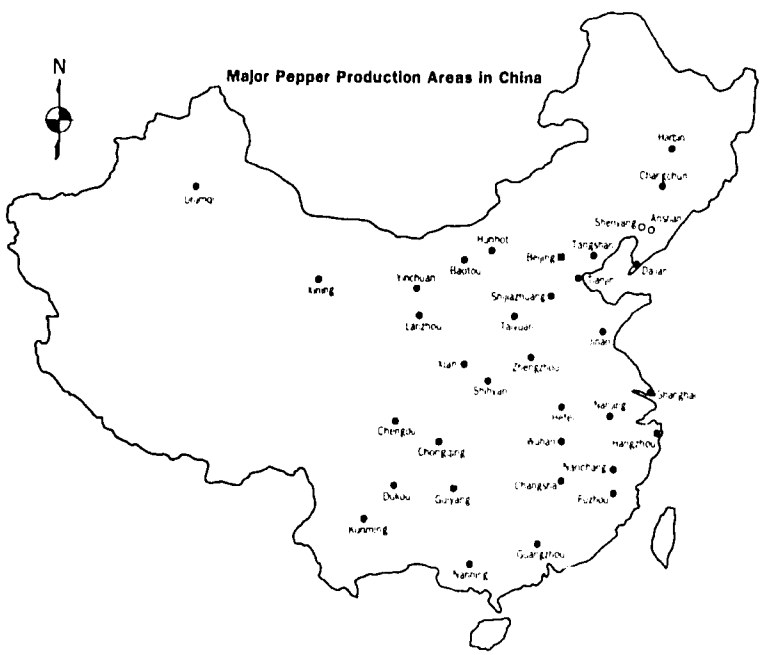
Pepper

Unlike tomato, the introduction and cultivation of hot and sweet peppers, *Capsicum annuum*, can be traced back to the 14th century. A semiwild chili pepper, the 'Xiao Mi Jiao', can still be found in the virgin forest area of Xishuangbanna Prefecture of Yunan Province. Sweet pepper is often part of the daily diet. In the provinces of Gansu, Shaanxi, Sichuan, Guizhou, Yunan, Hunan, Hubei and Jiangxi, chili peppers in the form of fresh chili, chili paste, pickled chili or dried chili powder are added to the food (Figure 3). The Chinese believe that chili peppers can provide medicinal cures for the human body, besides having high vitamin contents, particularly A and C.

Table 1. Tomato varieties commonly grown in China.

Cultivar	Use[z]	Major characteristics[y]
Beijing Zhao Hong	F, P	OP, det., early, red, 100 g
Zhao Fen #2	F, P	OP, det., pink, 150-160 g, cold tolerant
Shanghai Chang Chi Da Hong	F, P	OP, indet., medium-late maturing, red, 120-150 g
Yue Nung #2	F, P	OP, indet., Red, 60-70 g
Wu Chang Da Hong	P	OP, semi-det., medium maturing, red/green-shoulder, 100 g
Mansie (Manalucie)	F, P	OP, indet., medium-late maturing, 200-220 g, disease and heat resistant
Chiang Li Mi Shou	F	OP, indet., medium maturing, pink/green-shoulder, 150 g, disease resistant
Te Lo Pi Ke (Tropic)	F	OP, indet., late, orange red, 200-250 g, heat tolerant, disease resistant
Lo Cheng #1 (Roma)	P	F_1, indet., medium-late maturing, red, 60-80 g, heat tolerant
Pn Hong #1	F, P	F_1, (Beijing Zhao Hong × 402), det.
Zhe Hong	F, P	F_1, (Beijing Zhao Hong × Yue Nung #2), indet.
Ze Yuan 6-73		F_1, (2266 × Beijing Zhao Hong), indet.

[z]F = fresh; P = processing. [y]OP = open pollinated; det. = determinate; indet. = indeterminate; semi-det. = semideterminate.



Owing to the long history of pepper cultivation in China, the growing areas are widely scattered. Not counting the peppers grown by the farmers on their small strips of private land, the total area planted to chili peppers is about 60,000 ha. The total annual production is 1.7 million tons. Average yield of sweet pepper is 28 t/ha although yields as high as 75 t/ha have been achieved. Average yields of fresh chili range from 15.0 to 22.5 t/ha and of dry chili 2.25-7.50 t/ha. The sweet pepper production tends to be in the periurban areas of the metropolises in the eastern, northern and northeastern parts of China.

Only a single crop of chili is grown under open-field conditions. In the south and the middle and lower Yangtze River regions, seedlings are raised in November and December, in the northern region only in December and in the northeast and northwest during January and February. Transplanting is in February and March in the south, March and April in the middle and the lower Yangtze River regions, April in the north region, and May for both the northeast and the northwest of China. Harvesting is in May for southern China, May and June for the middle and the lower regions of the Yangtze River, June for northern China, and June and July for the northeast and northwest of China. Customarily, pepper cultivation is often extended beyond summer in the north and northeast of China. Besides open-field cultivation, a large amount of peppers are grown in plastic or net houses. Two crops a year (summer and fall), can be produced in heated glass houses. Chili produced in the Yunan-Gueilin Plateau is famous for its excellent eating quality and high yield.

Single-row plantings are practiced in the north, whereas double-row plantings are preferred in the south. The planting density of sweet pepper varies with the location, usually 74,000-82,500 plants/ha in the south to 100,000 plants/ha in the northeast to over 200,000 plants/ha in the Beijing area. Chili is generally planted at a density of 192,000 plants per hectare. As in tomato, high-raised beds are necessary for pepper production in the south, whereas low or no-bed formation is practiced in the north.

Great diversity in color, shape, maturity, pungency, sweetness, environmental adaptability and disease resistance exist in *Capsicum* sp. grown in China. More than 20 popular pepper cultivars are currently cultivated throughout the country (Table 2).

Insufficient supply of quality seeds and diseases are the major production constraints of peppers in China. Diseases, which often result in severe economical losses are viruses (TMV, CMV, PVX and PVY), anthracnose (*Colletotrichum* sp.), Verticillium wilt (*Verticillium albo-atrum*), bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*), soft rot (*Erwinia carotovora*), Phytophthora rot and sun scald. The major pepper pests are aphids, corn earworm and spidermites.

Pepper breeding in China emphasizes improvement of quality, yield and disease resistance. The major institutions involved in pepper research and improvement are listed in Appendix 1.

Table 2. Pepper cultivars most commonly grown in China.

Cultivar	Usage[z]	Major characteristics	Production area	Yield (t/ha)
Zao Yangjiao	F	Early maturing; dwarf plant, 35-45 cm	Jiangli and Sichuan	low
Hoo Ke Jiao	F (early stage)	Early maturing; dwarf plant, 40 cm	Jiangsu	22.5
	Pickled	Cylindrical fruit	Zhejiang and Sichuan	
Er Foo Tou	F	Medium maturing; tall plant, 73-96 cm	Sichuan	22.5-37.5
Chengdu Er Jin Tiao	D	Medium maturing; tall plant, 70 cm; conical fruit; strong pungency	Sichuan	22.5
Shi Feng Jiao		Resistant to virus		
Qi Men Jiao	F	Medium late; heat tolerant lantern shaped fruit, 100-250 g; sweet; good keeping quality; disease resistant	Shanghai, N and NE of China	30-60
Chang Sha Niu Jiao Da Jiao	F, Pickled	Medium-late maturing; tall plant, 93 cm; long conical fruit; disease resistant	Hunan, Sichuan	30
Si Fang Tao Tian Jiao	F	Medium-late; square lantern shaped fruit, over 200 g; sweet; susceptible to virus	N, NE and S of China	30-37.5

Table 2. Continued.

Cultivar	Usage[z]	Major characteristics	Production area	Yield (t/ha)
Chi Ying Jiao	F, P (dry)	Medium-late maturing; tall plant; conical fruit; strong pungency; heat tolerant; disease tolerant; tolerant to poor soil	Sichuan	12-15
Cherry Jiao	F, Pickled	Medium-late maturing; tall plant; round fruit; strong pungency; heat tolerant; disease tolerant; tolerant to poor soil	Yunnan and Tibet	12-15
Shaanxi Xian Jiao	P (dry)	Late maturing; medium-size; thread shaped fruit; strong pungency; disease tolerant	Shaanxi and Guangzhou (dry yield)	2.25-3.75
Yunnan Da La Jiao	F	Late maturing; tall plant; long conical fruit, 30 cm; juicy; disease resistant	Yunnan	22.5

[z]F = fresh; P = processing.

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Appendix 1. Major institutions involved in pepper and tomato improvement (China).

Institution	Crop	Location
Vegetable Research Institute, CAAS*	pepper, tomato	Beijing
Vegetable Research Institute, JAAS[y]	pepper	Nanjing
Vegetable Research Institute, Jiangsu AAS[x]	tomato	Nanjing
Vegetable Research Institute, Xinjiang AAS	pepper	Shih He Dze
Horticulture Research Institute, Liaoning AAS	pepper, tomato	Shenyang
Vegetable Research Institute, Jilin AAS	pepper, tomato	Gonjuling
Beijing Agricultural University	pepper, tomato	Beijing
Tienjin Vegetable Research Institute	tomato	Tienjin
Vegetable Research Institute, Beijing Municipal AAS	pepper, tomato	Beijing
Northwest Agricultural University**	tomato	Harbin
Hubei AAS**	pepper, tomato	Wuhan
Horticulture Department, Northeast Agricultural University	tomato	Yangling
Shanghai Agricultural Academy of Sciences	tomato	Shanghai
Economic Crop Research Institute, Guangdong AAS	tomato	Guangzhou
Plant Protection Department, South China Agricultural University	tomato	Guangzhou
Xian Vegetable Research Institute	tomato	Shaanxi, Xian

*Involved in both varietal improvement and quality analysis of vegetable germplasm.
**Quality analysis of vegetable germplasm only.
[y]CAAS = Chinese Academy of Agricultural Sciences.
[y]JAAS = Jiangsu Academy of Agricultural Sciences.
[x]AAS = Academy of Agricultural Sciences.

422

Production and Utilization of Pepper and Tomato in Taiwan, China

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Abstract

Pepper and tomato play an important role in the agriculture of Taiwan. In 1986 there were 2,853 hectares of pepper and 9,682 hectares of tomato cultivated which accounted for 0.13% and 0.53%, respectively, of the total agriculture and livestock production value. Among over one hundred vegetables in Taiwan, the combined production value of these two crops ranked third, behind watermelon and bamboo shoots. In addition to consumption as fresh vegetables, they are processed into sauce, juice and hot pepper powder for export. F_1 seed production of both crops for international markets also has become an important industry in Taiwan. However, because of recent sharp increases in labor costs, F_1 seed production has declined. Pepper and tomato are grown throughout the year in Taiwan with a significant seasonal fluctuation in supply and price due to environmental constraints in production during summer.

Introduction

Both pepper and tomato are important crops in Taiwan. Among over one hundred vegetables, the production value of these two crops together ranked third, behind watermelon and bamboo shoots (Table 1). In recent years, the consumption of rice has gradually decreased, while the consumption of vegetables, including pepper and tomato, has steadily increased. This trend is expected to continue.

Pepper and tomato are important vegetables in the Chinese diet and important commodities for processing. The processed tomato is one of the most important export agricultural products. The production of F_1 hybrid seeds of these two crops for international markets is also becoming an important agricultural business in Taiwan. However, hot and humid conditions limit the production of these two crops, which cause significant seasonal fluctuations in supply and price. This paper reviews the recent developments of these two crops in Taiwan, and outlines the research objectives for future growth.

Table 1. Percentage of value of agricultural production in Taiwan 1983-86.

Crop	1983	1984	1985	1986
Rice	22.70	21.20	20.61	17.51
Bamboo shoot	0.85	0.90	0.94	0.79
Cabbage	0.70	0.47	0.49	0.67
Watermelon	1.14	1.35	1.73	1.78
Cauliflower	0.35	0.63	0.61	0.53
Tomato	0.56	0.48	0.60	0.53
Pepper	0.22	0.15	0.18	0.17

Source: Taiwan Agriculture Year Book 1987.

Pepper

Production and Cultivars

The total hectarage and production of peppers increased dramatically since 1965, and remained relatively constant during the last decade. There was little change in average yields during the same period (Table 2). In 1986, the hectarage and total production were 2,853 ha and 21,218 t, respectively. The main production areas are Changhua (309 ha), Yunlin (393 ha), Pingtung (817 ha) and Nanto (275 ha) (Figure 1). The seed production areas were mainly located in Pintung and Tainan counties.

Compared to tomato (Lai et al. in the proceedings), the supply of pepper is relatively stable throughout the year (Figure 2). Although the best sowing season for pepper is from September to October, three main planting seasons have developed based on land utilization, cropping pattern and market:

- Autumn — Spring crop: Peppers are sown during September to October, transplanted in late October to November, and harvested from February to July.
- Spring — Summer crop: Peppers are sown during late January to March, transplanted in mid-March to in mid-May, and harvested from early June to early November.
- Summer — Winter crop: Peppers are sown from June to July, transplanted mid-July to mid-August, and harvested from October to February. This system rotates with the first crop of rice.

The elongated bell shape is the most popular sweet pepper type. The long pod with high pungency is the most desired hot pepper type. Hot pepper is usually processed into paste and powder. The most commonly grown cultivars and their characteristics are shown in Table 3. Cultural practices vary greatly in Taiwan: the plant density varies from 13,000 to 35,000 plants/ha and yields from 2 to 75 t/ha. It is necessary to develop appropriate management practices for different cultivars under different conditions.

Utilization

Sweet pepper is usually cooked with meat. A small amount of dehydrated fruit is exported to Europe and the U.S.A. Hot peppers are mainly processed into sauce, powder, etc.

Table 2. Acreage and yield of pepper, 1965-86.

Year	Area planted (ha)	Average yield (kg/ha)	Total production (t)
1965	249	6,989	1,741
1970	845	8,177	6,910
1975	1,266	8,636	10,933
1976	1,785	11,771	21,011
1977	1,710	10,547	18,035
1978	2,129	8,961	19,077
1979	2,267	9,402	21,314
1980	2,372	9,684	22,970
1981	2,459	9,139	22,472
1982	2,641	8,370	22,104
1983	2,775	7,637	21,031
1984	2,705	7,622	20,594
1985	2,652	8,618	22,725
1986	2,853	7,808	21,218

Source: Taiwan Agriculture Year Book, 1987.

Table 3. Commonly grown pepper cultivars.

Cultivar	Main characteristics[z]	Origin
Sweet pepper		
Ruby King	OP, long, bell shape, thin wall	
Blue Star	F_1, long, bell shape, thick wall	Known You Seed Co.
Giant	F_1, long, bell shape, thick wall	Known You Seed Co.
Uranus	F_1, long, bell shape, thin wall	Known You Seed Co.
California Wonder	OP, long, bell shape, thick wall	
Hot pepper		
Goat's Horn	OP, long, medium pungency	Local
Szuchuan	OP, high pungency	Local
New Comer	F_1, long shape, low pungency	Known You Seed Co.
Hot Beauty	F_1, high pungency	Known You Seed Co.

[z]OP = open pollinated.

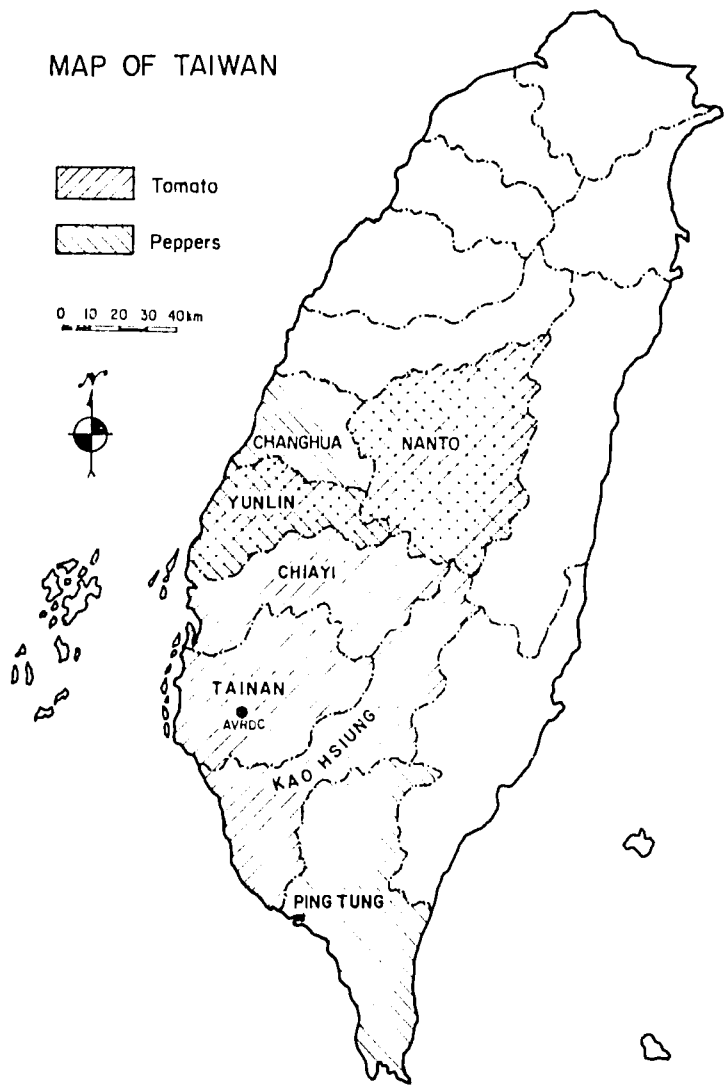

Figure 1. The major production areas of tomato and pepper in Taiwan, 1987.

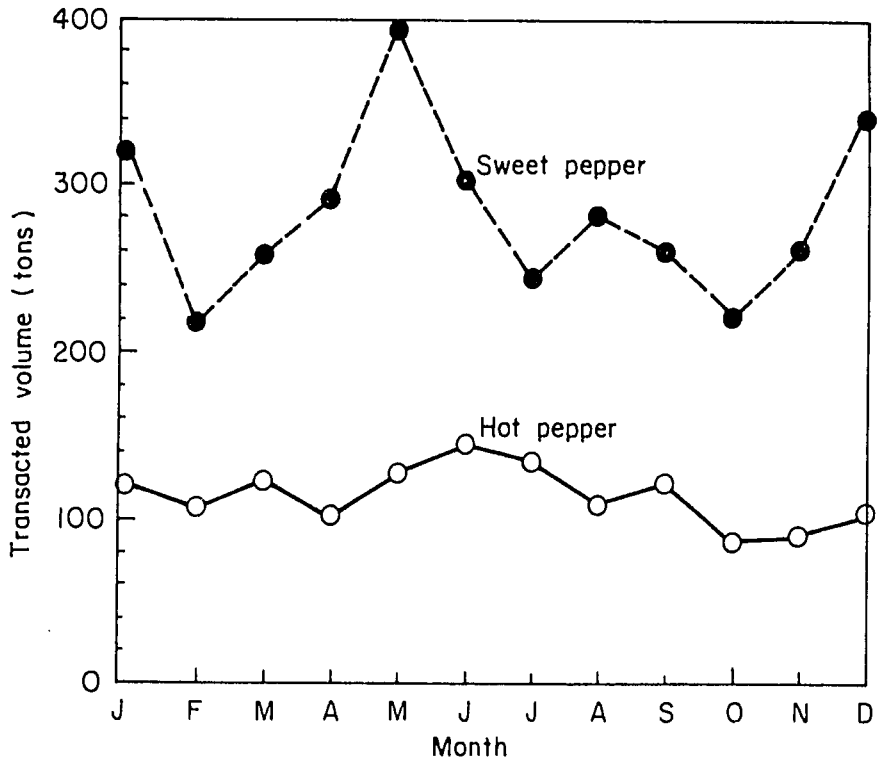

Figure 2. Average monthly transaction volumes of sweet and hot peppers in Taipei city, 1983-87.

Constraints

Diseases and pests. Phytophthora blight (*Phytophthora capsici*) attacks roots, stems, leaves and fruit during the hot and humid summer season. The disease is controlled by application of Terrazole on seedlings. Bacterial leaf spot (*Xanthomonas campestris* pv. *vesicatoria*) attacks leaves, stems and fruit also in summer. No practical control measures are recommended. Several viruses such as TMV, PVY, CMV, CVMV and others have been detected year-round in Taiwan. There are no local varieties resistant to these viruses. Chemical seed treatments are recommended to eliminate seed-borne TMV.

Mites are serious from October to March and thrips from May to October. Several pesticides have been recommended for control such as Rotenone, Furadan, Kelthane, etc.

Tomato

Production and Varieties

The combined hectarage for processing and fresh market tomatoes was 9,682 ha with a total yield of 396,201 t in 1986 (Table 4). Most tomato is grown in the central and southern parts of Taiwan (Figure 1): Changhua (442 ha); Chiayi, Yunlin, and Tainan (5,743 ha, processing tomato is produced mainly in these areas); Kaohsiung (1,505 ha); Pingtung (151 ha, mainly

for F_1 hybrid seed production). The suitable period for the cultivation of tomato is from September to April, because of the cool and dry environments (Table 5). They are usually transplanted after the second crop of rice during October-November, or at the same time when the first rice crop is planted in February. From May to September the fresh market type tomato is grown in highland areas, such as Yangmin Mountain (Taipei county) and Hsingyi (Nanto county, 246 ha). Hence fresh market tomato is available year-round in the market with a significant seasonal fluctuation (Lai et al. in the proceedings). The production of processing tomato is contracted between farmers and processing factories and produced only during November-April. The average yield and the per kg price have remained stable since 1982. The production cost was about 0.05 US$/kg in 1986, and it is composed of cost of materials (25%), labor (62.1%) and others (12.9%).

Table 4. Acreage and yield of tomato (fresh market and processing types) in Taiwan, 1978-86.

Year	Area planted (ha)	Average yield (kg ha)	Total yield (t)
1978	8,781	25,136	220,719
1979	9,126	26,629	230,019
1980	10,947	30,075	329,232
1981	8,567	23,734	203,188
1982	10,450	31,685	331,106
1983	12,248	39,389	480,945
1984	12,394	51,741	641,127
1985	11,212	43,181	483,756
1986	9,682	42,591	396,201

Source: Taiwan Agriculture Year Book, 1987

Table 5. Average temperature and rainfall in the main pepper and tomato production areas.

Month	Chiayi county		Tainan county		Pingtung county	
	Temperature (°C)	Rainfall (mm)	Temperature (°C)	Rainfall (mm)	Temperature (°C)	Rainfall (mm)
January*	14.5	32.1	15.7	25.3	18.2	6.3
February*	14.8	52.2	15.7	58.6	18.5	26.6
March	18.7	52.2	19.8	53.2	22.1	81.6
April	23.8	1.6	25.0	0.2	26.4	13.4
May	25.2	351.5	26.0	330.4	26.8	363.8
June	27.6	187.3	27.7	620.1	28.1	624.7
July	28.6	100.3	29.1	121.9	29.0	90.7
August	28.3	361.8	28.4	170.3	28.5	431.9
September*	26.6	226.2	27.1	149.2	27.7	189.5
October*	24.0	2.4	25.8	0.7	26.2	57.3
November*	20.4	40.8	23.2	55.2	24.2	20.9
December*	17.3	18.6	19.5	3.7	20.5	2.6

Source: Taiwan Agriculture Year Book, 1987. *Indicates the cultivation period.

The varieties cultivated in Taiwan and their main characteristics are shown in Table 6. Seeds of fresh market tomato are supplied by seed companies and seeds for processing tomato are supplied by the contracted factories. Most seeds, including those generated from F_1 hybrids and open pollination, are produced in southern Taiwan. A small amount of processing tomato seed is imported from Japan. Their cultural management is summarized in Table 7.

Table 6. Tomato varieties cultivated in Taiwan.

Cultivars	Main characteristics	Origin
Fresh market types		
Known-You 301	F_1 round fruit, nematode resistance	Known-You Seed Co.
Black Persimmon	OP[z], round fruit	Local
Taichung #3	OP, pink color, round fruit	Taichung DAIS[y]
T.S.S. #1	F_1 globe fruit, heat tolerance, bacterial wilt resistance	Taiwan Seed Service
Vanguard	F_1 round fruit, heat tolerance bacterial wilt resistance	Known-You Seed Co.
Sugar Pear	F_1 small fruit, Fusarium wilt resistance	Known-You Seed Co.
Processing types		
Tainan Selection #2	Square round fruit, firm, Fusarium wilt resistance	AVRDC
Kagome 70	Oblate fruit, dwarf plant, Fusarium wilt resistance	Kagome Co., Japan
UC 82	Square round fruit, firm	Univ. of California
Tainan Selection #3	Globe fruit, heat and bacterial wilt tolerance, TMV and nematode resistance	AVRDC
Known-You 112	F_1 oblong fruit, 90 g, Fusarium wilt tolerance	Known-You Seed Co.
Known-You 209	F_1 pear fruit dwarf plant, Fusarium and Verticillium wilt tolerance	Known-You Seed Co.

[z]OP = open pollinated. [y]DAIS = District Agricultural Improvement Center

Table 7. Cultivation practices of fresh market and processing type tomato.

Item	Fresh market tomato	Processing tomato
Area planted (ha)	5,380	4,302
Production (t)	231,340	277,800
Yield (t/ha)	43.0	64.6
Cultivars	Known-You 301 (Chang-Hua)[z] Black Persimmon (Yunlin)[z] Black Persimmon (Chiai)[z] T.S.S. No. 1 (Nanto)[z]	Kagome 70 (Tainan)[z] Known-You 112 (Tainan)[z] Tainan 2 (Yunlin)[z]
Sowing/Spacing	Seedling beds 1.5 m wide plots, 2 rows 0.45 m between plants	Seedling beds 1.2 m wide plots, 1 row 0.40 m between plants
Density	30,000 plants/ha	18,000 plants/ha
Staking	Bamboo	No
Cultural practices	Tying, pruning and weeding	Weeding
Irrigation	Ditch system, once 10-15 days	Ditch system, once 14-21 days
Harvest	Pink stage, hand picked, and classified	Full color mature, hand picked, and classified into 2 grades
Transport	Paper carton	Plastic container
Fertilizer	N:P:K = 150:120:210 kg/ha 3-4 side dressings	N:P:K = 160:130:150 kg/ha 1-2 side dressings
Harvest	Oct.-June (Changhua)[z] Oct.-June (Yunlin)[z] Oct.-June (Chiayi)[z] June-Sept. (Nanto)[z]	Nov.-April (Tainan)[z] Nov.-April (Yunlin)[z] & Chiayi

[z]Area where planted.

Utilization

Fresh tomato is sold directly in the local markets. In addition to its use as a vegetable, it is consumed as a fresh fruit. Processing tomatoes are canned into paste (54.3%), whole fruit (22.6%), pieces (18%) and others (slices, juice and sauce; 5.1%). Most of the canned products are exported.

Constraints

Diseases and pests. The three most serious diseases are bacterial wilt caused by *Pseudomonas solanacearum*, bacterial leaf spot caused by *Xanthomonas campestris* pv. *vesicatoria* and virus diseases.

Incidence of bacterial wilt can be as high as 100% in summer production. Control measures include crop rotation with paddy rice and the use of resistant varieties.

Bacterial leaf spot infects leaves and fruit causing a decline in quality and yield during the rainy season from March to August. Chemical control is not effective. A resistance breeding program has been initiated at the Taiwan Seed Improvement and Propagation Station.

TMV, CMV, and PVY occur year-round. TMV is controlled by planting resistant varieties such as Tainan No. 3 and by prevention of seed-borne inoculum through heat treatment of seeds at 78°C for 48 before sowing.

Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopercisi* race 2) occurs in the warm season. No resistant commercial variety has been developed locally. The disease is controlled by decreasing the fungus population in the soil through rotation with paddy rice and by treatment of the seeds with protective fungicides such as benomyl.

Late blight (*Phytophthora infestans*) occurs, usually from autumn to early spring, primarily on processing tomato. It is controlled by spraying Daconil or Ridomil-MZ at weekly intervals.

Early blight (*Alternaria solani*) occurs in the spring season. It is not a serious disease and can be controlled by spraying with Kocide 101.

Rootknot nematode (*Meloidogyne incognita*) is serious in the dry area and controlled by planting resistant varieties such as Tainan No. 3.

Leaf mold (*Fulvia fulva*) occurs in the warm and wet season and attacks stems, and leaves. It is controlled effectively by Maneb.

Damping off (*Pythium* spp.) infects young seedlings and is controlled by sterilizing the seed bed with Mylone or methyl bromide.

Fruitworm (*Heliothis zea*) attacks stems, leaves and fruit year-round. Lannate is recommended for its control. Cutworm (*Agrotis ipsilon*) attacks tomato year-round it is controlled by Furadan.

High labor cost. Due to the sharp increase in labor cost, the hectarage in processing tomato has declined from 8,541 ha in 1984 to 4,290 ha in 1987.

Pepper and Tomato

Production of F_1 Hybrid Seeds

The F_1 hybrid seed production of pepper and tomato is an important agricultural business with high economic value in Taiwan. Besides local use, a major proportion of F_1 seeds produced are exported to Europe, the USA and Japan every year. The production is mainly in southern Taiwan from September to February. For commercial F_1 hybrid seed production for export, the parental lines are usually supplied to the contracted farmers by the foreign seed companies. The yield is around 250 and 200 kg/ha for pepper and tomato, respectively. However, there is substantial variation in yields due to the unstable environmental conditions. The F_1 seeds are inspected by government agencies before being sent to foreign seed companies through the trading companies in Taiwan. However, because of recent sharp increases in labor costs and the dramatic

appreciation of the local currency against major international ones, F_1 seed production has declined during the last two years.

Marketing

Marketing of fresh pepper and tomato depends on the supply and demand in wholesale outlets. The products are usually transported from the field to the market by individual farmers or by farmers cooperatives. Distribution is mostly through retailers, and also through supermarket chains to the consumers (Figure 3). The market and production prices for these two crops are shown in Table 8. The quantity and value of fresh pepper and tomato exports are shown in Table 9.

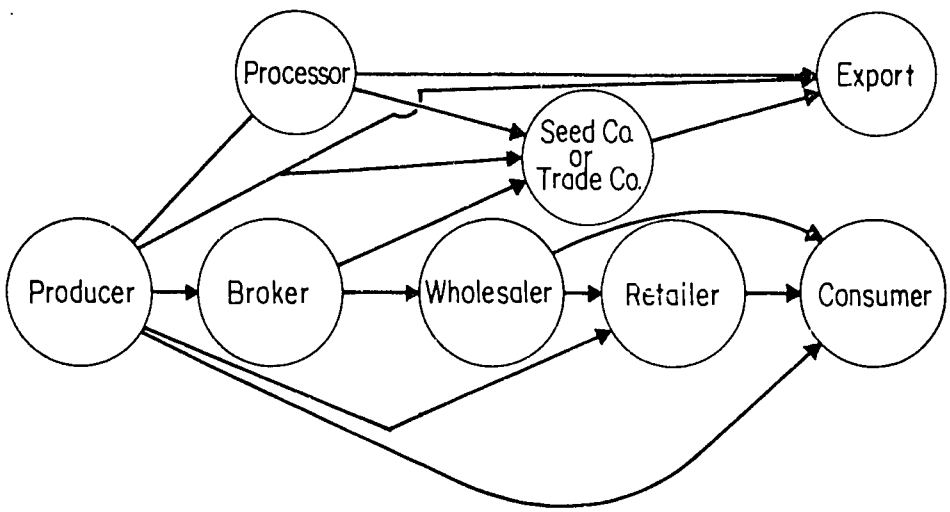

Figure 3. Tomato and pepper marketing.

Table 8. Farm and city market prices for fresh pepper and tomato.

Year	Tomato		Pepper	
	Farm price (US$/kg)	Market price (US$/kg)	Farm price (US$/kg)	Market price (US$/kg)
1984	0.30	0.84	0.51	1.09
1985	0.29	0.89	0.54	1.37
1986	0.43	1.19	0.57	1.66
1987	0.31	1.11	0.64	1.67

Source: Taiwan fruit and vegetable marketing corporation.

Table 9. Export of fresh pepper and tomato.

Year	Tomato		Pepper	
	Quantity (kg)	Value (US$)	Quantity (kg)	Value (US$)
1981	5,495,220	–	195,930	–
1982	11,198,742	834,602	1,035,092	192,434
1983	11,495,834	1,523,406	2,087,724	704,718
1984	13,780,246	1,799,369	1,595,314	926,286
1985	9,917,414	934,785	1,832,784	768,684
1986	8,752,885	932,088	1,283,747	482,727

Source: Taiwan Vegetable and Fruit Export Association.

Canned tomato products are mainly exported to the USA, Japan and Canada through processing factories or trading companies. The production, export quantity and value of canned tomato are shown in Table 10. The factories contract the farmers through farmer associations or brokers. The contracted hectarage and raw materials are in accordance to the predicted yield before the beginning of the season. The production and volume under contracts for canned tomato from 1984 to 1987 are shown in Table 11.

Table 10. Production, export quantity and value of canned tomato.

Year	Production (standard case)	Export (standard case)	Export value (US$)
1985	4,175	4,044	60,019
1986	2,508	2,430	40,377
1987	2,376	2,107	40,842

Source: Division of special crops, PDAF.

Table 11. Contract production of processing tomato, 1984-87.

Year	Contracted factory (no.)	Contracted township (no.)	Transaction volume (t)	Price under contract (NT$/kg)[z]	
				1st grade	2nd grade
1984	27	37	630955	1.8	1.4
1985	25	32	340579	1.8	1.4
1986	17	31	383603	1.8	1.4
1987	16	28	277784	1.8	1.4

Source: Division of Special Crops, PDAF. [z]US$1 = NT$40 before 1987; US$1 = NT$28.6 at present.

Research and Development

Research on pepper and tomato in Taiwan has focused on the varietal improvement for heat tolerance and disease resistance (TMV, bacterial wilt, bacterial leaf spot and rootknot nematode). Tomato varieties have been released with combined resistance to bacterial wilt, TMV, rootknot nematodes, and resistance to Phytophthora root rot. Several sweet pepper lines with resistance to Phytophthora root rot have been identified and the traits have been incorporated into commercial cultivars. However, virus problems have become more serious during the last few years and deserve high priority in research to alleviate these constraints.

Increasingly, efforts are also going to develop labor-saving techniques for tomato and pepper production, especially the mechanical harvester for processing tomato, to relieve the constraint caused by high labor costs.

Most pepper and tomato research is supported by the government. In 1988, the government provided about US$ 155 133 to support extension and research efforts on these two crops (Table 12).

Table 12. Government support for production and research on pepper and tomato.

Year	Extension (US$)	Research (US$)	Total (US$)
1984	39,166	55,533	94,699
1985	100,000	74,500	174,500
1986	100,000	73,800	173,800
1987	112,667	57,133	169,800
1988	46,000	109,133	155,133

Source: Horticulture Production Division, COA.

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48

The Contribution of AVRDC Tomatoes in Taiwan, China

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Abstract

Tomato (*Lycopersicon esculentum* Mill.) is an important cash crop in Taiwan. The processing type is produced mainly during the cool season in the central-southern region. The fresh market type is produced throughout most of the year all over the island, except that it needs to be grown in the highlands during the summer season. AVRDC breeding lines and management techniques are tested under Taiwan's varied physical and biological environments through a collaborative program with national institutes. Reduction in the production costs of processing tomato, and off-season production of fresh-market tomato, are the main objectives of this cooperative project. Genetic improvement of uniformity of maturity, and incorporation of multiple disease resistance into processing tomato lines, have been exploited to reduce the production cost. CL 1561-6-0-5-1-3, released in 1982 as Tainan selection No. 2, was the first processing line from AVRDC to be released to Taiwan tomato growers. This line has the special attributes of firm fruits, uniform maturity, and high yield potential; thus, the number of harvests per crop was reduced from the traditional 5-7 to 2-3. A heat-tolerant AVRDC hybrid, PT 3027, was released in 1986 as Tainan Selection No. 3. This hybrid has the potential to prolong the processing season in Taiwan. It is also resistant to bacterial wilt, tomato mosaic virus, and nematode, and can be more readily adopted in different cropping systems. The progress made under this cooperative program has formed a solid fundamental mechanism for future progress. The fresh-market tomato is consumed mainly as a fresh fruit in Taiwan, and the preferred type is apple-shaped, with dark red skin and green shoulders, and is sweet, and large in size. Production during the summer season is limited, due to the lack of arable land in the mountainous areas. Combining local preferences with the characteristics of AVRDC lines, such as heat tolerance and disease resistance, may lead to a breakthrough in the production pattern of summer tomato in Taiwan. Although significant progress has been made in both breeding and management techniques at AVRDC, further improvement is needed in order to make lowland tomato production during the summer season profitable in Taiwan.

Introduction

Taiwan is an island situated about 160 km from the south-eastern coast of Mainland China, lying between latitudes 21°53'N and 25°18'N. It has an oceanic subtropical climate with a long and hot summer, and a short and mild winter (Figure 1). The rainfall is abundant, varying from 1700 to 2000 mm a year on the plain, and 3000 to 4000 in the mountain areas (Kuo, 1978). Most of the rainfall occurs during summer, except in the northern part of the island where it is more evenly distributed year-round. There are distinct wet and dry seasons in the central and southern parts (Figure 2).

Tomato (*Lycopersicon esculentum* Mill.) is an important cash crop in Taiwan. The area planted to it has stayed above 10,000 hectares during recent years (Table 1). However, being

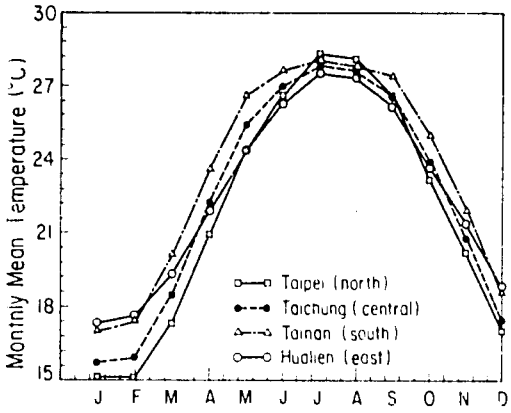

Figure 1. Temperatures in different regions of Taiwan.

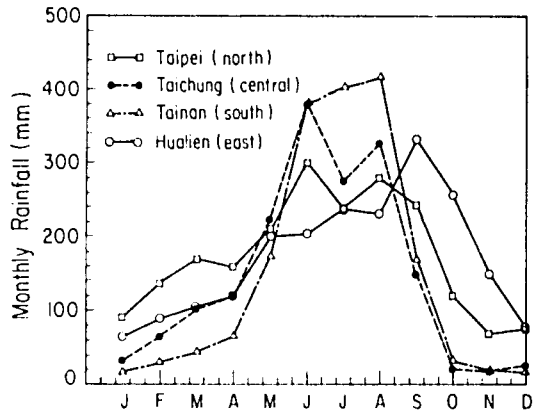

Figure 2. Rainfall distribution in different regions of Taiwan.

Table 1. Tomato production in Taiwan, 1979-84.

	Acreage (1000 ha)			Production (1000 t)		
Year	Total	Processing	Fresh-market	Total	Processing	Fresh-market
1979	9.1	5.9	3.2	450	365	85
1980	10.9	7.9	3.0	582	491	91
1981	8.5	4.5	4.0	370	274	96
1982	10.5	5.3	5.2	541	378	163
1983	12.2	7.7	4.5	549	370	179
1984	12.4	8.5	3.9	830	631	199

Source: Lai. 1986

limited by high temperature, the main production season of tomato is from December to April. The processing tomato in particular is grown only in the central-southern region where there is a cool and dry winter. The fresh-market tomato is produced year-round in the highlands during the summer season. However, there is a significant seasonal fluctuation in supply and price (Figure 3), due to the lack of arable land in the highlands and high labor costs.

Beside poor fruit-setting in high temperature environments (Kuo et al. 1979), there are other major constraints affecting tomato production in Taiwan. The important constraints are bacterial wilt (*Pseudomonas solanacearum*), viruses, nematodes (*Meloidogyne* spp.), and bacterial leaf spot (*Xanthomonas campestris* pv. *vesicatoria*) during the warm summer; leaf mold (*Fulvia fulva*), and late blight (*Phytophthora infestans*) during the cool winter; and leaf mold, viruses, and early blight (*Alternaria solani*) during spring. The hot humid conditions also affect fruit quality, by causing, for example, poor color, cracking, and sunburn (Lai. 1986).

The development of heat-tolerant and disease-resistant tomato varieties is considered by the national program as the most promising way to relieve these production constraints. The other strategy is to develop or introduce economic and effective management techniques to secure good yield and fruit quality.

The interaction between AVRDC and the national institutes in Taiwan is mainly through the AVRDC-Taiwan cooperative program known as 'On-Station Testing'. Among its objectives are to identify AVRDC's improved breeding lines and cultural practices which are appropriate for Taiwan, and to test them under Taiwan's varied physical and biological environments, through cooperative research projects between AVRDC and local research institutes (Table 2). AVRDC's promising tomato lines are recommended for entry to Regional Yield Trials (RYT) in Taiwan

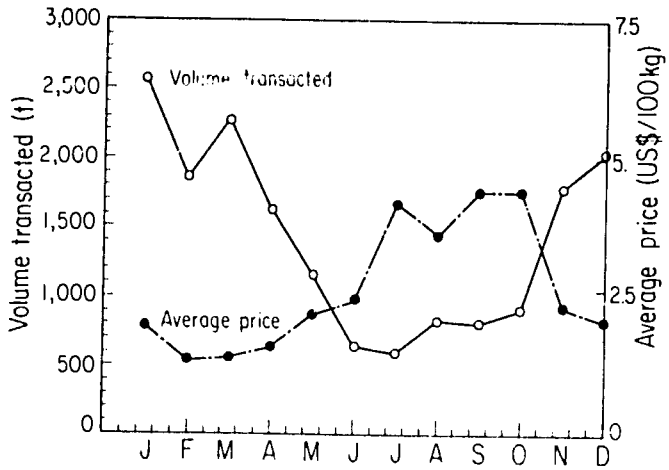

Figure 3.
Monthly transaction volume and mean price of tomato in the Taipei wholesale market, 1985. (TAPMC. 1986)

Table 2. Number of cooperative yield trials between institutes in Taiwan and AVRDC, 1979-87.

Crop	Year									
	1979	1980	1981	1982	1983	1984	1985	1986	1987	Total
Soybean		29	31	31	33	37	39	38	40	278
Vegetable soybean					14	13	12	8	1	48
Mungbean		8	22	13	17	8	8	10	9	95
Chinese cabbage			3	7	7	7	8	8	8	48
Sweet potato		5	7			8	7	6	6	39
Tomato										
Processing tomato	18	12	4	9	9	9	9	6	9	85
Fresh-market tomato				5	6	6	6	6	7	36
Cherry type tomato						2	2			
Sweet pepper								3	4	7
Snap bean								3	4	7
Radish								2	3	5
Total	18	54	67	65	88	90	89	90	91	652

for testing. These trials are carried out as cooperative projects between AVRDC and local research institutes, such as District Agricultural Improvement Stations (DAIS), and are conducted across the island every year. Meanwhile, new management techniques developed at AVRDC for growing tomato in the humid season are demonstrated and extended to local farmers by the national programs (DAIS or Farmers' Associations) with the assistance of the AVRDC outreach program in Taiwan.

This paper discusses mainly the considerations made when recommending AVRDC tomato lines and the contributions of these lines to tomato production in Taiwan. Some of the management techniques for summer tomato developed at AVRDC are also briefly reported.

The Processing Tomato Industry

The production of processing tomato in Taiwan is mainly for export (Table 3). It is essential to keep the production cost competitive with other major exporting countries. The industry successfully maintained annual export sales of two to four million standard cases with a production

Table 3. Export, production cost and contracted price of processing tomato in Taiwan, 1981-86.

Year	Production (Std. case)	Export (Std. case)	Production cost (US$/100 kg)	Contracted price (US$/100 kg)	
				1st gr.	2nd gr.
1981	2,504,010	2,066,914	3.50	4.00	3.00
1982	2,643,250	2,790,942	3.70	4.50	3.50
1983	2,468,068	2,475,929	3.70	4.50	3.50
1984	4,173,500	4,044,225	2.90	4.50	3.50
1985	2,508,912	2,434,925	3.50	4.50	3.50
1986	2,376,600	2,107,783	4.11	5.07	3.94

Source: Taiwan Canners' Association 1987, and Lai 1987

cost of around US$3.70/100 kg, and a contracted price of US$4.50/100 kg for first grade fruits between 1982 and 1986 (Table 3). The key factor which determines the future of the processing tomato industry will be how to reduce the production cost and yet maintain a stable and high yield with acceptable quality. Analyses of production costs have revealed that labor costs account for 60% of the total production cost. Half of this cost was spent on harvest because of the lack of uniformly maturing cultivars and because five to seven harvests per crop are required (PDAF, 1982). Reduction of harvest labor, thus becomes the first priority for technology development. Mechanical harvesting is the obvious direction in the future. In addition to the high labor cost, Taiwan has also suffered from: (a) having only one major cultivar, Kagome 70 (TK 70), which has little heat tolerance; and (b) a short and concentrated production season. Thus, the utilization of processing facilities has not been economical (Lai and Hwang, 1988). Research in the past has therefore aimed at enhancing yield, maintaining quality, extending the production season, and reducing labor use to improve the processing tomato industry.

AVRDC lines with better vine-keeping qualities were selected for a two-year RYT program starting in 1979. Three planting seasons were conducted per year. Promising lines were then subjected to district trials for one year. A line, 1561-6-0-5-1-3, was released as Tainan Selection No. 2 (TN 2) in 1982 because of its high yield, firm fruits (Table 4), good color (Figure 4), and relatively uniform maturity. It was observed that fewer harvests were needed for TN 2 because its firm fruits can stay longer on the vine than most other varieties. Better vine-keeping quality also provides ample time for the adequate development of fruit color, since the pigment accumulation in tomato is a function of temperature and time, and is additive and commutative (Thorne and Alvarez, 1982). With the extension of this line, the number of harvests per crop was reduced from the traditional 5-7 to 2-3. As a result, the harvested amount per man-hour was increased, and the labor requirement for harvesting was reduced. According to the report from the Provincial Department of Agriculture and Forestry (PDAF), the average harvest labor per hectare was reduced from 1162 manhours in 1982 to 589 manhours in 1983. Release of TN 2 might has made a significant contribution to this statistic. This new introduction was able to keep the Taiwan tomato processing industry competitive, and compensated for the sharp increase in field labor wages in recent years (Table 5). However, TN 2 does not carry the other important characteristics needed by the processing industry, such as heat tolerance and resistance to bacterial wilt and nematodes.

An F_1 hybrid, PT 3027, was released as Tainan No. 3 (TN 3) in 1986 for its high-yielding characteristics, its heat tolerance (Table 6), and its resistance to bacterial wilt, tomato mosaic virus (ToMV) and nematodes (Lin et al. 1985). Tomato mosaic virus is a major constraint for tomato production in Taiwan. Results from a survey on naturally occurring ToMV on tomato in Taiwan by AVRDC showed an infection rate of 30-70%, depending on locations and seasons (Lin et al. 1985). Rootknot nematode, which is especially a problem when tomato is grown after sugarcane, can reduce yields by up to 32% (AVRDC, 1985). Sugarcane is an important crop in Taiwan, and processing tomato is often intercropped or rotated with it in southern Taiwan.

Table 4. Firmness of some processing tomato varieties.

Varieties	Firmness (cm)[z]
CL 1651-6-0-5-1-3 (TN2)	1.55
UC 134	1.73
P 933	1.75
PT 3027 (TN3)	2.12
TK 18	2.66
TK 70	2.86

[z]Firmness was measured by Rheometer (Model FUDOH) with a sample probe No 3-15, and is expressed as the deformation distance (cm) when press pressure reached 500 g cm^2

Table 5. Yield and labor use for harvesting and average harvest rate of processing tomato in Taiwan, 1981-86.

Year	Yield (t ha)	Labor use (man-h ha)	Harvest rate (kg man-h)	Labor cost (US$ man-h)	Labor cost (US$ ha)
1981	70.2	1152	61	25	29,044
1982	74.2	1162	64	28	32,146
1983	50.9	589	86	40	40,228
1984	82.1	737	111	44	32,460
1985	68.0	640	106	44	28,020
1986	70.9	686	103	51	35,150

Source PDAF, 1982-1987

Table 6. Yield of tomatoes at AVRDC, late summer 1985.[z]

Lines	Yield (t ha)
PT 3027 (TN3)	23.5 a
CL 1651-6-0-5-1-3 (TN2)	1.6 b
TK 70	2.1 b

[z]Transplanted on 6 August 1985

Bacterial wilt is a serious problem during Taiwan's warm season. Resistance to bacterial wilt is an essential character for heat-tolerant tomatoes grown during the summer. All these pathogens are difficult to control by chemical means, and resistance is the most effective control. Thus, the F_1 hybrid TN 3 consistently yielded higher than TN 2 and TK 70 in RYTs, not only during the warm season but also over a wide range of environments (Figure 5). This F_1 hybrid has potentially extended the tomato processing season in Taiwan by at least two months, from October to May. However, its soluble solid content, a character closely related to tomato quality, is lower than that of the other two entries (Figure 6).

Processing tomato production in Taiwan has been declining since 1984 (Table 7), due to the increment in production costs, especially brought about by the dramatic appreciation of the local currency against major international ones, such as the US dollar, since 1986. This has resulted in a higher production cost than in many other major exporting countries (Table 8), especially because of the high labor costs in harvesting (Table 9). It appears that mechanical harvesting is necessary to enable the processing tomato industry in Taiwan to compete with other countries. The combination of all traits, namely heat tolerance, good firmness, uniform maturity for once-over harvest, good color, high soluble solid content, and resistance to diseases into a single processing cultivar is needed. In addition, studies on cultural management, cropping systems, the relationship of farm size and the efficiency of the harvester, the planning methods for planting areas and schedules, and the unloading, cleaning, and sorting systems in the factory are important for high and constant efficiency in processing tomato production.

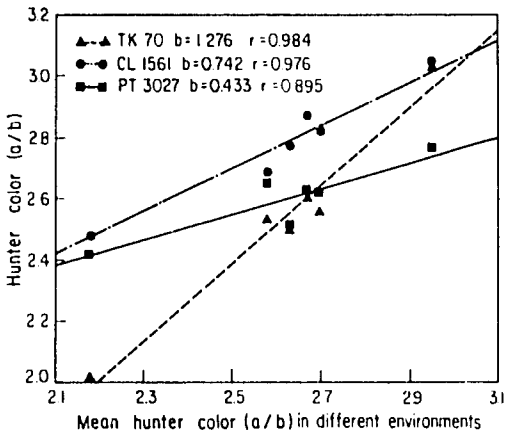

Figure 4.
The response in color of processing tomatoes to growing environments (mean of five entries: Pt 3027, PT 1600, TM 103, TK 70, and CL 1561) in Taiwan, summer 1985.

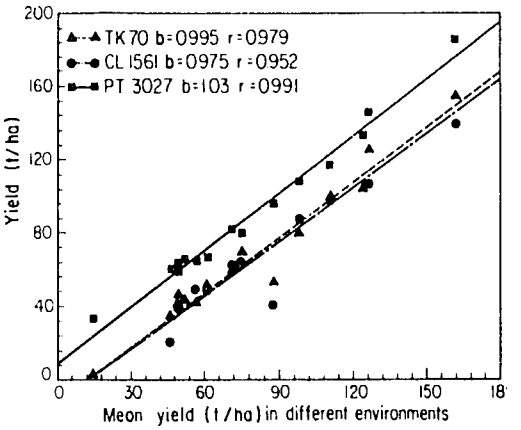

Figure 5.
The response in yield of processing tomatoes to growth environments (mean of five entries: Pt 3027, PT 1600, TM 103, TK 70, and CL 1561) in Taiwan, summer 1985.

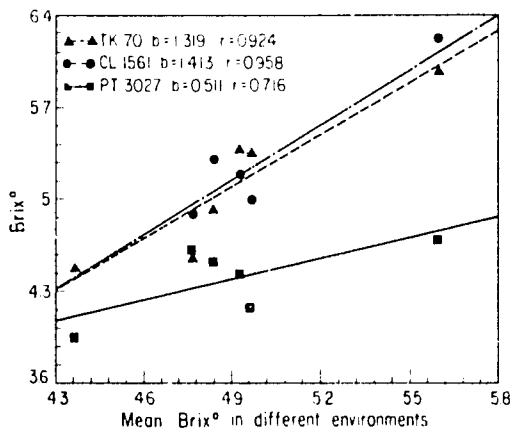

Figure 6.
The response in soluble solid content of processing tomatoes to growing environments (mean of five entries: Pt 3027, PT 1600, TM 103, TK 70, and CL 1561) in Taiwan, summer 1985.

Table 7. Acreage and production of processing tomato in Taiwan, 1984-88.

Year	Acreage (ha)	Production (t)
1984	8,541	630,955
1985	6,213	362,479
1986	5,993	383,603
1987	4,290	277,784
1988	3,449	206,930*

Source: Lai and Hwang. 1988. *Estimated figure.

Table 8. Price of processing tomato in the major production countries, 1986.

Country	Price (US$/100 kg)[z]
California (USA)	4.84
Italy	9.09
Greece	8.56
France	9.09
Spain	5.72
Portugal	5.26
Israel	5.79
Turkey	3.02
Taiwan, China	6.32

Source: Lai and Hwang, 1988. [z]Exchange rate: 1 US$ = 28.5 NT$.

Table 9. Production cost of processing tomato in Taiwan and in California, USA.

Item	Cost (US$/ha)		Percentage	
	Taiwan	USA	Taiwan	USA
Material and management	1,770	2,148	48.7	64.2
Harvest and transport	1,363	733	37.5	21.9
Others	502	463	13.8	13.9
Total	3,635	3,344	100	100

Source: Lai and Hwang, 1988.

Fresh-market Tomato Production in Summer

In Taiwan, a major proportion of fresh-market tomato is consumed as a fresh fruit without post-harvest ripening. In the Ilan, Taoyuan, Hualien and Taichung areas, consumers prefer apple-shaped, large (about 100 grams per fruit) and sweet tomatoes, with pink skin whereas fruits with dark red skin and green shoulders are preferred in other areas. As mentioned earlier, tomato is not suitable for cultivation during the hot humid summer on the plains. The fresh-market tomato production in summer is mainly in the highlands with an altitude over 500 m. However, the total production from June to October is low, compared to other seasons, because of the scarcity of arable land and competition with other crops in the highlands. Although the rate of tomato to total vegetable transaction volume during summer months (July-October) increased from 1979 to 1985 (Figure 7), and the relative price of tomatoes over the same period was reduced (Figure 8), the increase in volume was not great, and the strong seasonal fluctuation in supply is still significant. It appears that the development of tomato varieties suitable for summer conditions on the plain will be a breakthrough for fresh-market tomato production in Taiwan.

The genetic improvement of the tomato for tropical areas was initiated by AVRDC and is one of AVRDC's major missions since 1973. The most important breeding targets were heat tolerance and bacterial wilt resistance. The local preferences, in fruit size and skin color of the fresh-market type were not considered in the AVRDC's breeding program in the past. Thus the previous efforts have not made a significant contribution to summer tomato production in Taiwan so far. However, the selection for large-fruited lines has been started and some progress has been achieved. With the combination of large fruit size, heat tolerance, and bacterial wilt resistance, significant contributions to fresh-market tomato production in Taiwan may be expected in the near future.

Attempts were also made at AVRDC to improve cultural management practices so that the constraints on producing large-fruited fresh-market tomatoes during the hot humid season in Taiwan could be reduced. The types of crop management research that have been carried out are briefly discussed below.

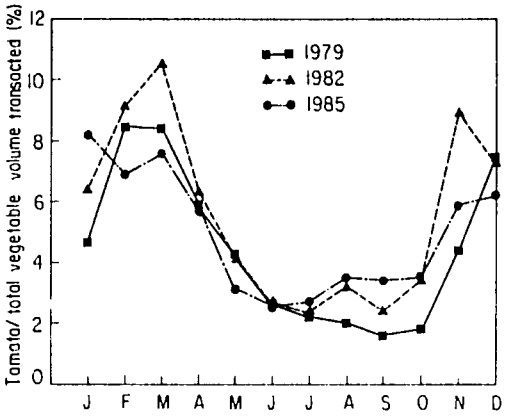

Figure 7. Contribution of tomato to total vegetable transaction volume in the Taipei wholesale market. (TAPMC. 1980, 1983 and 1986)

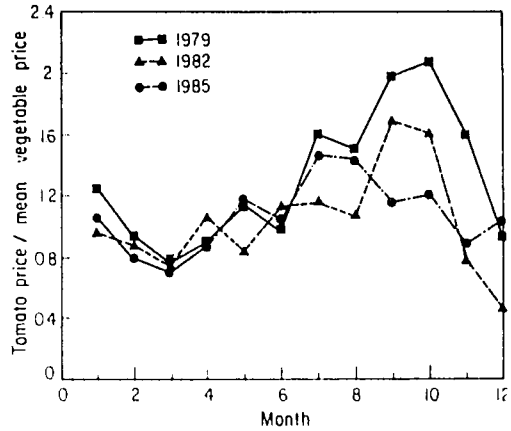

Figure 8. The rate of monthly average price of tomato to all vegetables in Taipei wholesale market. (TAPMC. 1980, 1983, and 1986)

Tomato Cultivation on a High Bed

Results showed that 70-cm-high raised beds with a clear plastic roof effectively minimized southern blight (*Sclerotium rolfsii*) in the summer cultivation of tomato. Tomato fruit yield (4.6 kg/plant) on the high beds was four times more than that (1.2 kg/plant) on low beds (AVRDC. 1987a).

Advanced Cultural Practices for Summer Tomato Production

A series of experiments using different cultural practices such as staking, the use of different-sized seedling pots, and drip irrigation techniques, were carried out on tomato varieties of varying fruit sizes during the 1986 summer season. The main findings were as follows:

1. The fruit size of large fruited cultivars was greatly affected by cultural practices and size was easily decreased under such undesirable environments as low light intensity, flooding and nutrient deficiency. Small-fruited tomatoes were not similarly affected.
2. Staking for summer tomato production is very important, and 'framing' (Figure 9) not only increased the fruit size of FMTT 4 significantly, but also protected the large-fruited tomato from lodging.
3. The high pot planting method, in which seeds were sown in a PVC pipe (10 cm × 12 cm) filled with seedling media, and seedlings were then transplanted by pushing the pipe down about 2 cm into the soil of the bed to avoid flooding, increased the yield of the large-fruited tomato in a summer cultivation.
4. Large-fruited cultivars, FMTT 4 and PT 4032, when protected from rain damage under clear plastic sheets and properly provided with both water and nutrients by drip irrigation, produced nearly 2 kg of fruits per plant within two months after transplanting. Both cultivars produced only 0.4 to 0.85 kg/plant in the open field during the same period. Average fruit size of FMTT 4 and PT 4032 exceeded 135 and 120 grams respectively, whereas those from the field were at most, 60 to 70 g.

It was concluded that timely irrigation, successive application of nutrients, and cultural practices to keep roots active throughout the growth period are primarily important in the summer cultivation of large-fruited tomato (AVRDC. 1987b).

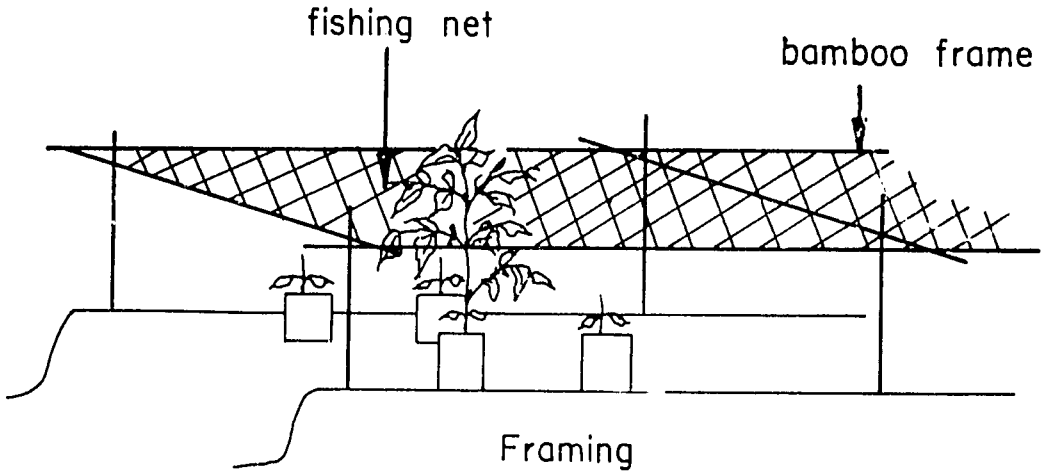

Figure 9. The 'framing' staking method for summer tomato cultivation.

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442

49

Hot Pepper and Tomato Production and Research in Ethiopia

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Abstract

Hot pepper and tomato are important vegetable crops, extensively grown in most parts of Ethiopia. Hot pepper is a vegetable and a spice crop of significant economic value. It is estimated that state farms plant 5,000 ha per season, while the small farmers' sector grows 200,000 ha and produces 100,000 t. The average yield is about 400 kg/ha. Average daily consumption per capita is approximately 15 g. Bakolocal and Marekofana are two local varieties extensively grown in the country. Both small farmers' and state farms raise young seedlings in the nursery and transplant them to the field. Most of the hot pepper is grown under rainfed conditions. The cost of production in the farmers' fields is estimated at US$376.12/ha and US$232.37/t, and in large farms at US$278.60/ha and US$1,020.29/t. The major production constraints include lack of disease and insect-resistant varieties, inadequate management of nursery beds and fields, diseases (bacterial blight, bacterial leafspot, viruses), insects (African bollworm and termites) and weeds. Research programs are underway to identify the most productive varieties that are also resistant to important diseases and insects, and to select the most efficient cultural practices, and the most appropriate crop protection and management schedules.

Tomato is an important vegetable crop, of greatest importance in the processing industry. It can be grown in most parts of the country if irrigation is practiced during the dry season. On large farms, an average yield of 7.7 t/ha of fresh fruit can be obtained. The cost of production is estimated at US$1,258.45/ha. Net profit is estimated to be US$5,251.21/ha.

The low level of yield and quality of the produce under commercial cultivation, the occurrence of frost at high altitudes, diseases such as Septoria leafspot and late blight, rootknot nematodes, pests like the African bollworm, the tobacco whitefly, aphids, the tomato erinose mite, potato tuber moth, and the parasitic weed *Orobanche* spp. are the principal factors limiting production.

Introduction

Ethiopia is situated in East Africa between 3° and 18° north latitude and 33° and 48° east longitude. The country has several distinct agro-ecological regions and ranges in elevation from 100 m below mean sea level to 4,550 m above. More than a third of the country lies above 1,800 meters. Rainfall varies from 2,550 mm in the highlands to 200 mm in the dry areas in the east and south. In recent years the country has experienced marked fluctuations in the total rainfall and in its normal seasonal distribution. Because of the varied climatic conditions a wide variety of cereal, legume and horticultural crops, both indigenous and introduced, are grown. Among the horticultural crops, hot pepper and tomato are important vegetable crops, extensively

grown in most parts of the country. Table 1 highlights the climatic data of the major production areas for tomato and pepper. While tomato is predominantly grown by the state farms and farmers' co-operatives, hot pepper is largely produced by small farmers. Sweet green pepper is only produced in some pockets of the country and is largely exported to Djibouti; local demand is rather limited. Statistics on the level of production and the volume of exports are not available (Hailemichael, 1969).

In order to meet the increasing domestic needs and to step up exports, research on these two crops was started 20 years ago to develop or select more productive varieties and to identify relevant crop production and protection management practices. This paper summarizes the current status of production, major production constraints and significant research results, based on the investigations carried out on these two crops at the Institute of Agricultural Research (IAR).

Table 1. Climatic data of the major production areas of tomato and pepper (Station:Bako).[z]

Month	Rainfall (mm)		Air temperature (°C) Minimum		Air temperature (°C) Maximum		Relative humidity R.H. (%)	
	1986	1961-85	1986	1961-85	1986	1961-85	1986	1980-85
January	6.1	(12.4)[y]	10.6	(10.4)	29.9	(29.6)	49.0	(50)
February	2.8	(17.7)	12.0	(12.0)	29.1	(30.7)	61.0	(41)
March	43.2	(46.8)	13.9	(13.9)	30.8	(31.3)	61.1	(52)
April	90.8	(59.9)	14.4	(14.7)	28.3	(30.9)	87.4	(51)
May	41.8	(153.9)	17.7	(14.8)	29.9	(28.7)	43.0	(64)
June	385.1	(195.1)	15.6	(14.4)	23.6	(26.0)	72.5	(72)
July	202.6	(257.1)	14.9	(14.1)	22.4	(23.6)	82.4	(78)
August	174.6	(219.1)	15.2	(4.0)	23.1	(24.1)	77.1	(79)
September	154.3	(139.9)	14.0	(13.4)	22.2	(25.3)	76.0	(77)
October	24.0	(65.0)	12.0	(11.9)	25.7	(27.8)	63.0	(62)
November	1.3	(27.1)	11.0	(10.5)	29.4	(28.3)	52.6	(59)
December	15.9	(12.3)	10.9	(9.4)	29.8	(28.9)	64.9	(53)
Total	1,147.9	(1206.3)						
Mean			13.5	(12.8)	27.0	(27.9)	65.8	(61.5)

Source: Institute of Agricultural Research Agro-Meteorological Service. Summary of meteorological data. [z]Longitude 37°5'E; Latitude: 9°08'N; Altitude: 1,650 m. [y]Values between brackets are averages.

Hot Pepper

Current Production and Consumption Status

Hot pepper (*Capsicum frutescens* L.), locally known as 'barbare', is both a vegetable and a spice crop of significant economic value to Ethiopia. Although it is important in the traditional diet, it is not indigenous to Ethiopia and was probably introduced to East Africa and Ethiopia by the Portuguese. There are many varieties of hot pepper grown in the country (Huffnagel, 1961), ranging from very long and broad types (length 16 cm, width 2.46 cm) to very small (2 cm length) and pungent types. The former are more extensively grown (Hailemichael, 1969). The major part of the growing area is located between 1,400 and 2,120 m (Sitti district). These regions have an average temperature range of 21° to 29°C, and soils are sandy loam to clay loam with high soil moisture retention capacity.

Local demand is largely met by small farmers. More recently state farms have also begun to cultivate hot pepper on an extensive scale; however, their yields are lower than the national average (Jackson, 1987). It is estimated that each season the state farms grow hot pepper on about 5000 ha, while the small-farming sector occupies an area of 200,000 ha and produces

100,000 tons (Jackson. 1987). The available production statistics for the period 1963-64 to 1970-71 show a steady increase in production and a marginal annual increase of 3,000 ha in the production area (Table 2). The average yield during this period was estimated at 0.4 t/ha.

The majority of the hot pepper is consumed locally as an important spice to yield the desired color, flavor and pungency in the everyday culinary preparation called 'wat'. For an average Ethiopian, a large part of the vitamin C intake comes from hot pepper, made available through 'wat', which also includes other spices. The average daily consumption of hot pepper by an Ethiopian adult is estimated at about 15 g. Thus, hot pepper is considered a food rather than a spice alone (Huffnagel. 1961). Fully mature green fruits are also used in salad and are popular Ethiopian appetizers.

Table 2. Production of hot pepper in Ethiopia 1963/64 to 1970/71.

Season	Area (ha)	Production (t)	Yield (t/ha)
1963/64	221,000	88,400	0.4
1964/65	224,500	89,800	0.4
1965/66	227,500	93,300	0.4
1966/67	230,000	94,300	0.4
1967/68	233,200	95,600	0.4
1968/69	236,500	97,300	0.4
1969/70	239,900	99,500	0.4
1970/71	243,200	102,200	0.4

Source: Jackson. 1987.

Cropping Systems and Cultural Practices

Hot pepper is predominantly grown as a monocrop and is rotated with other cereal or leguminous crops. It is mostly grown as a rainfed crop. The traditional method involves raising seedlings in nursery plots, about 2 m^2, fertilized with decomposed cattle manure. Seeds are densely broadcast, usually by the end of April, and are later mulched with grass straw and irrigated. With the emergence of the seedlings, the straw mulch is removed. The nursery is cultivated, weeded and irrigated. Four to-six-week-old seedlings are transplanted to the field in early to mid-June. The foremost factor in determining the date of transplanting is the availability of adequate moisture for establishing the seedlings. All regular field operations like weeding and cultivation are manual. Most farmers hand harvest the fruits after these are dry in the field; only a few farmers harvest after the pods have changed color but are still succulent. Harvesting, which is completed in two stages in most regions of the country, is usually undertaken from November to December. No staking is practiced in hot pepper production.

Large farms generally follow the practices of small farms except that their nursery plots are sown in rows 20 cm apart, and young seedlings are transplanted to the field until row-to-row and plant-to-plant spacings of 80 and 40 cm, respectively. Fully grown plants they will reach 70 to 80 cm. Commercial fertilizers and pesticides are used in the nursery plots as well as in the field to increase productivity and to protect the crop from diseases and insect pests.

Marketing and Processing

No comprehensive marketing survey for hot pepper has been undertaken in Ethiopia. Both green pods and dried whole or broken pods are also sold in the local market.

The produce from farmers or state farms is distributed by wholesalers, retailers and sometimes is directly marketed to consumers. Wholesalers sell to the spice extraction factory for oleoresin production and also to consumers. The dried pods are packed in bags and transported by donkeys or cars.

The price of hot pepper varies considerably from year to year depending upon the amount of production and on local demand. Traditional marketing practices result in high storage and distribution costs and lead to deterioration of the produce. Following harvests in December, most households purchase adequate quantities of hot pepper to meet their annual needs and process it along with other spices to make their own specific spice powder. An average family in Ethiopia annually uses one 'farasulla' (17.5 kg) costing US$19.32 (based on 1984-85 prices) for first-grade pepper (Jackson, 1987).

Oleoresin is the principal product made from hot pepper by the Ethiopian spice extraction factory; it is exported to the USA, Japan and the Federal Republic of Germany (Jackson, 1987). The amount of hot pepper pods purchased and oleoresin exported after processing during 1982-83 to 1986-87 is recorded in Table 3. Dried whole pods have also been exported at times. Statistics on the volume of exports made during 1977 to 1981 represent the minimum level of the country (Table 4).

Table 3. Hot pepper (whole dried pod) purchased and oleoresin exported 1982/86 to 1986/87.

Season	Dried pepper purchased (t)	Production of crude oleoresin (t)	Price/t (US$)
1982/83	1,180	10	906.76
1983/84	405	12	925.60
1984/85	1,551	80	912.56
1985/86	2,641	110	1,211.59
1986/87	2,934	128	1,128.99

Source: Unpublished data gathered from the Ethiopian Spice Extraction Factory.

Table 4. Export of whole dry hot pepper 1977-1981.

Region	1977		1978		1979		1980		1981	
	Volume (t)	Value (US$)	Volume (t)	Value (US$)	Volume (t)	Value (US$)	Volume (t)	Value (US$)	Volume (t)	Value (US$)
Middle East	6	2,415	2	966	16	33,333	145	341,545	430	759,420
Europe	476	177,778	0.1	145	1,080	428,019	0.1	193	33	35,266
Africa	15	5,797	-	-	-	-	-	-	-	-
Total	496	185,990	2.1	1,111	1,096	461,352	146	341,739	464	794,686

Source: Jackson, 1987.

Varieties Grown

Varieties with long and broad pods have been widely grown for the past 10 years to meet the local demand. The Institute of Agricultural Research (IAR) has recommended the cultivation of two distinctly different varieties. Bakolocal and Marekofana are two high-yielding varieties widely grown on large farms and to a limited extent by small farmers. The pod size of Bakolocal is 1.47 cm in width by 11.6 cm length, and pod color is light red. The pod size of Marekofana is 2.46 cm in width by 10.66 cm length with conical pod shape and dark red pod. Although Marekofana has the desired color it is a lower yielder than Bakolocal which lacks the deep red color. In yield tests conducted at research centers these varieties have shown a yield potential of 1.5 to 2.0 t/ha of dried pod. There is no data for fresh pod yield. The Bako Research Center has been supplying the seed of these varieties to farmers and state farms.

Major Production Constraints

Production of hot pepper in Ethiopia is increasing steadily; however, the full potential of the crop has not been exploited commercially for the various reasons considered below.

Diseases, insects and weeds. The major diseases affecting hot pepper include stem blight (*Phytophthora* spp.), bacterial leafspot (*Xanthomonas campestris* pv. *vesicatoria*), powdery mildew (*Leveillula taurica*), bacterial wilt (*Pseudomonas solanacearum*) and virus diseases such as tobacco mosaic virus, potato virus Y, leaf curl virus and Ethiopian mottle virus (Agranovsky, 1986; Tesfaye and Habtu, 1986). The major insects on hot pepper are the African bollworm (*Heliothis armigera*), termites (*Microtermes* spp.) and the tomato erinose mite (*Aceria lycopersici*) (Tsedeke, 1986). The major weeds are *Nicandra physalodes* (L.) Gaertner, *Galinsoga parviflora* Cav., *Datura stramonium* L., *Amaranthus hybridus* L., *Commelina benghalensis* L., *Cyperus* spp., *Ageratum conyzoides* L., *Eleusine indica* (L.) Gaertner, *Celosia trigyna* L., *Sorghum* spp., *Guizotia scabra*, and *Argemone mexicana* L. (Etagegnehu and Ahmed, 1986). Adequate control measures have not yet been developed. The two widely grown varieties Bakolocal and Marekofana are susceptible to leaf curl virus and other diseases and to some insects. Thus, under conditions favorable to the development of disease, the productivity of the crop drops sharply.

Lack of quality seed. Ethiopia does not have any well organized seed production or distribution program for hot pepper. Farmers collect their own seeds or they buy their seed from the market, where the supply in general is of open-pedigree stocks. Frequently, seeds from both bleached and healthy pods are extracted and mixed.

Inadequate preparation of nursery and fields. It is not unusual to see poor nursery plots, with weak seedlings, often already affected by diseases or insects. Most farmers prefer to grow the nursery plots close to their dwellings, which are often far away from major water sources. For this reason they cannot produce good healthy seedlings in sufficient number for transplanting at the most desirable time. As the time needed for management of nursery and other farming operations overlaps, the nursery plots are often improperly and inadequately looked after. Transplanting is often delayed and seedlings grow too tall, particularly when the rains come late and there is not enough moisture in the soil. To realize full yield potential of the variety the seedlings must be ready for transplanting before the onset of heavy rain, which in turn calls for raising them in the nursery plots with irrigation.

Inadequate information on fertilizer use. To obtain high productivity it is necessary to apply the optimum amount of balanced fertilizer in the nursery and in the field. This optimum is site specific and depends on various factors. In the absence of precise information, and if fertilizer is not available, the nutritional needs of the crop may not be fully met. This becomes an impediment in realizing full yield potential of the crop.

Lack of an efficient postharvest technology. Since production of hot pepper is still dominated by small farmers, little or nothing has changed from the traditional practices of harvesting, drying, handling and transport of the crop to the market (Jackson, 1987). Harvest is undertaken after all the pods have split or burnt, and drying is usually accomplished on flat areas that are not clean. The pods also break when they are packed in bags. Moreover, lack of proper transportation and poor storage conditions adversely affect the quality of the produce.

Inadequate marketing facilities. Produce is often not brought to the market immediately after harvest owing to lack of adequate transport. Pods are sometimes left uncovered or piled in bags in the field after harvest. Prolonged sun drying causes bleaching and also decreases weight. There are no purchasing centers at strategic points close to the production areas.

Inadequate technology transfer. Improved varieties and crop management practices have been developed at the research center. However, in the past these have not reached the producers because of poor liaison between research and extension and between extension and producers. Recently the Institute of Agricultural Research has addressed this problem by establishing research and extension linkage (REL) divisions at its major research centers. Substantial progress could be achieved in the dissemination of improved varieties and improved agricultural technologies.

Research Highlights

Varietal development. Researchers and producers have collected local hot pepper types and introduced different cultivars from abroad. Evaluation and selection have been carried out in different agro-ecological zones to identify varieties adapted to the local environmental conditions.

The most promising varieties were evaluated for four years at the Bako Research Center and at testing sites at Didessa and Gute. Santaka gave the highest yield, followed by Bakolocal and Marekofana. Bakolocal yielded the most pods, followed by Santaka (Godfrey-Sam-Aggrey and Yosef. 1987; Yosef and Yayeh. 1988). Santaka, with very small pods and poor consumer acceptance, was not recommended for commercial cultivation.

Management practices. A four-year trial was conducted to determine the optimum sowing date for hot pepper production. It was concluded that adequate soil moisture availability should be the prerequisite for sowing seed rather than calendar date (Godfrey-Sam-Aggrey and Yosef. 1987).

Plant population density studies have been carried out for four years with Bakolocal and Marekofana varieties. For Bako and similar areas, a spacing of 70 × 30 cm (48,000 plants/ha), and for Didessa and other similar areas a spacing of 60 × 20 cm (83,000 plants/ha), were recommended for the Bakolocal variety. Likewise for the Marekofana variety a spacing of 60 × 30 cm (56,000 plants/ha) and of 60 × 20 cm (83,000 plants/ha) was found to give highest yield at Bako and Didessa respectively (Yosef and Yayeh. 1988). The effect of different seed rates on seedling vigor, establishment and yield was also studied. The highest number of healthy seedlings was obtained from the highest seed rate. However seedlings were smaller in size, paler in color, taller and less suitable for transplanting compared with those obtained from plots using a low seed rate. More vigorous seedlings with dark green leaves were obtained from plots sown at lower seed rates. However, no significant difference in marketable and total yield was observed (Godfrey-Sam-Aggrey and Yosef. 1987). Practically, the use of 0.75 to 1 kg/ha of seed has been recommended (Yosef and Yayeh. 1988).

Diseases and insects cause considerable loss every year. Experiments have been carried out to seek control measures for the major pests.

For the control of powdery mildew (*Leveillula taurica*), triadimefon (25% WP), Denmert (19 EC), Kumulan (80% WP) and thiophanate-methyl (70% WP) were reported to be effective (Tesfaye and Habtu. 1986). For stem blight (*Phytophthora* spp.) metalaxyl-montozed at 3.5 kg/ha was effective (Tesfaye and Habtu. 1986). For bacterial leafspot (*Xanthomonas campestris* pv. *vesicatoria*), seed dressing with chlorox or trisodium phosphate in combination with Ceresan was found effective (Tadesse. 1986).

Deltamethrin, cypermethrin and endosulfan were effective against African bollworm (ABW) (*Heliothis armigera* [Hb.]). Yield loss due to ABW damage ranged from 0.2% to 26.7% (Tsedeke. 1986). Investigations on the use of trap crops against ABW also showed that when two or three rows of lupin (*Lupinus albus*) were planted at a 5 m distance from a field of hot pepper, the lupin attracted 4 to 18 times as many insects as the hot pepper (Abraham and Tsedeke. 1987). To control termite, root dips in aldrin 40% WP at the rate of 200 g/10 l of water is recommended (Tsedeke. 1986). Various rates of N and P were tested for four consecutive years on the two local varieties on red soil at Bako and Didessa. At both locations significant response to N was recorded. Maximum marketable yield was achieved by applying 100 kg N/ha and 100 kg P_2O_5 /ha (Soil Fertility Division Progress Report 1985/86. unpublished).

Economics and marketing. In small farmers' fields, production costs average US$376/ha or US$232/t. Labor accounts for 67% of the cost; 54% of the labor is used to control weeds by hoeing and hand-weeding. With an average price of US$797.10, the net return per hectare is approximately US$924.70.

For large-scale managed farms the average cost of production, based on a four-year study, was US$278.60/ha or US$1,020.29/t. At the sale price of US$1,207.72/t, the gross return

per hectare was US$329.71 which was US$51.10 above the direct cost of production in farmers' fields (Getahun, 1986, unpublished). The cost of production of basic seed multiplication is estimated at US$730.80/ha or US$703.33/t. Around 59% of the cost is labor, 21% for machinery and 20% for material inputs. The cost of raising the seedlings on the seedbeds was US$30.52/ha.

Hot pepper is a labor intensive crop. With better management, increase in yield and profit is possible in Ethiopia (Getahun, 1986, unpublished). No systematic study has been undertaken in Ethiopia on marketing of hot pepper. No research on utilization and processing of hot pepper has yet been conducted.

There are no externally funded projects on hot pepper and its production in Ethiopia. Research on the crop is conducted mainly by the Institute of Agricultural Research.

Future Research Trends

The following areas need to be addressed in the future:

1. Introduction and evaluation of cultivars of *Capsicum* spp. for desirable horticultural characteristics, pest and disease resistance high oleoresin content, and for growth in the different agro-ecological zones.
2. Breeding and selection for desirable characteristics, utilizing elite germplasm sources.
3. Cultural practices for the selected elite cultivars for different agro-ecological zones.
4. Control measures against major insect pests and diseases.
5. Postharvest technologies.

Tomato

Current Production, Consumption and Costs

Precise information on the history of tomato in Ethiopia is not available. Unlike hot pepper, local types have not evolved or been developed. However, a 'wild' plant type with small fruit is at times seen in parts of the country. Tomato ranks the foremost among vegetables in the processing industry (IAR, 1986). Tomatoes are grown all over the country up to an elevation of 2,000 m. The temperature range in the regions of tomato cultivation is around 21°-29°C.

Definite statistics relating to the area occupied by this vegetable in the small-farming sector are not available; however, information on the area planted to tomato and on yields is presented in Table 5. Current yields of the fresh fruit are about 7.7 t/ha (national average yield). However, potential exists for realizing a yield of 20 t/ha.

Table 5. Tomato production in Ethiopia.

Year	Nura-Era State farm			Melge Wondo State farm			Elabert State farm		
	Area (ha)	Yield (t/ha)	Total yield (t)	Area (ha)	Yield (t/ha)	Total yield (t)	Area (ha)	Yield (t/ha)	Total yield (t)
1982	175	7.7	1,342	–	–	–	50	20	1,000
1983	331	7.7	2,565	–	–	–	50	20	1,000
1984	550	17.5	9,625	244	20	4,880	50	20	1,000
1985	1,045	21.5	22,512	244	20	4,880	50	20	1,000

Source: Heussler and Ayele 1987.

Small farmers cultivate nondescript varieties, while the state farms widely grow Roma VF. Both small farmers and state farms practice transplanting of 4-6 week-old seedlings raised in small nursery plots. While the small farmers mostly use manure in the nursery and field, the

state farms apply fertilizers. Plants are frequently staked to avoid direct contact between fruit and the soil, and to avoid rotting. With irrigation, tomatoes can be successfully grown in most parts of the country during the dry season. Furrow irrigation is frequently followed (IAR, 1986).

The produce of small farmers is directly marketed as a fresh vegetable in the local markets as well as in metropolitan areas like Addis Ababa, Asmara, and Dire Dawa. The produce from the large state farms is sent directly to three processing plants, which are located in the major tomato-producing areas. Canned tomatoes and other products are marketed locally, as well as exported. Tomatoes regularly form a part of the daily diet, eaten raw as a salad or cooked together with vegetables or pulses. It is interesting to note that this recently introduced crop has found a unique position in the diet of the average Ethiopian.

The cost of production is estimated at US$1,258.45/ha. This includes the cost of nursery operations (nursery seedbed preparation, seeding, watering and weeding) field preparation, transplanting, irrigation, cultivation, training, spraying and harvest operation. Training of plants (including cost of materials), and spraying contribute 36% and 29%, respectively, towards the cost of production. The estimated net profit is US$5,251.21/ha (Zemedu et al. 1969).

Production Constraints

In view of the low yield and quality of the varieties under commercial cultivation, the processing plants find it difficult to fully recover production costs at prices that can be paid by the factories without losing their competitiveness. According to accepted international standards, a soluble solids content of 5° Brix is desirable for processing; however, the total soluble solids content of the commonly grown processing varieties is below 5° Brix (Heussler and Ayelle, 1987).

At high altitudes frost occurs in the months of November to February and limits tomato production (Hailemichael, 1969).

The most prevalent diseases are Septoria leafspot and late blight (Tesfaye and Habtu, 1986) the incidence of both can be reduced by the application of 0.2% captafol combined with 0.23% Ridomil at seven-day intervals (Tesfaye and Habtu, 1986). Maneb (1 tablespoon/l) gives good control of late blight. The African bollworm (*Heliothis armigera*), the tobacco whitefly (*Bemisia tabaci*), several species of aphids, the tomato erinose mite (*Aceria lycopersici*) and the potato tuber moth (*Phthorimaea operculella*), are the most important insect pests of tomato in the country (Tsedeke, 1986). Rootknot nematodes and the parasitic weed *Orobanche* spp. are additional menaces to the successful cultivation of tomato.

Research Highlights

Many tomato cultivars have been introduced and evaluated for yield, disease and insect pest resistance under natural infestation in different agro-ecological zones in the country. Rossel VFN, Pearson AL, Heinz 1370, Money Maker, Marglobe, Glamour, Napoli VF and Tropic performed well and gave high marketable yields (Godfrey-Sam-Aggrey et al. 1987; Hailemichael, 1969).

The time of sowing and different plant spacings of 10, 20, 30 and 40 cm within rows, and spacings of 80, 100, 120 and 140 cm between rows using the variety Heinz-1350, were investigated. August to February sowings were found to give the highest yields (Godfrey-Sam-Aggrey et al. 1987). Closer within-row and between-row spacing gave the least number of sun-scorched fruit. Generally, the number of unmarketable fruits increased as within-row spacing of plants decreased and between-row spacing increased. Increasing the plant population density did not necessarily increase tomato yield but shaded the fruit against direct sunlight (Godfrey-Sam-Aggrey et al. 1987).

An observational replicated trial was carried out to assess staking and single-stem pruning using the indeterminate cultivars Heinz 1350 and Heinz 2274 at spacings of 100 × 45 cm (staked plants) and 150 × 30 cm (unstaked plants). Pruning resulted in severe reduction of yield in

all cultivars. Staking the indeterminate cultivar Money Maker increased yield by 6 t/ha. Heinz 1350 showed an increase of 6.5 t when staked, while Heinz 2274 benefited only from a 17% reduction in the percentage of unmarketable fruits (Godfrey-Sam-Aggrey et al. 1987).

In an experiment conducted at Alemaya, it was noted that the cultivar Glamour, pruned to three stems and staked, gave better yield than unpruned plants. Incidence of bird damage and physiological defects such as sunburn and cracking of fruits were, however, more pronounced in pruned and staked tomatoes (Hailemichael. 1969).

The effect of straw mulching of unstaked tomatoes was studied. Yield was not increased nor was the percentage of unmarketable fruit reduced (Godfrey-Sam-Aggrey et al. 1987).

Direct sowing and transplanting was also investigated. Directly sown plots could be harvested eight days earlier than the transplanted plot and gave significantly higher total yield; however they required more irrigation. Sun-scorching of fruits was higher in transplanted plots (Godfrey-Sam-Aggrey et al. 1987).

Research on tomato production in Ethiopia is not receiving any foreign funding.

Future Research Trends

1. Introduction of foreign tropical tomato germplasm and evaluation for yield, disease and pest tolerance under rainfed and irrigated conditions.
2. Establishment of suitable agronomic practices for the selected cultivars.
3. Study of quality and postharvest handling of selected cultivars.
4. Study of major biotic constraints and means for their control.

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452

50

Present Status of Tomato and Pepper Production in India

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Abstract

Tomato is one of the most widely grown vegetable crops in India and has become popular within the last six decades. It occupies an area of 82,000 ha, with a total production of 802, 000 t and an average yield of 9.78 t/ha. Pusa Ruby, Roma, HS 101, Pusa Early Dwarf, Punjab Chhuhara, Punjab Kesri, Arka Vikas, Arka Saurabh, and Co-3 are open-pollinated varieties which are widely grown, and Karnataka Hybrid, Mangla, Rupali and Vaishali are widely grown hybrids. Tomato is prone to diseases such as damping off, Fusarium wilt, bacterial wilt, early blight, late blight, buckeye rot, Septoria leafspot, leaf curl virus, and tobacco mosaic virus. The important pests are fruitborer, jassids, aphids, and rootknot nematodes.

Hot pepper or chili is an important commercial crop in India occupying an area of 891,800 ha with an annual production of 677,300 t of dry chilies. About two percent of the total production is exported to foreign countries. Sweet pepper production is confined mainly to hilly tracts of the country. The fruits are used mainly for culinary purposes. The most important hot pepper varieties are K1, G2, Pusa Jwala, NP-46, Pant C1, Punjab Lal; the most important sweet pepper cultivars are California Wonder and Bharat, a new F_1 hybrid. The most common diseases of pepper are damping off, anthracnose, early blight, bacterial leafspot and viral diseases such as TMV, CMV, PVY and leaf curl virus. Among the most important pests are aphids, cutworms, white ants, thrips, and mites.

Seeds of both crops are available from the State Government, the National Seeds Corporation, the agricultural universities, and private seed companies.

Tomato

Tomato (*Lycopersicon esculentum* L.) is one of the most widely grown vegetable crops in India (Table 1) and has become popular within the last six decades. It is grown in farm gardens, small home gardens and market gardens for fresh consumption as well as for processing purposes. Tomato occupies an area of over 82,000 ha, with a total production of 802,000 t and an average yield of 9.78 t/ha (Anon. 1985). It is consumed raw, cooked, or processed as catsup and sauce.

Climate of Production Areas

Climatic conditions vary in the different regions of India. The central, western, eastern and southern parts of India exhibit tropical conditions. Parts of north India, the northwest and northeast, fall into the subtropical zone. In southern and western India, the weather is mild throughout the year. On the other hand in north India, the hilly areas experience heavy snowfall during winter months, while the plains are subjected to frost. During summer, the hilly areas are cooler than the plains where the temperature often exceeds 45°C.

Cultivation Practices

The sowing time for tomato varies in the different regions of the country (Table 2). It is grown on practically all soils from light sandy soils to heavy clay. The application of farmyard manure varies from 15 to 25 t/ha. Application of commercial fertilizers varies and ranges from 50 to 120 kg N/ha, 25 to 60 kg P/ha and 25 to 40 kg K/ha. Total P and K along with half of N are applied at the time of transplanting. The remaining half of N is applied in one or two split doses as top dressing. In the northern plains the spring/summer crop is protected from frost by covering the plants either with polyethylene bags or dry grass. This covering is removed in mid-February when the danger of frost is over.

Table 1. Total area, production and average yield of some important vegetable crops in India.

	Area ('000 ha)	Yield (kg/ha)	Production ('000 t)
1 Potato	853	14815	12642
2 Chilies (dry)	781	775	605
3 Onion (dry)	269	10599	2855
4 Cauliflower	92	7377	675
5 Peas	92	2826	260
6 Tomato	82	9780	802
7 Cabbage	81	6040	490
8 Garlic	79	3723	293
9 Beans (green)	21	2143	45

Source: Anonymous 1985

Table 2. Growing periods of tomato in the different regions of India.

Region	Growing periods	Temperature range (°C) (min-max)	Rainfall range (mm)
Tropical Areas			
Southern region		20-37	6-308
Andhra Pradesh, Karnataka, Kerala and Tamil Nadu	June/July-September/October October/November-February/March June-March (Tamil Nadu)		
Central region		10-40	3-428
Madhya Pradesh	January-June June-December		
Eastern region		12-36	3-250
Central Uttar Pradesh, Bihar and West Bengal	September/October-March/April		
Western region		12-40	0.3-162
Maharashtra, Gujarat	September/October March/April		
Subtropical Areas			
Northwest region		6-40	0.3-271
Punjab, Haryana, Rajasthan and parts of western Uttar Pradesh	July-November October/November- May/June		
Hilly regions		3.5-35	35-105
Jammu and Kashmir, and Himachal Pradesh	March/April-August/September		

The staking of tomato plants has proved to be beneficial in the southern and western regions where indeterminate varieties are grown because of their long growing and fruiting season, whereas in the northern plains mostly determinate varieties are grown because of their short fruit-setting period. The pruning and training of plants has not become popular due to inconsistent results at various places and because of the cost involved.

Marketing and Processing

The stage of maturity at which tomatoes are picked depends on the purpose for which they are grown and the distance over which they are to be transported. The Indian Standards Institute has specified four grades: Super A, Super, Fancy and Commercial utilization (Choudhury, 1977). However the grading of tomatoes is undertaken to a limited extent only for the specialized city markets.

Almost all the produce which matures during the early seasons of the year is sold fresh in the city markets at very high prices. Since the climatic conditions vary in the different parts of the country, the fruit is transported by truck to distant markets where it fetches higher prices. During the peak season when the price is low, a limited proportion of the produce is processed by government bodies and private industry.

Cultivars and Seed Supply

A number of varieties which have been released at the national level by the Central Research Committee are being grown in the different parts of the country (Table 3). The important hybrids are Karnataka Hybrid, Rupali, Vaishali, SG-12, SG-28, among others. The seeds of the various varieties are supplied by agricultural universities, state agriculture departments, the National Seeds Corporation and State Seeds Corporations. Almost all hybrids have been developed by private seed companies which are the only seed suppliers for hybrid varieties. However, no complete information neither on the total number of seed companies in the country, nor on their selling volume, is currently available.

Utilization

Most of the produce is consumed fresh. Because of the high cost of processing, the common processed products like catsup, sauce and so on fetch at high prices and are thus purchased by only a small section of the society.

Foreign Trade

Tomato fruits are not exported. Some of the private seed companies in India (some of which are multinational organizations), utilize the cheap labor available in the country to produce seed of various hybrids and varieties which is then exported to other countries. However, detailed information is not available on this activity.

Major Constraints

The crop is prone to many diseases caused by fungi, bacteria, viruses and rootknot nematodes. Most of the varieties grown are susceptible to diseases and insect pests, and erratic yields are common. The most important pest and diseases affecting tomato in India, and the control measures used to counter them, are listed below:

Damping off (*Rhizoctonia* spp., *Phytophthora* or *Pythium* spp.). Losses of up to 100% have been reported (Kalloo, 1986). Control measures are sterilization of nursery soil by formalin, or seed treatment with protective fungicides such as Captan or Thiram.

Table 3. List of tomato varieties released at the national/state level and which are grown in the different regions of India.

Variety	Source	Year of release	Varietal characteristics
Punjab Tropic	Punjab Agricultural University (PAU), Ludhiana	1971	Indeterminate, vigorous and abundant foliage. Fruits large, round, attractive with somewhat green stem end, red at maturity, less seedy with a good blend of acidity and sugars, suitable for marketing fresh and for juice making, matures late. Average yield 60 t/ha.
Pusa Ruby	Indian Agricultural Research Institute (IARI), New Delhi	1975	Plant height 80-85 cm, indeterminate growth habit, spreading, less-branched and hardy. Fruits flat, round, small to medium, uniform, deep red, slightly lobed (4-5 locules), slightly acidic, 25-30 fruits per plant. Early maturing variety, 60-65 days. Suitable for autumn and spring-summer seasons in plains. Good for juice and catsup. Average yield 33 t/ha.
H.S. 101	Haryana Agricultural University (HAU), Hissar	1975	Plant height 50 cm, dwarf multibranched, sturdy and determinate in growth habit. Fruits in clusters of 2-3, round small to medium in size, 3-4 locules. Fruits ripe uniformly, 40-50 fruits per plant. Average yield 25 t/ha.
S-12	Punjab Agricultural University (PAU), Ludhiana	1975	Plants are dwarf, bushy, vigorous, fruits are medium-sized, compressed round. Uniformly colored red at maturity, juicy, highly acidic. Suitable for marketing fresh for the table. Average yield 45 t/ha.
Sel-120	IARI, New Delhi	1975	Semideterminate, spreading type, foliage dark green, fruits attractive, round to flattish round, medium to large in size, smooth, uniform, red in color, less acidic and less seeded. Resistant to nematodes. Suitable for summer production.
T-1	GB Pant University Agricultural and Technology, Pantnagar	1975	Plant height 100-120 cm, erect and of indeterminate in growth habit, foliage green in color. Fruit round, slightly pointed at the stigmatic end, 4-5 locules, non-cracking, red on ripening.
Sweet-72	Gwalior	1975	Plants determinate type, fruit flattish round, green stem end, slightly furrowed. Uniform maturity.
Pusa Early Dwarf	IARI, New Delhi	1975	Plant typical dwarf, 50-55 cm in height with determinate growth habit. Fruit round, slightly flattish, medium large, uniform red, ribbed. Maturity 55-60 days after transplanting. Suitable for rainy season in plains. Average yield 39.5 t/ha.
Punjab-Kesri	PAU, Ludhiana	1978	A sister variety of Punjab Chhuhara. Fruits oval Kesri round, firm, thick-walled, usually trilocular, juicy, sour and seedy. Very good for juice making. Average yield 70 t/ha.

Table 3. Continued.

Variety	Source	Year of release	Varietal characteristics
Punjab Chhuhara	PAU, Ludhiana	1981	Plants determinate dwarf, bushy, dense and luxuriant foliage. Fruits medium-sized, pear-shaped, firm, fleshy, usually bilocular, less seedy, less sour, thick-walled, uniform colored, red at maturity, retain marketable quality for a week after harvesting under ordinary conditions during summer. Suitable for long transportation. Average yield 75 t ha.
Pusa Gaurav (Sel. 152)	IARI	1983	Plants determinate, light green foliage, fruit yellow, smooth, oblong, two locules, uniform ripening. Excellent for processing and suitable for long transportation. Average yield 30 t ha.
KS-2	Kalianpur	1985	Plants determinate, foliage light green, fruits flattish round, slightly furrowed. Stem end and leaves are slightly rolly, 4-5 locules.
Pant Bahar	Pantnagar	1985	Plant height 93 cm, bushy indeterminate in growth habit and branched. Light green foliage, stem relatively thin, leaflets small in size. Fruits flattish round, medium in size, 5-6 locules, slightly ridged on maturity. Resistant to Verticillium wilt and Fusarium wilt under field conditions. Good storage and processing qualities.
Improved Meeruti	IARI		Indeterminate, medium maturity, fruit suitable for long distance marketing, flattened, grooved with distinct ribs, medium size. Average yield 32 t ha.
CO_3	Tamil Nadu Agricultural University, Coimbatore	–	Dwarf determinate, fruit round, juicy and suitable for fresh consumption
Punjab Nematode Resistant-7 (PNR-7)	PAU, Ludhiana	1985	Plants are bushy, foliage medium, fruits round, flat, medium to large, juicy and acidic, resistant to rootknot nematodes and Fusarium wilt. Average yield is 40 t ha

Fusarium wilt (*Fusarium* spp.). The disease is controlled by crop rotation every two or three years to decrease fungus population in the soil, and by growing resistant varieties like Marglobe and Rutgers (Premnath, 1976).

Bacterial wilt (*Pseudomonas solanacearum*). The disease is particularly severe in the eastern, western and southern parts of India. Effective control has been reported using crop rotations such as cowpea-maize-cabbage or okra-cowpea-maize (Sohi et al. 1981) and 2-3 year crop sequence with (i) sunhemp-wheat, (ii) guar-garlic, (iii) pea-paddy rice and (iv) mungbean-cauliflower (Keshwar et al. 1975).

Early blight (*Alternaria solani*). Losses of up to 57% due to early blight have been reported (Anon. 1987). The disease is controlled by spraying mancozeb or captafol at biweekly intervals (Gill. 1985).

Late blight (*Phytophthora infestans*). This disease has become very serious particularly in the northern parts of India, resulting in considerable yield losses (Anon. 1987). It is controlled by spraying Dithane M-45 at weekly intervals, commencing at the appearance of the disease (Gill. 1985).

Buckeye rot (*Phytophthora parasitica*). The pathogen affects different stages of crop growth, viz. seedling (damping off, collar rot), flowering (blossom blight) and fruiting (fruitrot) resulting in losses from 30-50% (Sokhi and Sohi. 1974; Sharma. 1974; Sharma and Sokhi. 1975). Fruit infection is characterized by grayish and brownish spots. The disease is controlled by spraying mancozeb (Gill. 1985).

Leaf curl. This is the most serious virus disease throughout the country particularly during summer and is responsible for the failure of many rainy season crops. Disease incidence of 100% is reported and yield losses up to 92% during the summer months, when plants become infected shortly after transplanting (Singh and Sastry. 1976). Most of the suggested control measures are related to the control of the insect vector. Sastry and Singh (1971) suggested phorate, phosphamidon and dimethoate for control of whitefly. In another report, the spraying of mineral oil four times at 10-day intervals reduced whitefly populations and increased yields (Singh et al. 1973).

Fruitworm (*Heliothis* spp.). Infestation with this pest has resulted in yield losses of 18 to 55% (Singh and Chabl. 1978) but complete destruction of a tomato crop sometimes occurs. Fruitworm is generally controlled by spraying deltamethrin (Gill. 1985). Recent studies have revealed that two sprays with Fenvalerate and one spray with quinalphos are also effective in reducing fruit damage and increasing yield.

Rootknot nematodes (*Meloidogyne* spp.). Three species of *Meloidogyne* - *incognita*, *arenaria* and *javanica* are known to occur in India (Singh and Choudhury. 1972). Pest incidences of up to 90% with *M. javanica* have been reported (Bhatti and Jain. 1977). Rootknot nematodes are controlled by growing resistant varieties like S-120 and Punjab Nematode Resistant-7.

Besides the above diseases and pests, tomato is prone to physiological disorders like sunscald, cracking, blossom end rot and catface.

Socioeconomic and Marketing Aspects

The majority of the farmers in India grow the traditional cereal crops; only a very small percentage are engaged in vegetable growing. The reason is that vegetable growing is laborious and costly because of the need for frequent weeding, hoeing, irrigation, and so on, and the need to spray fungicides and insecticides to control pests and diseases. Furthermore, the fruits have to be transported promptly to the market, which is not possible because of poor transportation facilities. Prices greatly fluctuate in the market and are not stable as in the case of cereals. Thus the grower is at the mercy of the middleman for fixing the price and middlemen can exploit this situation because of the perishable nature of the produce.

Research and Development

Agricultural universities in different states, government institutions attached to the Indian Council of Agricultural Research (ICAR), and private seed companies are involved in tomato improvement. At the national level, research is managed by ICAR with headquarters at New Delhi. A project designated as the All-India Coordinated Vegetable Improvement Project was set up in 1970. It is headed by a Project Coordinator, with headquarters at the Indian Agricultural Research Institute in New Delhi. Under this project there are seven main centers, 15 sub-centers and 20 voluntary centers located in different parts of the country. The research program on tomato which forms part of this project is detailed in Table 4. The new varieties developed by

Table 4. Tomato research program in India under All-India Coordinated Vegetable Improvement Project.

Objective	Name of the Center[2]
I. Breeding	
1. Collection and maintenance	National Bureau of Plant Genetic Resources (NBPGR) of New Delhi, Hesserghatta (Karnataka), Ludhiana (Punjab) and Kalianpur (Uttar Pradesh)
2. Varietal trials	Kalianpur (UP), Pantnagar (UP), Sabour (Bihar), Delhi, Ludhiana (Pb), Rahuri (Maharashtra), Hesserghatta (Karnataka), Durgapura (Rajasthan), Ambajogai (Maharashtra), Srinagar (J and K), Junagadh (Gujarat), Hissar (Haryana), Katrain (HP), Kalyani (W. Bengal), Bhubaneswar (Orrisa), ARU Almora (UP), Jabalpur (MP), Aurangabad (Maharashtra), Tezpur (Assam), Parbhani (Maharashtra), Ranchi (Bihar), Kanpur (UP), Anand (Gujarat), Faizabad (UP), Coimbatore (Tamil Nadu)
3. Hybrids	IARI, New Delhi, Ludhiana (Pb), Hesserghatta (Karnataka), Pantnagar (UP), Katrain (HP), Rahuri (Maharashtra), Coimbatore (Tamil Nadu), Hissar (Haryana), Solan (HP), Sabour (Bihar), Kalianpur (UP), Ranchi (Bihar), Kalyani (W. Bengal), Aurangabad (Maharashtra)
4. Pest and disease resistance	
a) Late blight and buckeye rot	Solan (HP), Katrain (HP), Ludhiana (Pb), Almora (UP), Srinagar (J and K), Shillong
b) Bacterial wilt	Hesserghatta (Karnataka), Ranchi (Bihar), Jorhat (Assam), Vellanikara (Kerala), Jabalpur (MP), Solan (HP), Ranchi (Bihar), Bhubaneswar (Orissa) and Dapoli (Maharashtra)
c) Fruitborer	Ludhiana (Pb) and Hissar (Haryana)
d) Rootknot nematode	Ludhiana (Pb) and Hesserghatta (Karnataka)
II. Agronomy	
1. Varietal-cum-spacing trial	Durgapur (Rajasthan), Jorhat (Assam) and Rahuri (Maharashtra)
2. Varietal-cum-fertilizer trial	Jorhat (Assam), Hesserghatta (Karnataka), Srinagar (J and K), and Coimbatore (Tamil Nadu)
3. Foliar fertilization	Srinagar (J and K), Jorhat (Assam), Bhubaneswar (Orissa), Kanpur (UP), Hissar (Haryana), Faizabad (UP) and Vellanikara (Kerala)
4. Weed control	Durgapur (Rajasthan), Hissar (Haryana), Coimbatore (Tamil Nadu) and Srinagar (J and K)
III. Physiology	
1. Growth analysis, flowering and fruit-setting behavior	Hesserghatta (Karnataka)
2. Drought tolerance	Sabour (Bihar) and Hesserghatta (Karnataka)
IV. Biochemistry and Processing	
Evaluation of important varieties for quality and processing characters	Sabour (Bihar) Ludhiana (Punjab)
V. Chemical Control of Pests and Diseases	
1. Early blight	Pantnagar (UP), Ambajogai (Maharashtra), Kalianpur (UP), Faizabad (UP) and Bhubaneswar (Orissa)
2. Buckeye rot	Katrain (HP), Solan (HP), Almora (UP)

Table 4. Continued.

Objective	Name of the Center[2]
3. Late blight	Pantnagar (UP), Ludhiana (Pb) and Kalyani (W. Bengal)
4. Fruitborer	Ludhiana (Pb), Karnal (Haryana), and Hesserghatta (Karnataka)
5. Nematodes	Ludhiana (Pb)

[2]Full addresses are given in the Appendix.

the different agricultural universities or institutes are tested for three years at different centers. Finally the best performing variety is released at the national level by the Central Research Committee. The scientists from these centers meet every year to discuss new developments and plan future strategies.

Future Needs

There is an urgent need to extend the period of market availability of the tomato. This will only be possible if varieties/hybrids are developed which grow and set fruit under low and high temperature conditions. If the period of availability is extended, wide fluctuations in prices will disappear. The other factors that limit tomato cultivation are diseases and pests for which resistant varieties or hybrids need to be developed. Furthermore, processing varieties which can be harvested once over need to be developed to enable production of processed products at a reasonable price. To reduce losses during transportation there is need for firm and thick-skinned varieties. The system of transport should also be improved so that the produce reaches the market at the earliest.

Hot Pepper

Hot pepper (*Capsicum annuum* L.), commonly known as chili, is an important commercial crop which occupies an area of 891,800 hectares, producing 677,300 t of dry chilies (Anon. 1986-87). The major chili growing states are Andhra Pradesh, Maharashtra, Karnataka, Orissa and Tamil Nadu which together account for about 70% of the total area planted to this crop in India (Table 5). Highest yields are recorded in Andhra Pradesh, Nagaland, Punjab, Haryana and Mizoram. In India, most chilies are consumed as a condiment and coloring agent in food preparation in dry powdered form. Only 1-2% is exported to foreign countries such as the USA, Nepal, the USSR, and Malaysia (Table 6).

Production

Chili requires a warm climate for optimum growth and dry weather as the fruits mature. Chili thrives well in the tropical regions of India (Madhya Pradesh, Gujarat, Maharashtra, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal, Bihar, Mizoram, Tripura, Pondichery), and in the sub-tropical regions (Himachal Pradesh, Punjab, Haryana, Delhi, Rajasthan, Assam, Arunachal Pradesh, Meghalaya, Manipur, Nagaland, Uttar Pradesh).

Most of the crop is grown in the subtropical areas, where planting takes place from July to September. In the tropical regions of the country two crops are generally produced. The first crop is usually planted in August (Reddy, 1988), and the second in February-March, but irrigation is essential to raise a successful crop. A midseason crop planted in May-June is also under cultivation in some parts of the country taking advantage of monsoon rains.

Manure and Fertilizers

About 25 t/ha of farm-yard manure in addition to 300 to 400 kg/ha of oil cakes (groundnut or neem) may be incorporated into the soil during the last ploughing. Growing green manure

Table 5. Area and production of chilies during 1985-86.

State	Area ('000 ha)	Production of dry chilies ('000 t)	Average yield (t/ha)
Andhra Pradesh	204.9	309.4	1.51
Assam	10.9	6.3	0.58
Bihar	10.9	10.8	0.99
Gujarat	13.7	9.4	0.69
Haryana	11.2	12.1	1.08
Himachal Pradesh	0.9	0.2	0.22
Jammu and Kashmir	0.8	0.4	0.50
Karnataka	135.0	40.6	0.30
Kerala	–	0.9	–
Madhya Pradesh	50.1	11.1	0.22
Maharashtra	143.7	71.5	0.50
Manipur	4.2	2.5	0.60
Meghalaya	1.6	1.1	0.69
Nagaland	1.6	2.2	1.38
Orissa	98.3	75.5	0.77
Punjab	7.1	7.8	1.10
Rajasthan	46.1	30.7	0.66
Tamil Nadu	71.4	58.4	0.82
Tripura	1.5	0.7	0.47
Uttar Pradesh	28.7	23.0	0.80
West Bengal	40.8	30.6	0.75
Arunachal Pradesh	0.7	0.6	0.86
Delhi	0.2	0.2	1.00
Mizoram	1.7	1.8	1.06
Pondicherry	0.1	0.1	1.00
Total	886.1	707.9	0.80

Source: Anonymous. 1986-87.

Table 6. Production and export of chilies.

Year	Area ('000 ha)	Production ('000 t)	Export (t)	Value (millions of US$ approximately)[2]
1981-82	796.8	524.9	4,659.2	4.684
1982-83	818.0	538.99	12,888.5	13.284
1983-84	808.1	566.5	10,610.5	7.319
1794-85	794.8	630.5	8,226.9	7.856
1985-86	877.9	708.9	1,241.1	1.642

Sources: Anonymous. 1988. [2]US$1.00 = 13 rupees.

crops like cowpeas or sunhemp and incorporating these after about 40 days of growth with early rain is also practiced to good effect, wherever possible (Anon. 1982). In the case of irrigated crops, a basal dose of N, P and K at the rate of 60, 60 and 30 kg/ha, respectively, is applied at the time of final ploughing. At 45 days after transplanting, three split doses of 20 kg N and 8.3 kg K_2O are applied, each at 15 days intervals. Later two more split doses of N alone at 20 kg per hectare are applied. For rainfed conditions 60 kg N, 30 kg P and 50 kg K per hectare are applied at the time of transplanting.

Although the use of various chemical weedicides has been investigated, hand-weeding was found to be most effective and economical (Anon. 1980-81; 1981-82).

Cultivars and Seed Supply

A large number of local varieties of chilies belonging to the species *Capsicum annuum* are cultivated in different parts of the country. The varieties are annual and differ considerably in size, shape, color and pungency of fruit. Only a few improved varieties have been developed so far. The important characteristics of these varieties are given in Tables 7 and 8.

Table 7. Important chili cultivars released at national state level.

Name of cultivar	Developing institute	Year of release	Important characteristics
Andhra Jyoti	Lam (Andhra Pradesh)	1977	Fruit medium pungent with thick glossy red pericarp. Average yield 1.14 t ha under rainfed and 5 t ha under irrigated conditions.
Bhagyalakshmi	Lam (Andhra Pradesh)	1977	Average plant height 52.9 cm. Leaf lamina dark green. Fruit 8.2 cm long with 0.7 cm width. Crop duration 180 days. High yielding, i.e. 1.6 t ha dry chilies under rainfed and 4.5 t ha under irrigated conditions.
K2	Kovilpatti (Tamil Nadu)	1985	Plant height 90-95 cm. Tall and bushy. Fruit length 6.1 cm and 4 cm girth, bright red. Tolerant to thrips. Seed yield 0.75 t ha.
NP 46	IARI (New Delhi)		Plant dwarf and bushy with light green leaves. Fruits are long (8-9 cm) and thin, wrinkled with high green color, turning light red on ripening. High yielder, tolerant to thrips. Cultivated throughout the country. Average yield is 1.5 to 2 t ha.
Pusa Jwala	IARI (New Delhi)	1977	Developed from a cross of NP-46 and Purl Red. Plant dwarf and bushy with light green and broad leaves. Fruits long (9-10 cm) with light green color. Highly wrinkled, pericarp thin and light red in color. High yielding, resistant to TMV. Cultivated throughout the country. Also spread to Australia and Europe. Average yield is 2 to 2.5 t ha.
Sindhur (CA-960)	Lam (Andhra Pradesh)	1978	Fruit long (9.2 cm) and short with broad base with semishaped calyx. Pericarp thick with light green color, turning to attractive red color, pungency mild. Suitable for green and red chili production. Average yield 1.2 t per hectare under rainfed and 6 t under irrigated conditions.
X-235	Lam (Andhra Pradesh)	1985	Early maturing plant with short internodes. Leaves small and dark green. Flowers with yellow anther, fruit 5 to 6 cm long, calyx deeply cup shaped. Fruit tip pointed, highly pungent, seed percentage 45%. Maximum yield potential up to 7.5 t ha dry chili.
Pant C-1	Pantnagar (Uttar Pradesh)		Plants dwarf and bushy, erect type fruit, medium size light green at immature size

Table 7. Continued.

Name of cultivar	Developing institute	Year of release	Important characteristics
			and red at maturity. Resistant to leaf curl virus. Average yield is 2 to 2.2 t/ha.
Jawahar 218	Jabalpur (Madhya Pradesh)	1987	Plants dwarf and spreading, light green leaves. Fruit erect long, 10-12 cm, wrinkled, light green at immature stage and turning rosy red at maturity. Early and heavy bearing variety. Average dry yield 1.8 to 2.2 t/ha. Suitable for green and red chili production. Tolerant to leaf curl and fruitrot.
Punjab Lal	Ludhiana (Punjab)	1985	Plants dwarf and bushy with dark green leaves. Fruit erect, medium size, dark,green, turning dark red glossy at maturity. Average dry yield 2 to 2.2 t/ha. Rich in capsaicin, oleoresin, dry matter, pigment highly suitable for dry powder prodcution. Resistant to TMV, CMV, PVY and leaf curl viruses. Moderately resistant to fruitrot and dieback diseases (Thakur et al. 1987). Released at state level.

Table 8. Chemical evaluation of some important varieties of chilies (dry weight basis) at Ludhiana (1984).

Variety	Dry matter (%)	Capsaicin (%)	Total alcoholic extracts (%)	Coloring matter (ASTA unit)
Pant C-1	22.97	0.76	15.00	9.84
Jawahar-218	20.30	0.70	16.00	19.68
Muslawadi	21.55	0.50	16.00	19.68
CO-2	22.97	0.20	16.00	28.86
Punjab Lal	27.09	0.60	21.00	9.18
Sindhur	18.52	0.24	20.00	9.18
Pusa Jwala	20.42	0.52	15.00	7.87
X-235	0.36	17.00	6.56	

Source: Anonymous 1987

The National Seeds Corporation (NSC) has been producing the seeds of almost all vegetables. However, it is very difficult for NSC to produce seeds of all improved varieties of each vegetable recommended by the different states. Therefore, the production and multiplication of quality seeds will increasingly become the responsibility of the State Seed Corporations. At present, quality seed is being produced by the agricultural universities and by the Agriculture Departments of each state. The seed is certified by the government certifying agencies. However the quantity of quality seed is still insufficient to meet the demands of any state in full. Therefore, farmers have to purchase seed from the private seed companies, and this seed is often not of good quality.

Major Constraints

Insects. The most important insect pests which attack chili in India are thrips, mites, podborers and aphids. These are more serious in the tropical regions of Andhra Pradesh, Tamil Nadu, Karnataka, Orissa, Maharashtra and West Bengal. Thrips are considered the major pest of chili

in India (Ayyar et al. 1935; Ananta Krishnan. 1973), often causing 25 to 50% yield loss. Application of chloropyrifos at 15-day intervals is recommended (Gill. 1985) to control the pest complex (podborer, mites, thrips and aphids). This control gave a Rs. 11,309 (US$870) per hectare advantage over the untreated control. Cypermethrin has been recommended for the control of podborer (Gill. 1985).

Breeding work carried out at Lam station reported that the following lines were tolerant to different pests (Anon. 1972-76): Caleapin Red, Chamtkar, NP 46-A, X 1068, X 743, X 1047, BG-4 X 226, X 230, X 233 (tolerant to thrips), LEC 1, Kalyanpur Red, X 1068, X 204, Goli Kalyanpur (tolerant to mites), LEC 28, LEC 30, LIC 34, Kalyanpur Red and X 1068 (tolerant to aphids). At Hesserghatta (Karnataka) only five lines out of 157 lines tested, viz. 309-1-15, 300-1-5-1, S 118, 635 and 565, showed a high degree of tolerance to thrips, with a population of less than 10 thrips/5 plants compared 85 to 142 thrips in susceptible varieties (Tewari et al. 1985).

Diseases. The most important diseases of chili in India are anthracnose (fruitrot and dieback caused by *Colletotrichum* sp.), powdery mildew, bacterial leafspot and viral diseases (Anon. 1972-76). Anthracnose and viral diseases are serious in all tropical and subtropical chili-growing areas of the country. Powdery mildew and bacterial leafspot are serious in the southern part of the country where tropical conditions prevail. Yield losses of up to 34% from powdery mildew (*Oidiopsis taurica*) (Anon. 1972-76; 1981-82) and up to 60% from fruitrot (*Colletotrichum* sp.) (Bansal and Grover. 1969) have been reported.

Two or three sprays of mancozeb at the fruiting stage are recommended for the control of fruitrot and dieback. With this treatment there was an increase of 0.8 or 1.2 t per hectare of fruit yield with additional return of Rs. 4000 (US$307) (Gill. 1987). Seed treatment with Ceresan and carbendazim have also shown promise in the control of anthracnose (Gill. 1985).

TMV, CMV, PVY, PVX, chili mosaic virus, and leaf curl virus are the most important viruses of chili throughout the country (Ramakrishnan. 1959; Jeyaranjan and Ramakrishnan. 1969). Yield losses ranging from 80 to 100% have been reported in cases of early infection (Singh et al. 1979). Leaf curl incidence could be reduced from 82% to 5% when the crop was treated with Furadan plus mineral oil. A number of lines/varieties have been reported resistant and tolerant to various diseases in India (Table 9); some of the lines are being used for further breeding. Three male sterile lines, viz. MS12, MS13, MS41 possessing multiple disease resistance, including resistance to viral diseases, have been developed (Singh and Kaur. 1986). Recently four additional lines, viz. MF 11-1, MF 41-1, Tiwari and Laichhi, have been reported to have multiple resistance and good agronomic traits.

Table 9. Lines and varieties with reported resistance to diseases.

Disease	Resistant line/cultivar	Institute	Reference
1. Cercospora leafspot	328, 344-9	Hesserghatta (Karnataka)	Cheema et al. (1985)
2. Fruitrot	Lorai, Perennial, S27, Bangla Green	Ludhiana (Punjab)	Kaur and Singh (1985)
3. Powdery mildew	El Salvador, C. baccatum, C. frutescens	Hesserghatta (Karnataka)	Deshpande et al. (1985)
4. CMV, TMV and leaf curl virus	Pant C-1, Punjab Lal, Lorai, Perennial, Longi, S20-1, Bangla Green, Tiwari, Laichhi	Ludhiana (Punjab)	Singh and Kaur (1986)
	Delhi Local, 38-2-1, 96-4-9-3, 141-2-33	Delhi	Tewari and Vishwanath (1986)

Varieties and management. Although chili is an important and widely cultivated crop in India, improvement work is limited. Only a few varieties have been released in the past, and these are only suitable for some regions. Mostly local varieties are grown, which are poor in yield and susceptible to pests and diseases. There is great need to develop varieties with high yield potential and good agronomic attributes, and which are suitable for processing, resistant to diseases and insect pests, and adapted for growth in the different zones of the country. Hybrids utilizing male sterility have great potential in the country (Singh, 1987) but so far not a single F_1 hybrid has been released in India.

Since India has varying climatic conditions from region to region, different cultural management practices are required for different areas. There is a need to establish optimum doses of fertilizers, proper spacing, and seed rate, and the most appropriate weedicides, irrigation practices, harvesting machinery, and so on to achieve the best results from this crop.

Socioeconomic and Marketing Aspects

India's vegetable production per unit area is one of the lowest in the world (Sheshadri and Chatterji, 1983). This is mainly due to the fact that land holdings are small in India and that farmers cannot invest too much in the latest techniques. The percentage of marginal farmers (below one hectare) is about 55% and of small farmers (1-2 hectares) is 18%.

Marketing in India is very disorganized. The produce passes through several hands to reach the consumer. It is estimated that 70-75% of the price paid by the consumer goes to the middleman. Also lack of proper packing, transport and storage facilities doom 25 to 30% of the vegetables to waste during postharvest handling (Choudhury and Shivakami, 1983).

In India, chilies are mainly consumed as a condiment. There is a great need to promote other uses of this crop, such as for the production of oleoresin, paprika powder and paste which have a great potential in the world market.

Research and Development

Chili improvement is conducted by the agricultural universities as well as by research institutes. Although germplasm is maintained by each center, the Indian Council of Agricultural Research (ICAR) has selected three main centers namely Lam (Andhra Pradesh), Coimbatore (Tamil Nadu) and Kalianpur (UP), for the collection and maintenance of chili germplasm. In addition, the National Bureau of Plant Genetic Resources (NBPGR) established at New Delhi in 1976 also holds a germplasm collection. The All India Coordinated Vegetable Improvement Project was initiated under ICAR during 1970-71 to improve multidisciplinary research on important vegetable crops, including chili. The headquarters is located in New Delhi, but there are seven main centers, 15 subcenters and 27 voluntary centers distributed throughout the country. The research programs for chili under this project are detailed in Table 10. A workshop is organized every year to discuss the salient achievements of various centers and to formulate new programs. Any new recommendation is based on three years' consistent data.

Utilization and Processing

In recognition of the potential offered by the processing industry for export of processed food, an Export Production Council was set up in 1963. The main problem is the lack of raw material suitable for processing. The processing industry mainly depends upon whatever varieties or mixture of varieties are available as surplus in the market. Better varieties exclusively for processing need to be developed. The second major constraint is the high cost of packing material. The processing industry will have to cooperate with the engineering industry to evolve cheap good quality packing material which may help reduce the cost of processed foods.

Table 10. Research program on chili under the All-India Coordinated Improvement Project.

Objectives	Institute[z]
1) Collection and maintenance of germplasm	National Bureau of Plant Genetic Resources (NBPGR) Lam (AP), Kovilpatti (TN), Kalianpur (UP)
2) Varietal trials	ARU (UP), Almora (UP), Hissar (Haryana), Bhubaneswar (Orissa), Coimbatore (TN), Jabalpur (MP), Kalianpur (UP), Lam (AP), Hesserghatta (Karnataka), Kovilpatti (TN), Ludhiana (Punjab), Rahuri (Maharashtra), Sabour (Bihar), Akola (Maharashtra), Dapoli (Maharashtra)
3) Breeding for export	Lam (AP), Kovilpatti (TN), Coimbatore (TN)
4) Screening of improved varieties for biochemical traits	Ludhiana (Punjab)
5) Fertilizer-cum-spacing trials	Kalianpur (UP), Rahuri (Maharashtra), Lam (AP), Coimbatore (TN), Pantnagar (UP), Sabour (Bihar), Hesserghatta
6) Weed control	Coimbatore (TN), Lam (AP), Ludhiana (Punjab)
7) Breeding for pest and disease resistance	
(a) Fruitrot (*Colletotrichum* spp.)	Kovilpatti (TN), Solan (HP), Lam (AP), Ludhiana (Pb)
(b) Leaf curl and TMV	Rahuri (Maharashtra), Ludhiana (Punjab), Hesserghatta (Karnataka)
(c) Thrips, mites, aphids and fruitborer	Lam (AP), Rahuri (Maharashtra), Kovilpatti (TN), Ludhiana (Punjab), Parbhani (Maharashtra)
8) Chemical control of powdery mildew, fruitrot, dieback, bacterial leafspot and viruses	Lam (AP), Rahuri (Maharashtra), Parbhani (Maharashtra)
9) Chemical control of pests (thrips and mites)	Lam (AP), Kovilpatti (TN), Parbhani (Maharashtra), Jabalpur (MP), Rahuri (Maharashtra)

[z]Full addresses given in Appendix

International Support for Research and Production

International agencies do not provide support for any research project on this crop in India. All projects are funded by the states and by ICAR.

Future Needs

There is a great need to develop varieties with high yield potential and with wider adaptability, possessing resistance to diseases and insect pests, suitable for the processing industry and for mechanical harvesting. A climate suitable for seed production, and the low cost of labor in India, mean that there is great potential for a hybrid seed industry for domestic as well as for export purposes. Cultural management practices such as optimum doses of fertilizer, spacing, and the use of mechanical harvesting need to be determined for each variety in order to increase net returns. Research on postharvest technology needs to be strengthened. Efficient methods for drying fruits and for seed extraction using mechanical means also need to be studied.

Sweet Pepper

Sweet or bell pepper (*Capsicum annuum* L.) locally known as 'Simla Mirch' is mainly grown for its immature fruit. This crop is not important in India, and production statistics are not available. The crop is cultivated mainly in the tropical and subtropical regions of India during

the cooler season. In tropical south India it is raised during the winter months (August to December) and on the subtropical plains during the spring season (February-June). In hilly areas the crop is cultivated from April to October. The cultural practices are similar to those described for chili.

Introductions from other countries such as California Wonder, Bullnose, Chinese Giant and Yolo Wonder are cultivated in India. The leading cultivar is California Wonder covering more than 90% of the area under this crop. In 1985 a new variety, Punjab Mirch-27, was released by the Punjab Agricultural University in Ludhiana. This variety produced 100% more yield than California Wonder. It can tolerate high heat and can set fruit and seed under high temperature conditions (Singh and Thakur, 1987). A number of other cultivars developed at various institutes such as Arka Mohni and Arka Gurav at Hesserghatta and HC 201, HC 202 and HC 213 at Almora (UP) are quite promising and are being tested under the All-India Coordinated Vegetable Improvement Project. A number of F_1 hybrids are being produced by private seed companies. Among these, 'Bharat' developed by the Indo-American Seed Company, has gained popularity in the country. But the cost of seed is 30 times more than that of open-pollinated cultivars. The most popular local cultivars and F_1's are listed in Table 11.

The pests and diseases are similar to those that attack chili. However sweet pepper appears to be more susceptible. At present efforts to breed for pest and disease resistance and to control insect pests and diseases are negligible for this crop.

Table 11. Local sweet pepper cultivars.

Cultivar	Developing institute[2]
HC-202	Almora (Uttar Pradesh)
HC-213	Almora (Uttar Pradesh)
Selection-13 (Arka Mohni)	Hesserghatta (Karnataka)
Selection-16 (Arka Gurav)	Hesserghatta (Karnataka)
Kt-1 (F_1)	Katrain (Himachal Pradesh)
Bharat (F_1)	Indo-American Seed Co., Bangalore (Karnataka)
Early Bounty (F_1)	Sutton & Sons, Calcutta (West Bengal)
Sutton Gem Giant (F_1)	Sutton & Sons, Calcutta (West Bengal)

[2]Full addresses given in Appendix

Research and Development

Research work on this crop is conducted by the agricultural universities as well as by the research institutes. Under the All-India Coordinated Vegetable Improvement Project two centers, namely Solan and Katrain in Himachal Pradesh, have been selected for the collection and maintenance of germplasm.

Varietal trials conducted during 1984-85 showed that California Wonder was the highest yielding cultivar (Anon. 1987). Among the hybrids, Kt-1 gave promising results. Research work is in progress at Hesserghatta and Ludhiana to develop sweet pepper cultivars suitable for high temperature conditions. Several lines are reported to perform better than California Wonder (Anand and Deshpande, 1986).

Future Needs

Cultivars with good quality attributes such as a high content of vitamin C and vitamin A, red pigment (for paprika production), resistance to pests and diseases, and ability to set fruits and seeds under high temperatures (above 23 °C), need to be developed. Male sterile lines for the production of F_1 seed at lower cost also need to be developed. Appropriate cultural management practices including spacing, irrigation, and fertilizer and herbicide application, must be established to get high returns from this crop.

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Appendix: All India Coordinated Vegetable Improvement Project (addresses of participating centers)

Centers

1. Coimbatore	Dean (Horticulture) Tamil Nadu Agricultural University Coimbatore-641 003 (Tamil Nadu)
2. Delhi	Head, Div. of Vegetable Crops, IARI, New Delhi-110 012
3. Hesserghatta	Head, Division of Vegetable Crops Indian Institute of Horticultural Research, 255-Upper Palace Orchards, Bangalore-560 080
4. Katrain	Head, IARI Regional Station Katrain-175 129 (Kulu Valley, H.P.)

5. Ludhiana	Professor and Head Department of Vegetable Crops Landscaping and Floriculture Punjab Agricultural University Ludhiana-141 004 (Punjab)
6. Rahuri	Senior Vegetable Breeder Mahatma Phule Krishi Vidyapeeth Rahuri-413 722, Dist. Ahmednagar (Maharashtra)
7. Sabour	Head, Dept. of Vegetable Crops and Floriculture Rajendra Agricultural University Dist. Bhagalpur, PO Sabour-813 210 (Bihar)

Sub-centers

8. Parbhani	Jr. Vegetable Breeder, Taluka Seed Farm, Agricultural University Paribhani-431 517, Dist. Bhir (Maharashtra)
9. Bhubaneswar	Professor and Head Department of Horticulture Orissa University of Agriculture and Technology Bhubaneswar-751 003 (Orissa)
10. Durgapura	Associate Professor, Dept. of Horticulture Agricultural Research Station Durgapura-302 015, Jaipur (Rajasthan)
11. Faizabad	Professor and Head Department of Vegetable Science Narendra Dev. University of Agriculture and Technology, Narendranagar, PO Kumarganj, Faizabad-224 229 (UP)
12. Hissar	Head, Dept. of Vegetable Crops, Haryana Agricultural University, Hissar-125 004 (Haryana)
13. Jabalpur	Professor of Vegetable Crops Department of Horticulture, College of Agriculture, J.N. Krishi Viswavidyalaya Jabalpur-482 004 (MP)
14. Jorhat	Professor and Head Department of Horticulture Assam Agricultural University Jorhat 785-013 (Assam)
15. Kalianpur	Associate Professor, Dept. of Horticulture, Chandra Shekhar Azad Univ. of Agriculture and Technology Kalianpur, Kanpur-208 002
16. Kalyani	Professor of Vegetable Crops Bidhan Chandra Krishi Viswa Vidyalaya Kalyani-741 235, Dist. Nadia (West Bengal)

17. Kovilpatti	Professor and Head Agricultural Research Station Kovilpatti-627 701
18. Lam	Vegetable Breeder (Chilies) Agricultural Research Station, Lam Farm, Guntur-522 034 (AP)
19. Pantnagar	Professor of Horticulture GB Pan Univ. of Agriculture and Technology Pantnagar-263 145, Dist. Nainital (UP)
20. Solan	Head, Dept. of Veg. Crops and Floriculture Dr. Y.S. Parmar University of Horticulture and Forestry, Solan-173 203 (HP)
21. Srinagar	Associate Professor of Vegetable Crops Sher-E-Kashmir University of Agricultural Sciences and Technology, Shalimar, PO Harwain, Srinagar-191 121 (J and K)
22. Vellanikkara	Professor of Horticulture Kerala Agricultural University Vellanikkara-680 654 (Trichur-Kerala)

Voluntary Centers

23. Almora (VPKA)	Director, Vivekananda Parvatiya Krishi Anusandhanshala, Almora-263 601 (UP)
24. Almora	Officer-in-Charge, Ministry of Defense, Agricultural Research Unit, Almora-263 601 (UP)
25. Akola	Professor of Horticulture Punjab Rao Krishi Vidyapeeth, Akola-444 104 (Maharashtra)
26. AADF, New Delhi	Associate Agricultural Development Foundation, East of Kailash, Sapna Building, New Delhi-110 024
27. Karnal	Senior Scientist IARI Regional Station Karnal-132 001 (Haryana)
28. NAFED (Nasik)	Associated Agricultural Development Foundation, Dr. Lohat's Building, 18-Lingayat Colony, Deolaly Goan, Nasik Road-422 101 (Maharashtra)
29. Navsari	Associate Professor of Horticulture N.M. College of Agriculture Gujarat Agricultural University Navsari-396 450 (Gujarat)

30. Nilgiris (Ooty)	Jt. Director of Horticulture Udagamandalam, The Nilgiris Dt. 643 002
31. NBPGR, New Delhi	National Bureau of Plant Genetic Resources, IARI Campus, New Delhi-110 012
32. Ranchi (CHES)	Scientist S-3 and Head, C.H.E.S. Hinoo Ranchi-834 002 (Bihar)
33. Ranchi (BIRSA)	Professor of Vegetable Crops Birsa Agricultural University Ranchi-834 006 (Bihar)
34. Shillong	Sr. Horticulturist. ICAR Research Complex for North Eastern Regions. Amrit Bhawan, Laban, Shillong-793 004
35. Dapoli	Vegetable Scientist Central Experiment Research Station Wakawali-415 711 (Maharashtra)

Symposium Discussion

B.H. Chew: Malaysia imports large amounts of dry chilies from India; are there varieties specifically bred for dry processing?
J.H. Singh: So far no variety has been specifically bred for dry processing export purposes, although varieties have been developed possessing high dry matter content.

J. Hallard: Can you please give more details and information on screening for biochemical traits?
J.H. Singh: Biochemical traits like dry matter content, vitamin C, vitamin A, oleoresin, color pigments and capsaicin content are tested before releasing cultivars for general cultivation.

A. Yu: The seeds of hot pepper are extracted from dry fruits. Does this affect the germination of the seeds?
J.H. Singh: In hot pepper germination of seed extracted from red ripe fruit or from dry fruit is equally good.

47

51

Tomato and Pepper Production in Indonesia: Problems, Research and Progress

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Abstract

Pepper ranks first with an area of about 200,000 ha or 18% of the total vegetable area and tomato ranks sixth with 35,000 ha or 2.5% of the total vegetable area in Indonesia. Productivity is generally low, 2-3 t/ha for pepper and 4-5 t/ha for tomato, although yields of 10-15 t/ha of pepper and 13 t/ha of tomato can be achieved in the main production areas. The low productivity is one of the reasons why vegetable consumption in Indonesia is only 66% of the recommended amount. The major production constraints for the two crops are: (1) Insufficient seed supply of improved lines. To overcome this problem, the Lembang Horticulture Research Institute (LEHRI) was assigned to supply breeder seed, the Directorate of Horticulture Production to produce foundation seed, and the Extension Service to supply extension seeds. (2) Lack of improved varieties especially for pepper. (3) Lack of suitable cultivation methods for tomato in the lowland and medium elevations. (4) Pests and diseases: *Spodoptera litura* and thrips on pepper and *Heliothis* sp. on tomato. Presently, control of these important pests is mainly by chemicals. The major diseases of pepper are anthracnose and viruses, and those of tomato are bacterial wilt, leaf mold and viruses.

Tomato

Production

The shortage in vitamin A and iron are two main nutrition problems in the Indonesian diet. One of the reasons is the low vegetable consumption of 39.1 kg per capita per year, which is only two-thirds of the recommended daily intake. Both tomato and pepper are good sources of vitamin A and C, and they are well accepted by the Indonesian people. Although most cultivation occurs during the dry season, both crops are cultivated year-round.

Tomato is cultivated year-round throughout Indonesia. Total production was 126,019 t in 19. The major production areas are in Java, Sumatra and Sulawesi with 49%, 26% and 17% of the total pepper production in the country, respectively. Although the total production area is increasing (Table 1), productivity is very low with an average of 3.6 t/ha. However, yields of 25 t/ha have been achieved in experimental fields.

Table 1. Harvested area and average productivity of tomato in Indonesia, 1981-1985.

Year	Area ('000 ha)	Production ('000 t)	Average yield (t/ha)
1981	25.7	107.3	4.2
1982	26.9	119.4	4.4
1983	30.2	88.9	2.9
1984	41.8	138.1	3.3
1985	47.8	151.0	3.2
Average	34.5	120.9	3.6

Source: Anonymous, 1987a.

Most of the tomato production is in the highlands, although recently lowland tomato production has been increasing, particularly around big cities and/or around industrial areas. This development is related to the increasing demand for vegetables due to increasing income and awareness of nutrition needs. The existence of heat tolerant and bacterial wilt resistant varieties is also supporting tomato development in the lowlands. Before 1976 farmers were unwilling to grow tomatoes in the lowlands because of the bacterial wilt problem (Sunarjono et al. 1976).

Varieties and Seed Supply

Fruit with a weight of 75-100 g/fruit or 10-14 fruit/kg, with pear or elongated square shape, sweet-sour taste, and thick flesh and smooth surface is preferred. Varieties grown in the highlands are Gondol, and the imported varieties Moneymaker and recently also King Kong (F_1). The F_1 seed commands a very high price. Therefore some farmers try to utilize pinched rooted lateral shoot cultivars for the next planting. In medium elevations or in the lowlands the cultivars Intan, Ratna, Tomat Hijau, Tomat Ranti Intan, Tomat 1R, and Tomat Sayur are frequently grown. Although the crop is cultivated year-round, it is usually cultivated during the period of less rain. This situation results in uneven supply to the regional markets, and in sharp price fluctuations (Figure 1). The shape of Tomat Hijau and Tomat Ranti is generally oblate with undulate surface and thin skin which is not suitable for long distance transportation. Recently a bacterial wilt tolerant multiline called NTR has become popular in the highlands of West Java. It has also been tested in the swampy lowland areas of South Sumatra where it performed better than Intan, Ratna, Berlian and C1-1094. Its yield potential is 27.2 t/ha as compared to 15.1, 16.5 and 20.0 t/ha for Intan, Berlian and C1-1094, respectively.

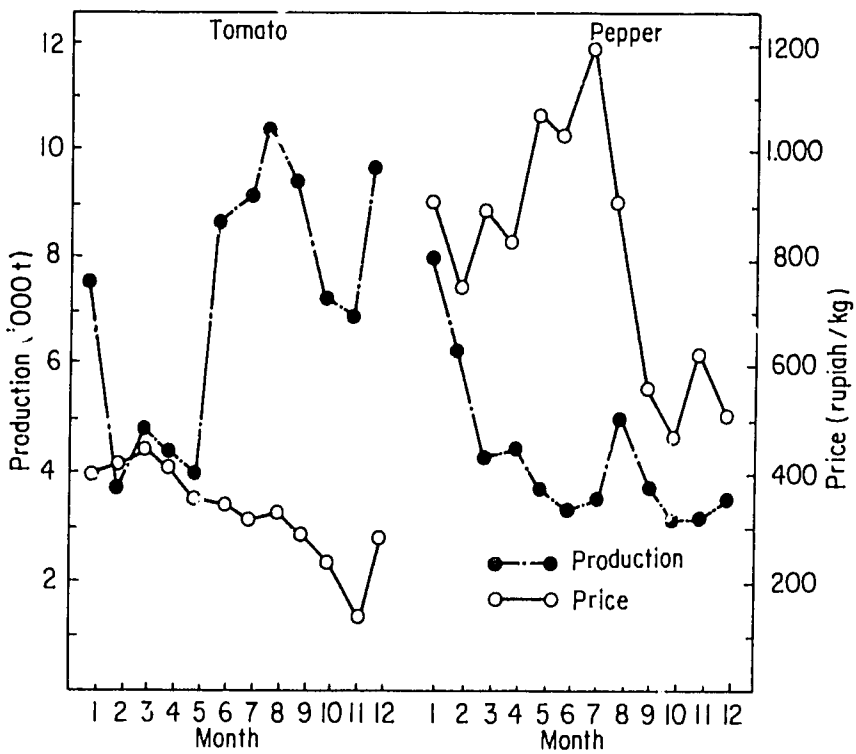

Figure 1. Monthly production and price of tomato and pepper in West Java, 1985.

Farmers generally produce their own seeds. Some farmers also sell the seeds to seed merchants (collectors). In East Java 90% of the farmers produce their own seed. Two small seed growers in Central Java produce seed of the cultivar Intan.

Cultivation Practices

The mid/lowland tomato cultivation of West Java is usually between two rice crops. Determinate and indeterminate types (Tomat Hijau) without staking are usually grown and yields average 5-15 t/ha in West Java (Adiyoga et al. 1987), 4-7 t/ha in East Java (Moenarni et al. 1986) and 3.8 t/ha in South Sulawesi (Fadhly et al. 1983). Lowland tomato is planted in two-row beds of 80-100 cm, with a distance of 50-75 cm between rows and 20-25 cm within row, or in three-row beds with 50 cm between and within rows (Adiyoga et al. 1987). In East Java, lowland tomato is usually produced in rain-fed areas, planted in beds of 55 × 80-200 cm with various planting distances ranging from 30-75 cm × 30-100 cm.

Marketing

In general the pattern of production, supply and demand of various vegetables in Indonesia is highly influenced by the season. In the peak harvest season the supply is greater than the demand resulting in a low price of the produce and vice versa. Variation in price among production areas is due to the high marketing costs which is mainly caused by high transportation and storage costs and high marketing risk. Table 2 shows price differences of tomato in different provinces.

In the last few years, the government of Indonesia developed a market information system (MIS) for several vegetables of high commercial value such as pepper, shallot, tomato, cabbages, etc. MIS intends to (1) strengthen the farmers bargaining position, (2) reach a more balanced supply and demand, and (3) reduce spatial price differences. It quotes and disseminates wholesale prices every day via the national radio broadcasting system and price information boards at rural and wholesale markets.

Table 2. Fresh market tomato prices in several locations in Indonesia, 1979-80.

Price/kg	Sumatra			Java			South Sulawesi	Bali
	North	West	South	West	Central	East		
Rupiah[x]	92.50	238	223.50	129	145.50	139	159.75	142
US$	0.15	0.40	0.37	0.22	0.24	0.23	0.27	0.24

Source: Anonymous. 1981. [x]US$1.00 = Rp. 600 (estimated foreign exchange rate in 1980).

Cost of Production

The indeterminate type of tomato is usually cultivated in Indonesia. The use of bamboo sticks for staking accounts for 20%-25% of the total production cost. The production cost of tomatoes consists of 3.3% for seed, 16.2% for fertilizer, 15.9% for pesticides, 48.1% for labor, 13.3% for land rent and 3% for others (Anonymous. 1987b).

Import and Export

The average yearly volume of fresh tomato export during 1981-86 was 219 t valued at US$24,150. The export was mainly from North Sumatra to Malaysia and Singapore. However, in the same period, approximately 13 t/year of tomato products were imported from countries such as Singapore, Australia, USA, etc., to meet the demand of the tomato processing industries (Anonymous. 1987c).

Constraints

Several production constraints have been identified (Adiyoga et al. 1987):

Lack of suitable varieties and seed. Lines adapted to high rainfall or drought are not available. In the past, many farmers were unaware of the release of improved varieties and used local varieties with heterogenous populations. Because of the lack of a sound vegetable seed industry in the country, seed of improved varieties were not available and consequently farmers produced their own seed. The high price of seed does not appear to be a problem, as long as the purity and good performance of the variety is assured.

Pests and diseases. Fruitworm, *Heliothis* sp., is the most important pest and bacterial wilt, leaf mold and viruses are the most important disease problems. The use of pesticides is still the most common practice for pest control.

High marketing cost. Generally farmers obtain a low share of the consumer's price due to inefficient marketing systems i.e., poor marketing organization in the production centers, improper handling which results in high losses of the produce, poor infrastructure and high transportation cost to small-scale and scattered farms.

Supply problems. Uneven supply to the regional market which results in sharp price fluctuation even within a few hours (Basuki. 1987) (Figure 1).

Other problems are the lack of recommendations for appropriate cultural practices (including fertilizer application) for lowland tomato. The lack of skilled extension workers in the past has prevented technology transfer from the research station to the farmers' fields (Anon. 1986).

Research and Development

In the past, tomato research emphasized highland production and only very little research on lowland tomato was conducted. Introduced lines with reported resistance or tolerance to heat and bacterial wilt (*Pseudomonas solanacearum*) and crosses of local × introduced cultivars were evaluated. The best materials, which included several AVRDC lines (Permadi et al. 1987; Hanudin. 1987), selections from Louisiana State University (LSU), and lines from Lembang originating from Intan × Gondol, Ratna × Gondol, (Kartapradja et al. 1987) were used in the breeding program. High yielding lines with resistance to bacterial wilt and heat tolerance were obtained and released as new varieties such as Berlian and Mutiara. These new varieties were distributed to the farmers after being multiplied by the Directorate of Horticultural Production. Accessions with tolerance to late blight were also identified (Permadi et al. 1987). The development of lines with long fruit storage capability is in progress using 'alcobaca'. In recent years, research on improving tomato cultivation methods in the lowland has begun. The effects of mulching, plant spacing, and fertilizers on growth and yield of tomato were investigated. Mulching with rice straw increased marketable fruit yield by as much as 16.3%. A combination of straw mulch and a 60 × 50 cm plant distance gave the best yield (Gunadi and Suwandi. 1987). Highest fruit weight/plant was obtained by applying 90 kg N/ha in the form of a combination of urea and ammonium sulfate (1 = 1) (Hilman and Sumarna. 1988). Research on integrated pest management for tomato has been emphasized recently.

Pepper

Production

Pepper is an important constituent of the Indonesian diet. Most of the produce is consumed fresh. Pepper is cultivated year-round throughout Indonesia, usually in the lowlands. The major

production area is in Java where more than 70% of the total pepper crop is grown. The other areas of production are in Sumatra and Sulawesi where 20% and 4% of the total pepper is produced, respectively. The yield is very low, averaging 1.8 t/ha (Table 3). In experimental fields and where farmers use higher plant densities about 12 t/ha and 13 t/ha could be obtained, respectively (Sumiati 1985; Basuki, 1987).

Pepper is cultivated year-round but mainly during the dry season. This situation of uneven seasonal production results in sharp price fluctuations (Figure 1) which can affect the inflation rate of the country (Adiyoga, 1985).

Table 3. Harvested area and average productivity of pepper in Indonesia, 1981-86.

Year	Area ('000 ha)	Production ('000 t)	Average yield (t/ha)
1981	157.3	219.4	1.4
1982	138.4	175.1	1.3
1983	120.4	295.8	2.5
1986	202.0	387.0	1.9
Average	154.5	269.3	1.8

Source: Anonymous, 1987a.

Cultivars

The two most commonly cultivated pepper species are *Capsicum frutescens* (chili pepper) and *Capsicum annuum* (cayenne pepper). The former is less important than the latter. There are two types of chili peppers based on fruit color, i.e. green and light yellow, both of which are hot to very hot.

The cayenne is the most important pepper. Based on the fruit characters, particularly fruit shape, there are two types, i.e. the long (more than 15 cm-long, 0.7-1.0 cm-wide and thin flesh) or curly type (with slender, undulate surface, high pungency and long growth period) which is mostly cultivated in Sumatra and some parts of West Java. The other type is long (10-15 cm-long and 1.5-2.0 cm-wide) but rounder than the first type, smoother in surface, thicker flesh, and less pungent and has a shorter growth period. This type is mostly cultivated in Java, Bali and Sulawesi. The local cultivars are preferred than the introduced varieties although their yields are generally low, i.e. 3.3 t/ha (Hartiningsih and Sunarjono, 1976).

Seed Production

In East Java 90% of the farmers produce their own seed, by selecting the best plant, according to fruit density, high yield, disease tolerance, etc. However, since pepper has a relatively high degree of outcrossing, i.e. up to 32%, the following generations are progressively heterogeneous, most probably due to segregation. Therefore, all local cultivars found in the production areas are segregating populations with varying uniformity.

Cultivation Practices

In the major pepper production area in Central Java, pepper is planted in a relay system with shallot. Shallot is planted in 1.50 m-wide and 40-60 cm-high beds with 40 cm-wide furrows between beds. The furrow is filled with water up to 20 cm below the bed surface. This high bed cultivation type called 'surjan' allows more efficient watering and avoids flooding. At the time of shallot planting, pepper seed is sown. Thirty-five days later, after weeding shallot, pepper

seedlings are transplanted between the shallot. These two crops grow together for 25-35 days before the shallot is harvested. With this method there is no need to prepare the soil for pepper production (Basuki. 1987). The 'surjan' cultivation method is also practiced in South Bandung (West Java), where farmers monoculture pepper on high beds with or without rice in the furrows between the beds (Permadi et al. 1987). In East Java, pepper is also planted on 100-150 m-wide and 20-30 cm-high beds with 30-50 × 100-125 cm plant distance.

Cost of Production

The average cost of production, yield and net return of pepper farming in 15 centers of production in Indonesia are listed in Table 4. The standard deviations indicate that the figures vary greatly depending on the production center. A study of one of the production centers in Brebes (Central Java) in 1987 showed that pepper farming can be very promising. The cost of pepper production consisted of pesticides (51%), labor (20%), fertilizers (11%) and others (seed, land rent, etc.) (Basuki. 1987). However, in most cases shortage of capital and small land ownership are the main constraints for small farmers.

Table 4. Cost of production, yield and net return of pepper farming in Indonesia.

Location	Production cost ('000)	Yield (t ha)	Net return ('000)
Indonesia[z]	Rp. 816 ± 554 US$ 0.68 ± 0.46	4.1 ± 3.3	Rp. 1,456 ± 1,333 US$ 1,213 ± 1,111
Brebes[y]	Rp. 4,380 US$ 2,737	12.0	Rp. 5,688 US$ 3,555

Source: Anonymous. 1987a. Basuki. 1987. [z]Fifteen centers. [y]One center.

Consumption and Utilization

Both chili and cayenne peppers are usually ground and used as a spice or paste, often mixed with shrimp or as a sauce. However, production can not meet the domestic needs, a small amount of dry pepper (1.3 t) and fresh pepper (2 t) is still imported. Because it is an essential part of the daily diet, pepper consumption is much higher than tomato consumption.

Constraints

Several factors, some of which may be interrelated, contribute to the low average yield of pepper.

Lack of good quality seed. The existing local varieties are all segregating populations and no effort is made to produce good seed. Farmers produce their own seed or sell their seed to the local seed merchant, consequently all seeds are mixtures. Seed of imported cultivars is of good quality. However imported cultivars are not very popular because they are not adapted to the local conditions.

Pest and diseases. The most important pests are *Spodoptera litura* and thrips, while the major diseases are anthracnose and viruses. Farmers are using chemicals to control pests and diseases. This is the reason why pesticides contribute to more than 50% of the production cost of pepper (Basuki. 1987).

Environmental stress. Excessive rains cause high flower and fruit drop in cayenne pepper, resulting in serious yield loss. Chili pepper appears to be less affected.

The lack of suitable fruit storage is particularly important for the fat types, which are commonly grown in Java.

Research and Development

Varietal improvement for disease resistance was initiated by collection and evaluation of local cultivars from Java and Sumatra. Breeding and yield trials of improved inbred lines are in progress. The improvement of off-season production by the use of plastic-lath or screenhouse, hydroponics, and by the application of plant growth regulators has been investigated in order to overcome seasonal fluctuations in production and price. Presently the cultivation under plastic roofing is not economical at a price of US$1.22/kg (Basuki and Asandhi. 1987; Ameriana and Kusumo. 1987). Plant growth regulators (GA 3 , NAA, and Alar) have not shown significant effects on total fruit yield or yield components (Sumiati et al. 1987). Sodium nitrophenolic compounds, containing 0.022% a.i. were found effective in preventing flower and fruit drop and in increasing average length and weight per fruit and total fruit yield (Pekerti. 1980).

Different cropping systems such as relay, mixed or intercropping and plant rotation have been investigated for more efficient use of inputs, maximizing net return and least disturbance of the environment. Intercropping of garlic and pepper was compared to monoculture of both crops. When pepper was planted two months after garlic, at a spacing of 60 × 60 cm between plants, land productivity was 82% higher compared to monoculture (Asandhi et al. 1987).

For the development of an efficient and safe, integrated pest management, the economic threshold of the pests and insecticide residues has been studied. Residues of synthetic pyrethroids were lower compared to organophosphate, i.e. 0.02 to 0.03 ppm vs 0.06 to 0.2 ppm, respectively (Dibyantoro. 1987). Efforts are also underway to control viruses by cross protection.

Postharvest handling of pepper, aimed at longer storage life and storing the fruits when supply is high and market prices are low has also been given attention.

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480

52

Pepper and Tomato Cultivation, Production and Research in Japan

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Abstract

Vegetable production was valued at Y = 2,144 billion (US$15 billion) in 1985, which was 18.2% of the total value of agricultural production in Japan. The acreage of tomato is about 15,000 ha, of which 6,000 ha is under protection in glasshouses or vinyl filmhouses or in vinyl tunnels. Total production was 802,000 t in 1985. 142,000 t of which was for processing and 660,000 t for sale to the fresh market. The average yield of tomato is 50 t/ha although 100-150 t/ha has been achieved. Import of processed tomato products is 77,000 t, import of fresh tomato is nil. The most important tomato diseases are Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*), leafmold (*Fulvia fulvum*), bacterial wilt (*Pseudomonas solanacearum*), bacterial canker (*Corynebacterium michiganense*), TMV, CMV, and rootknot nematodes (*Meloidogyne incognita*). Pepper was introduced to Japan at the end of the sixteenth or the beginning of the seventeenth century. At that time pepper varieties were either hot pepper or sweet pepper with long and thin fruit. By the end of the eighteenth century cultivation of hot pepper was widespread and by the 1920s about 900 tons were exported. In the 1950s the amount of hot pepper exported reached 6,800 t, 70% of which was exported to Sri Lanka, and 20% to 30% to the USA. Japanese hot pepper was well known on the international market for its high pungency. Sweet peppers, especially the bell-type cultivars, were introduced in the 1940s from the USA and their cultivation was established by the 1960s, using protected facilities. In 1984 about 5,300 ha of pepper were cultivated, and production was 188,800 t, of which only 3% was hot pepper. The average yield was 36.8 t/ha. The cropping patterns of pepper resemble those of tomato. Pepper, however, requires high temperature in forcing culture in winter, that is why resistance to cool temperature is an important breeding objective.

Tomato

Production and Cultural Practices

Tomato is a comparatively new vegetable for Japan. Although tomato is first recorded about three hundred years ago, commercial cultivation began only 60-70 years ago. A rapid increase of acreage began about 25 years ago, with the use of protected facilities (Table 1).

The total area of tomato cultivation is about 15,000 ha, of which about 6,000 ha is grown under protected facilities, such as glasshouses or vinyl filmhouses, or in vinyl tunnels. The major production areas are in Nagano and Tochigi prefectures. In 1985, total tomato production was 802,000 t, of which 660,000 t was fresh-market tomato and 142,000 t processing tomato. The average yield is around 50 tons per hectare but the most skillful farmers can obtain about 150 tons of tomato per hectare (Table 2).

Table 1. Protected facilities in Japan.

Year	No. of farmers ('000)	Vinyl house		Glasshouse	
		Farmer ('000)	Acreage (ha)	Farmer ('000)	Acreage (ha)
1965	72	62	2,819	15	440
1970	130	121	8,459	14	597
1975	172	162	17,760	17	1,001
1980	203	195	25,687	17	1,405
1985	254	245	32,329	17	1,671

Source: Ministry of Agriculture, Forestry and Fishery, 1965-85.

Table 2. Tomato production in Japan.

Year	Acreage ('000 ha)	Harvest ('000 t)	Yield (t/ha)
1965	18.8	536	28.5
1970	19.3	793	41.1
1975	19.0	1,024	53.9
1980	19.3	1,014	52.5
1985	15.3	802	52.4

Source: Ministry of Agriculture, Forestry, and Fishery 1965-85

The most important characters required for fresh-market tomato production in Japan are: high fruit quality (vivid color, high vitamin C, content, sugar, carotene); good germination, fruit-setting or parthenocarpy at cool temperatures; and resistance to soil-borne diseases.

Japan is located between 25°N and 45°N and climate varies with latitude and altitude (0 to 1,500 m). Consequently various cropping types of tomato have been differentiated. The typical cropping types in the central part of Honshu island are listed below.

Forcing culture. Sown in August, transplanted to glass or plastic houses at the end of September or the beginning of October, and harvested from December to May of the next year. Heating is started at the beginning of December. In winter, the maximum day temperature is kept at 25°C and the minimum night temperature at around 7°C. The total labor time is about 14,000 h per hectare of which 5,300 h is for harvesting.

Semiforcing culture-1. Sown in November in the greenhouse, transplanted to glass or plastic houses in January or February of the next year and harvested from March to June. Heating is started at sowing.

Semiforcing culture-2. Sown in February in the greenhouse, transplanted to plastic houses in April, harvested from June to August. Artificial heating is not required.

Open-field culture. Sown in February/March in the greenhouse, transplanted to open fields and mulched with black film in April or May. Harvested from June to August.

Forcing culture in autumn. Sown in June/July, transplanted to plastic houses in August, harvested from September to December. Heating is necessary about harvesting time.

Hydroponic culture. Only about 100 ha, representing less than 1% of the total production area, is grown using hydroponic culture.

Compared to other fruits and vegetables the cost of tomato production is not high. The production cost was about (US$12,346 at US$1.00 = Y=162) for 10 a in 1986 for forcing

culture (Figure 1). In the cases of forcing, semiforcing and open-field culture, wages make up about half of the production costs. Costs of facilities and fuel for protected cultures is about 20% and 10%, respectively. The costs of seeds (seedlings), fertilizer and agrochemicals are small compared to the other costs.

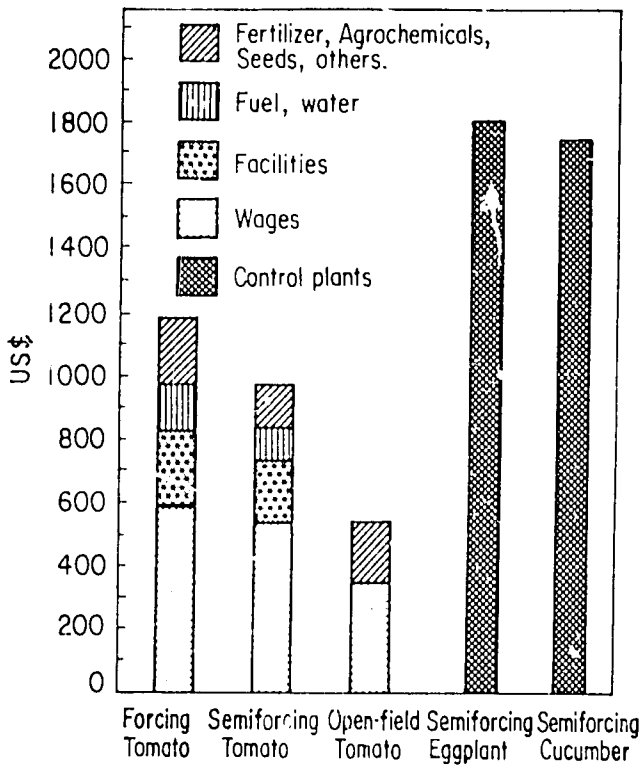

Figure 1.
Cost of tomato cultivation (MAFF. 1986).

Diseases

The most important tomato diseases are Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*, race 1 and race J3) J3 is a new race of *Fusarium oxysporum* f. sp. *lycopersici*, in Japan (Yamamoto et al. 1974) - leafmold (*Fulvia fulvum*), bacterial wilt (*Pseudomonas solanacearum*), bacterial canker (*Corynebacterium michiganense*), Verticillium wilt (*Verticillium dahliae*), tobacco mosaic virus (TMV), cucumber mosaic virus (CMV), and rootknot nematodes (*Meloidogyne incognita*) (Sugawara et al. 1971).

Verticillium wilt and bacterial wilt are very serious and few cultivars with resistance to these diseases are available. However, resistant cultivars for use as root stock have been bred. The hectarage of tomato cultivated by grafting on resistant root stocks is being increased in an effort to avoid damage by Fusarium wilt (particularly by race J3), bacterial wilt, Verticillium wilt and rootknot nematodes.

Consumption, Export and Import

Although the country produces 106,700 t of tomato ketchup (Table 3), 85,500 t of juice, and 7,700 t of tomato puree, the local demand cannot be met. Since the 1970s the consumption

Table 3. Production of processed tomato.

Type of product	1965 ('000 t)	1970 ('000 t)	1975 ('000 t)	1980 ('000 t)	1985 ('000 t)
Ketchup	27.3	35.9	84.9	97.3	106.7
Juice	11.4	26.7	94.2	128.8	87.0
Puree	10.5	13.4	36.6	23.4	7.7
Others	1.6	3.3	33.4	58.1	35.4
Total	50.8	79.3	249.1	307.6	236.8

Source Ministry of Agriculture, Forestry and Fishery 1965-85

of tomato ketchup and juice has rapidly increased, because of changing food habits adopted by the younger generation in Japan. Products have to be imported. Imports of processed tomato products amount to 77,000 t, of which 60,000 t is tomato paste and puree, and 1,300 t ketchup and others. There is no import of fresh tomato.

Research and Development

Breeding. The national and prefectural institutes and experiment stations and the private seed companies are actively engaged in tomato breeding. The Laboratory of Breeding Solanaceous Vegetables of the National Research Institute of Vegetables, Ornamental Plants and Tea (NIVOT), has developed tomato varieties with resistance to Fusarium wilt (race 1 and race J_3), CMV and TMV. At the Morioka branch station, processing tomato has been developed, and at the Kurume branch station lines have been developed suitable for forcing culture in the southern part of Japan. At the prefectural experiment stations cultivars have been developed which are adapted to the particular local environments.

At NIVOT three lines and two F_1 hybrids (Table 4) were bred using the following three lines as parentals: *L. peruvianum* line PI 126944, resistant to corky root (*Pyrenochaeta lycopersici*), curly top virus, Verticillium wilt, Fusarium wilt (race 1 and J_3), leafmold, tomato spotted wilt virus, tobacco mosaic virus (Tm2 gene), and rootknot nematodes; L 253 from Louisiana State University, resistant to cucumber mosaic virus, tobacco mosaic virus (Tm), and rootknot nematodes; and Ohio 690712, resistant to Fusarium wilt (race 1) and TMV ($Tm2^2$) (Yamakawa, 1977).

Lycopersicon pennellii has been used for its resistance to Fusarium wilt race J_3 and bacterial canker, *L. glandulosum* and *L. hirsutum* for their resistance to corky root; and *L. pimpinellifolium* University of Missouri Accession 160 (Bohn and Tucker, 1940) for resistance to Fusarium wilt race 1.

The resistance gene I seems very stable and consequently all newly bred cultivars have this gene. Fusarium wilt race J_3 first occurred at Kochi Prefecture in 1967 and attacked cultivars with the I genes. Resistance to J_3 was found in PI 126944 (Komada, 1974) and was bred into Ano 4 and Ano 5, the first lines resistant to race J_3 (Table 4).

Table 4. Resistant tomato lines bred at NIVOT

Line	Fusarium		CMV	Nematodes	TMV
	Race 1	Race J_3			
Ano 3	+		+	+	Tm Tm, Tm 2a Tm 2a
Ano 4	+	+			Tm 2a Tm 2a
Ano 5	+	+			Tm 2 Tm 2
$(F_1)^z$	+	+	+	+	Tm +, Tm 2a Tm 2a
Ryugyoku $(F_1)^y$	+	+	+	+	Tm +, Tm 2 Tm 2a

$^z F_1$ (Ano 4 × Ano 3) $^y F_1$ (Ano 5 × Ano 3)

The lines developed at the national institutes with resistance to various diseases are listed in Table 5. Breeding of processing tomato is carried out at the Morioka branch station of NIVOT and the Nagano Chusin Agricultural Experiment Station. The genes controlling fruit color such as hp (high pigment), og (old gold), r (yellowish flesh), t (tangerine) etc. are used for improving fruit color and carotene content (Mochizuki and Kaminura, 1986). Mature fruits of *L. esculentum* and *L. pimpinellifolium* do not contain sucrose, but the fruits of other wild relatives such as *L. cheesmanii* do. A collection of wild relatives has been assembled for use in improving the processing qualities.

Table 5. Disease resistant improved tomato cultivars by public stations.

Cultivar	Year	Resistance[x]						
		F		V	Cl	N	TMV	Institute[y]
		Race 1	Race J3					
Morioka 10	1972	+						NIVOT
Wakashio	1972	+					+	Chiba
Hohyoh	1972	+			+			Ohita
Tanomo	1973	+			+		+	Nagano
Tsukama	1973	+			+		+	Nagano
Happo	1973	+					+	Nagano
Raiden	1973	+			+	+	+	Nagano
Morioka 11	1974	+						NIVOT
Morioka 12	1974	+						NIVOT
Morioka 13	1974	+						NIVOT
Shuhgyoku	1974	+			+			NIVOT
Sugano	1976	+					+	Nagano
Morioka 15	1977	+						NIVOT
Morioka 16	1977	+						NIVOT
Shunrei	1978	+			+		+	Naganc
Fujimi	1980	+		+		+		Tokyo
Chiba first	1981	+				+		Chiba
Kanare	1981	+					+	Aichi
Shinanoaka	1982	+		+				Nagano
Rojiyutaka	1982	+		+			+	Nagano
Kurume pink	1983	+						NIVOT
Kagyoku	1984	+	+			+	+	NIVOT
Ryugyoku	1984	+	+			+	+	NIVOT
Shuhhoh	1985	+		+				Nagano
Sanppo first	1985	+	+				+	Aichi

[x]F = Fusarium wilt, V = Verticillium wilt, Cl = *Cladosporium fulvum*, N = rootknot nematodes, TMV = tobacco mosaic virus [y]For full names see the Appendix

Physiology and ecology. With the advance of tomato cultivation under protection, research on the physiology and ecology of tomato has been stimulated. In a typical vinyl house the CO_2 content is 500-600 ppm just before sunrise and 150 ppm at noon without ventilation, leading to decreased photosynthetic ability (Hisatomi and Morioka, 1978). Ventilation and sufficient supply of CO_2 is therefore very important. The CO_2 saturation content is 1,000-1,500 ppm (Hisatomi and Morioka, 1978).

Generally, it was found that the optimum air temperature was 25-28 °C in the daytime and 5-7 °C at night. The optimum soil temperature in the daytime was found to be 20-22 °C, which is lower than the air temperature (Kaname and Itaki 1973).

Cold tolerance is important for forcing culture. Varietal differences for cold tolerance exist (Masaki and Oono 1981). *Solanum lycopersicoides* has resistance to low temperature. Hybridization between *L. esculentum* and *Solanum lycopersicoides* is very difficult but by the use of sesquidiploids (Rick et al. 1988) or somatic hybrids (Handley et al. 1986) it has recently

become possible to introduce the resistance gene(s) for cold tolerance from *S. lycopersicoides* to tomato. Physiological disorders are common in protected cultivation. Excess nitrogen and potassium, boron or calcium deficiency, or low night temperatures, cause fruit disorders (Katoh, 1986). Salt accumulation usually results from continuous cropping of tomato under protection.

Hydroponic culture has shown promise as a means of avoiding the problems associated with continuous cropping. However the acreage of hydroponic tomato culture is only about 100 ha.

International collaboration. At NIVOT, a three-year joint research program entitled Biotechnological Development of Tropical Microorganisms and Plants was initiated in 1983 in cooperation with the Malaysian Agricultural Research and Development Institute (MARDI). Native varieties and wild relatives of solanaceous vegetables were collected and screened for resistance to bacterial wilt, Verticillium wilt and some insect pests. The resistant varieties will be utilized for resistance breeding in both countries.

The institutes and researchers working on tomato are listed in the Appendix.

Pepper

Current Pepper Situation

Pepper was introduced into Japan at the end of the 16th or the beginning of the 17th century. Both sweet pepper and hot pepper spread rapidly both as a vegetable and an ornamental plant. By the end of the 19th century, cultivation of hot pepper was widespread and Japanese pepper was very famous for its high pungency. Export of hot pepper amounted to about 900 t in the 1920's. In the 1950's, the amount of hot pepper exported was 6,800 tons, 70% of which was to Ceylon (Sri Lanka) and 20% to 30% to the USA.

Many cultivars of sweet pepper were introduced in the 1940's from the USA. Commercial cultivation of sweet pepper as a vegetable was established in the 1950's and increased rapidly using forcing culture under protected facilities in 1960's.

In 1984, the total hectarage of pepper (excluding hot pepper) was 5,127, producing 188,801 tons, (Table 6). The yield of sweet pepper was about 36 to 37 t/ha. The total hectarage of hot pepper was 142, producing 381 tons on a dry weight basis. The average yield was 36 tons per ha.

The four types of pepper cultivation (forcing, semi-forcing, open-field, and autumn forcing) resemble those for tomato. The minimum air temperature for winter cultivation has to be about 18-20°C; the heating in forcing or semi-forcing cultures is extremely expensive, and consequently one fourth of the production cost is accounted for by artificial heating. Tolerance to cool temperatures is therefore one of the most important breeding objectives.

Table 6. Pepper production in Japan, 1984.

	Acreage (ha)	Harvest ('000 t)	Main producing prefecture
Sweet pepper	5,127	188.8	
- bell type	4,790	180.3	Ibaraki, Miyazaki
- other types	377	8.5	Kyoto, Chiba
Hot pepper	142	0.4	Ibaraki, Tochigi
Total	5,269		

Diseases. Generally, diseases of pepper are similar to those of tomato although they are not considered important production constraints. Special disease problems exist locally, such as Phytophthora rootrot (*Phytophthora capsici*) in the central part of Honshu and the southern part of Kyushu island.

The use of an attenuated strain (Pa18) was found to be very effective to control TMV-P on pepper plants (Goto et al. 1984). Pa18 was isolated from pepper plants inoculated with TMV-P, using Holmes' method (Holmes. 1934). Plants inoculated with Pa18 showed mild symptoms throughout the growth period but were protected from the attack of TMV-P. Although the use of attenuated strains for protecting against TMV-P is effective, there are some practical problems. One is the variety of differences in reaction to inoculation with the attenuated virus; another is the difference in symptom expression under different environmental conditions (Yoneyama et al. 1985).

Research and Development

Research. Sweet pepper breeding is dealt with by national and prefectural institutes and experiment stations and private seed companies. At the Nagano Chushin Agricultural Experiment Station the main objectives for breeding pepper are resistance to TMV-T (tomato strain), TMV-P (pepper strain), cucumber mosaic virus (CMV), and Phytophthora rootrot (Kobayashi et al. 1984). Tolerance to cool temperatures is the most important pepper breeding objective at NIVOT. One line of *Capsicum baccatum* has been found which is more resistant to CMV than commercial cultivars of *C. annuum* (Narikawa et al. 1987). One *C. pubescens* line, introduced from France, was found with high resistance to CMV. The resistant gene of *C. pubescens* will be incorporated into *C. annuum* as follows: (a) crossing of *C. annuum* and *C. pubescens* directly to obtain hybrids; (b) crossing of *C. frutescens* and *C. pubescens* using *C. cardenasii* (Pickersgill. 1986) and crossing of *C. annuum* and the hybrids; (c) cell fusion techniques to obtain somatic hybrids.

Almost all commercial cultivars have resistance to TMV-T. Presently there is no commercial pepper cultivar with resistance to TMV-P. However resistance to TMV-P has been found in *C. chinense* PI 152225, PI 159236, PI 315008 and Smith SA 411 (Yamakawa and Nishio. 1979) and will be incorporated into commercial cultivars.

International collaboration. At the Tropical Agricultural Research Center (TARC) of the Ministry of Agriculture, Forestry and Fishery (MAFF), Japan, a joint research project (Joint Research on the Development of Breeding and Cultivation Methods for the Stable Production of Vegetables in the Tropics) was started in 1987 in cooperation with the Shanghai and Guangdong Academy of Agricultural Sciences of the People's Republic of China. Sweet pepper, Chinese cabbage and cucumber are the major vegetables of this project. The major objectives for sweet pepper are heat tolerance, and resistance to CMV and other diseases.

A joint research project between NIVOT and MARDI (Malaysia) has been completed, in which native varieties of pepper as well as tomato and eggplant were collected for use in breeding for heat tolerance and disease resistance.

Future Needs

The development of techniques to obtain hybrids between distant relatives will be necessary to transfer the promising characters of the wild species, such as tolerance to environmental stresses or resistance to CMV from *C. pubescens*, into the cultivated species.

The institutes and researchers working on pepper are shown in the Appendix.

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Appendix. Institutes and researchers working on pepper and tomato improvement.

National Research Institute of Vegetables, Ornamental Plants and Tea (NIVOT), Ano, Mie 514-23.

Breeding (tomato, pepper): Kunio Yamakawa, Tomoaki Narikawa, Ken'ichi Hida, Yoshiteru Sakata.

Quality (pepper, tomato): Shinji Monma, Osamu Nakagawa.
Disease (pepper, tomato): Masayoshi Ishii, Kazuo Abiko, Ichiro Fujisawa.
Cultivation (tomato): Hiroshi Nakamura, Takehiko Nakashima.
Physiology (tomato): Norio Seyama, Yoshihiro Shishido, Shigeo Imada, Naoki Katsura, Takaaki Nishijima.
Postharvest (tomato): Ryoyasu Saijo, Gensoh Ishii, Masayasu Nagata, Makoto Nakashimada, Shuichi Fukatsu.

NIVOT Morioka Branch Station, Shimo-kuriyagawa, Morioka, 020-01.
Breeding (tomato): Denji Ishiuchi, Kimio Itoh. Cultivation (tomato): Kazuo Arai.

NIVOT Kurume Branch Station, Mii, Kurume, 830.
Breeding (tomato, pepper): Yoshihiro Iwanaga, Tatemi Yoshida, Keita Sugiyama.
Post harvest (tomato): Setsuo Obama.

National Agricultural Research Center, Kan'non-dai, Tsukuba, 305.
Diseases (tomato, pepper): Hajimu Komada, Katsuto Kuniyasu, Hiroshi Tochihara.

Hokkaido National Agricultural Experiment Station, Hitsujigaoka, Toyohira, Sapporo, 004.
Diseases (pepper): Norio Iizuka, Tadanori Goto.

Hokkaido Donan Agricultural Experiment Station, Ono, Kameda-gun, 041-12.
Tomato: Kazuo Sawada Koji Shiozawa, Yutaka Inagawa.

Nagano Chusin Agricultural Experiment Station, Soga, Shiojiri, 399-64.
Breeding (tomato, pepper): Tadakazu Kobayashi, Suguru Kobayashi, Yukio Yanokuchi.

Chiba Agricultural Experiment Station, Daizenno, Chiba, 280-02.
Pepper: Yuji Nagai, Akio Murata Taeko Takeuchi, i. Hiroshi Aoki, Yuji Udagawa.

Kochi Horticultural Experiment Station, Noichi, Kochi, 781-52.
Pepper: Mitsuo Matsumoto, Seiichi Saito Hiromasa Sawada.

Shizuoka Agricultural Experiment Station, Toyoda, Iwata, 438.
Tomato: Tetsiji Suzuki, Hideo Mochizuki, Shin'ichi Nakamura, Hiroshi Arakawa.

Aichi Agricultural Experiment Station, Institute of Horticulture, Nagakute, Aichi-gun, 480-11.
Tomato: Yozo Sakurai, Shinji Sugawara.

Nara Agricultural Experiment Station, Yojocho, Kashiwara, 634.
Tomato: Tokio Hisatomi, Kiyoshi Naito, Masayoshi Minegishi.

Symposium Discussion

L.C. Chang: (1) Do you have any problem of fruit deformation or other constraints in pepper production under low temperatures? Do you have a pollination problem when you grow pepper in vinyl houses? (2) Do you apply artificial/insect pollination in the greenhouse to assist fruit-set?
A. Tsumita: (1) We have problems of deformed fruit in pepper production during the winter season. Fruit is longer in shape and has a nipple at the bottom. This problem occurs under low night temperatures and low daylight. Farmers control low temperature by heating; the minimum temperature is 15°C to 18°C. (2) Normally we do not have to apply artificial insect pollination.

only natural pollination. Our winter season varieties have very good fruit-set under low temperatures.

W.J. Ho: As you mentioned , the market price of fresh tomato in winter is very high in Japan. Winter is the wrong season to produce inexpensive tomatoes. Why is Japan not importing fresh tomato from neighboring countries, where conditions are more favorable for tomato production during the winter months? Is there any possibility of lifting the import ban for fresh tomato?
M. Hatanaga: The average consumers price is US$3/kg (highest price US$8). The requirements of Japanese consumers are very specific: (1) pink fruit color (100%); (2) high fruit quality and sweet flavor (7 degrees brix); and (3) freshness (90% of tomatoes are consumed fresh). If neighboring countries can produce such tomatoes, I think they can export fresh tomatoes to Japan.

J.M. Meunier: (1) What is the hectarage of tomato affected by the J_3 race of Fusarium wilt? (2) Is there any red tomato fruit grown in Japan? If yes, how many hectares?
M. Hatanaka: (1) 400-600 ha. (2) No. All tomatoes grown in Japan have pink-skinned fruit.

490

53

Tomato and Pepper Production and Research in Korea

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Abstract

In Korea, pepper and tomato can be grown in the open field only from April to October, even at the southern tip of the peninsula. Hot pepper is an essential vegetable, used mainly for seasoning the local dish 'kimchi' and for making hot pepper paste for various local foods. Total hot pepper production in Korea is about 197,000 t, with an average yield of 1.5 t/ha and an annual consumption of about 4.8 kg per capita. Seedlings are usually raised in nursery beds and transplanted soon after the last frost. Production is hampered by a high incidence of pests and diseases, and high temperatures and rainfall in summer are also limiting factors. Research initially focused on the evaluation of local and introduced varieties, followed by line selection and cross-breeding. The use of male sterility for F_1 hybrid varieties was established. Other research areas include disease and pest control, plant nutrition, flower and fruit drop, and problems arising from continuous cropping. Tomato, however, is a minor vegetable in Korea, with a total growing area of about 3,000 ha and a total production of 93,000 t. Annual consumption is about 3.2 kg per capita for fresh fruits and about 0.5 kg for processed products. All fresh fruit is produced locally, but most processed tomato products are imported, mainly in the form of paste, of which 5,107 t was imported in 1985. Fresh-market tomato production is often hampered by unsuitable temperatures and a high incidence of disease. Research efforts have recently been intensified to improve fruit quality and disease resistance. The breeding of once-over harvest varieties for processing has also been initiated.

Introduction

Korea is located between 33.06° and 43.00°N latitude, and 124.11° and 132.51°E longitude. The peninsula is surrounded by the sea in the east, west and south. The country is located in the monsoon zone, and has four distinctly different seasons with cold and dry winters, and hot and humid summers. Average annual temperature in the lowland areas ranges from 10°C to 16°C. Temperatures are high from June through August, with daily maximum temperatures ranging from 30°C to 35°C. Temperatures below 0°C are experienced during three to four months in winter. Frost occurs from early October to late April in the central region, and from early November to mid-March in the southern region. The annual precipitation is 1,000-1,700 mm, with 50%-60% falling in June to August (Compilation Committee Society for Korean Agricultural Art History, 1983). The above climatic conditions make field cultivation of tomato and pepper feasible only from April or May to mid or late October. At other times cultivation is possible only under tunnels or plastic houses

Pepper

Present Status

Production and consumption. Hot pepper is an important vegetable mainly used for seasoning 'kimchi' and for making hot paste, both of which are essential components of the rice-based Korean diet. In recent years the green fruit is also gaining importance as a vegetable.

The hectarage of hot pepper for dry red powder production has increased by 20% in recent years, from approximately 110,000 ha in 1979 to about 130,000 ha in 1986. This accounts for 35% of the total hectarage of vegetable planting in Korea. Production has increased by almost 80% during the corresponding period (Tables 1 and 2). The yield per ha has also been increasing in the past few years (Ministry of Agriculture, Forestry and Fisheries, 1982, 1987) brought about by the introduction of high-yielding varieties and of better growing techniques including the use of plastic mulch covers and the raising of seedlings on hot beds (Park, 1983).

Table 1. Cultivation hectarage of open-field vegetable crops in Korea (1986).

Crop	Hectarage (ha)	Percentage of total
Cucumber	3,955	1.1
Oriental melon	5,040	1.4
Squash	2,451	0.7
Water melon	22,625	6.1
Tomato	1,117	0.3
Strawberry	4,105	1.1
Chinese cabbage	48,131	13.1
Cabbage	4,052	1.1
Spinach	5,046	1.4
Lettuce	2,981	0.8
Radish	37,683	10.2
Carrot	5,105	1.4
Red pepper	128,963	35.0
Garlic	48,240	13.1
Welsh onion	24,248	6.6
Onion	9,791	2.7
Ginger	3,445	0.9
Others	10,941	3.0
Total	367,959	100.0

Source: Ministry of Agriculture, Forestry and Fisheries 1987.

Table 2. Production and hectarage of hot pepper in Korea (1979-86).

Year	Dried pepper			Fresh pepper (under protection)		
	Hectarage (ha)	Yield kg/ha	Production (t)	Hectarage (ha)	Yield kg/ha	Production (t)
1979	109,203	1,030	112,479	1,431	11,050	15,826
1980	132,700	940	125,100	1,611	11,830	19,067
1981	151,037	910	137,575	1,521	14,050	21,368
1982	113,368	1,150	130,465	1,708	14,630	24,989
1983	122,188	1,590	194,184	1,871	14,500	27,129
1984	99,796	1,170	116,910	1,742	14,030	24,447
1985	117,877	1,400	165,277	2,412	12,520	30,191
1986	128,963	1,530	197,804	3,155	13,390	42,257

Source: Ministry of Agriculture, Forestry and Fisheries, 1982, 1986.

The area under plastic house cultivation for the supply of fresh vegetables during the winter months has increased steadily since 1979 and reached 3,155 ha in 1986 with an annual production of 42,257 t (Table 2) (Ministry of Agriculture, Forestry and Fisheries. 1982, 1987).

The annual per capita consumption of dry red pepper amounts to 4.8 kg while that of green pepper is about 1 kg (Ministry of Agriculture, Forestry and Fisheries. 1987).

Major production areas. Hot pepper is widely cultivated throughout the nation. However, the major production areas are in the hilly areas of Chungcheongbuk-do and Kyungsangbuk-do provinces which are located in the central part of the country. Figure 1 indicates that 44% of the national total hectarage grown to hot pepper is located in these two provinces (Park. 1983).

Temperatures are similars in the major areas and in the less important areas. However, the major production areas have longer mean sunshine hours and lower rainfall, providing more favorable conditions during the growing period (Table 3).

Cultivation patterns and cultural practices. Several cultivation patterns for pepper have differentiated on the basis of sowing time (Table 4). Early season farming is generally adopted for dried hot pepper production. The seeds are sown in early February, seedlings are grown in plastic pots for about 90 days until they are transplanted into the field in late April or early May as soon as the frost is gone, and harvesting continues from July to October. Since the early 1970's, green hot pepper has been grown under plastic houses in the southern region. This growing method has differentiated into forcing, semi-forcing and late culture (Compilation Committee Society of Korean Horticultural Development History. 1980).

The cultivation practices for hot pepper vary considerably, depending upon growers and districts. However, seedlings are generally raised for 90 days in cold beds, and transplanted at a rate of about 45,000 plants per ha. About 450-700 kg/ha of fertilizer is used. Manure is applied at about 10,000-20,000 kg with little of lime. The soil is usually covered with plastic film to raise soil temperature and to retain soil moisture. Chemicals are sprayed about 10 times during the growing period to control diseases and pests such as *Phytophthora* blight, anthracnose, bacterial leafspot, aphids, tobacco budworm and others. In almost all major production areas,

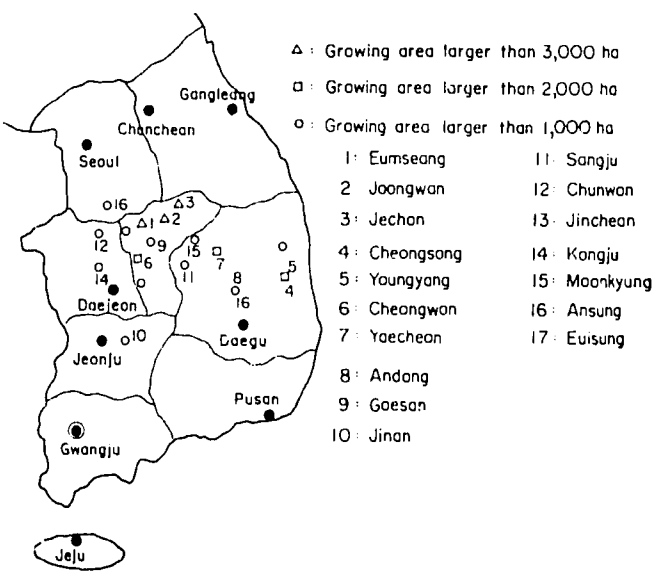

Figure 1.
Major production areas of hot pepper in Korea.

Table 3. Climatic conditions in major hot pepper production districts during growing periods from June to September (1931-60).

District	Temperature (°C)			Sunshine (h)	Precipitation (mm)
	Mean	Maximum	Minimum		
Major Producing Districts					
Jecheon	21.4	26.9	16.4	865.8	594.9
Chungju	22.5	28.0	17.9	1,047.9	675.6
Goesan	22.2	28.1	17.4	1,088.5	658.7
Eumseong	21.9	27.8	17.5	971.0	770.3
Andong	22.7	28.6	17.7	1,019.0	549.8
Euiseong	22.5	28.4	17.4	934.1	583.9
Cheongsong	21.5	27.9	16.2	862.4	563.9
Mean	22.1	28.0	17.2	969.8	628.2
Minor Producing Districts					
Seoul	22.8	28.1	18.7	800.3	893.8
Gangleung	21.8	26.3	18.2	716.5	735.2
Jeonju	23.4	28.8	19.2	813.6	830.3
Gwangju	23.5	28.7	19.8	812.0	783.1
Busan	22.7	26.6	20.0	791.0	815.2
Yeosu	23.0	26.1	20.6	750.2	787.8
Jeju	23.3	27.2	20.4	850.5	844.0
Mean	22.9	27.4	19.6	790.6	812.6

Source: Central Meteorological Office. Climatological statistics from 1931 to 1960 (cited in Park, S.K. 1983.

Table 4. Cultivation patterns of hot pepper in Korea.

Cultivation patterns	Sowing time	Planting time	Harvesting time	Cultivation region
Forcing culture	September	January	March-October (under protection)	Southern region
Semi-forcing culture	December	February	April-October (under protection)	Southern region
Early maturing culture[z]	February	May	July-October (open field)	Whole country
Direct sowing culture	April	–	July-October (open field)	Whole country
Late culture	July	September	November-June (under protection)	Southern region

Source: Compilation Committee Society of Korean Horticultural Development History. 1980. [z]Seedlings are grown on hot or cold beds under protection.

farmers have been continuously growing peppers for at least five years (Table 5), which has resulted in a 'sick soil' problem. Deteriorating physical and chemical properties, accumulation of phytotoxic substances, and high population densities of soilborne plant pathogens and pests are typical symptoms of 'sick soil' (Kim et al. 1987; Lee and Kim. 1985).

Marketing. Hot red pepper is sun or oven-dried after harvest and marketed by each grower in the production area. Marketing channels from producers to consumers vary. The most popular ones are: (i) growers - collecting merchants who visit and buy from growers-metropolitan wholesalers (agents) - retailers - consumers, and (ii) growers wholesalers (agents) - retailers

- consumers. The marketing margin is 44.5% of the consumer's price, out of which 26.9% is for packing, transportation, service charges, loading, unloading and tax, and 17.6% is the middleman's profit (Cho and Kim. 1982).

Utilization. Hot pepper fruits harvested from the field are dried and powdered as spice or condiment for kimchi, hot paste, and other foods. Hot pepper is also eaten fresh or in pickled form. Plastic house cultivated peppers are generally consumed raw and only a small portion is used for processing into spices (Cho and Kim. 1982).

Varieties. In the early 1970s, open-pollinated land races were predominantly grown. However, since the mid-1970s F_1 hybrids gradually replaced the local cultivars in most production areas. In 1986 F_1 hybrid cultivation accounted for 80% of the total cultivation acreage (Horticultural Experiment Station. 1986). Eighty-six F_1 hybrid varieties bred by local commercial seed companies have been released and marketed since 1979. The present leading cultivars are shown in Table 6 (Korean Seedling Society. 1986).

Table 5. Cultivation methods of hot pepper in Korea.

Item	Method and percentage of adoption
Seedling raising	Direct sowing (1), cold frame (61), manure-heated hot bed (28), electrical hot bed (10)
Days of seedling raising	70-80 (15), 81-90 (41), 91-100 (30), over 101 (14)
Height of bed	Below 10 cm (11), 11-15 cm (52), 16-20 cm (37)
Number of plants per ha	Less than 40,000 (43), 40,000-50,000 (43) more than 50,000 (14)
Fertilizer application (kg/ha)	Less than 450 (28), 460-650 (38), more than 651 (34)
Nitrogen	Less than 150 (29), 160-250 (44), more than 260 (15)
Potassium	Less than 150 (34), 160-250 (48), more than 251 (15)
Phosphorus	Less than 150 (39), 160-250 (54), more than 251 (11)
Manure application (kg/ha)	Less than 10,000 (47), 10,000-20,000 (40), more than 20,000 (28)
Chemicals application frequency	Not applied (64), less than 1,000 (8), more than 1,001 (28)
Mulching	No mulching (2), mulching with plastic film (98)
Pesticide application frequency	Less than 5 (31), 6-10 (46), more than 11 (23)
Continuous cropping (years)	Less than 5 (33), 6-10 (34), more than 11 (33)

Source: Annual Research Report of Hort. Expt. Sta. 1986

Table 6. Hot pepper varieties and their characteristics.

Variety	Year of registration	Maturity	Fruit length (cm)	Fruit weight (g)	Use	Cultivation type	Pungency	Yield (kg/ha)
Hongilpoom (F_1)	1981	Medium	7-8	6-8	Dried	Open field	Strong	8,000-10,000
Bulamput (F_1)	1979	Early	12-14	12-14	Fresh	Under protection	Medium	18,000-20,000
Hanpyul (F_1)	1980	Medium	10-13	10-13	Dried	Open field	Strong	18,000-20,000
Cheongyang (F_1)	1983	Early	7-9	7-10	Dried	Open field	Strong	10,000-13,000
Cheonghong (F_1)	1983	Early	13-15	13-15	Dried, fresh	Open field, Under protection	Strong	12,000-14,000
Jinpoom (F_1)	1984	Early	7-9	5-7	Dried	Open field	Strong	12,000-14,000
Sinhong (F_1)	1985	Medium	9-11	4-5	Dried	Open field	Strong	16,000-19,500
Hongsil (F_1)	1983	Medium	9-11	10-12	Dried	Open field	Medium	16,000-19,000
Koreagon gochu (F_1)	1979	Medium	8-10	15-18	Fresh	Open field	Medium	10,000-16,000
Ilwolgon gochu (F_1)	1985	Early	7-9	6-8	Dried	Open field	Strong	11,000-13,000

Source: The Korean Seedling Society. 1986.

Trade. Local demands for dried hot pepper are usually met by domestic production. Before 1983, dried fruits were imported from China, India, Pakistan and Singapore to make up the domestic demand in case of a crop failure. Since 1984 dried fruits have only been imported from China. A large amount of dried fruit was imported in 1984 and 1985 owing to crop failures (Tables 7 and 8). Dried and fresh hot pepper, and hot paste, are mainly exported to Japan, the USA, Saudi Arabia and other countries (National Agricultural Cooperative Federation. 1987).

Table 7. Export and import of red pepper 1980-86.

Year	Export				Import	
	Dried pepper		Fresh pepper		(dried pepper)	
	Amount (t)	Value (US$1,000)	Amount (t)	Value (US$1,000)	Amount (t)	Value (US$1,000)
1980	26.7	264.7	220.8	1,687.9	5,625	7,963
1981	20.8	124.5	481.3	1,883.5	516	782
1982	231.3	487.5	970.4	2,920.8	2,243	2,951
1983	188.9	386.9	1,194 2	3,128.5	1,198	1,627
1984	120.2	418.9	411.7	1,177.7	8,245	10,931
1985	150.4	526.0	497.9	1,313.3	11,210	11,762
1986	170.6	500.7	9,732.5	1,876.2	875	1,151

Source: Trade statistics from the Office of Tariff. 1986. (cited in the National Agricultural Cooperative Federation, 1987).

Table 8. Export and import of pepper paste (1980-86).

Year	Export		Import	
	Amount (t)	Value (US$1,000)	Amount (t)	Value (US$1,000)
1980	1,053	1,373	2	2
1981	1,080	2,058	8	11
1982	1,311	1,439	–	–
1983	1,444	1,676	7	11
1984	1,648	1,817	275	217
1985	1,708	1,846	716	574
1986	1,665	1,932	263	212

Source: Trade statistics from the Office of Tariff. 1986. (cited in National Agriculture Cooperative Federation, 1987).

Production Constraints

Environment. Low cumulative temperatures in Korea allow only a relatively short growth period (150-190 days). Excessive rainfall, high temperatures and typhoons in the summer often result in great damage to the crop (Park. 1983).

Soil conditions. Korea has much acid soil, which requires liming (Compilation Committee Society for Korean Agricultural Art History. 1983). Continuous cropping in most of the major production areas has resulted in the following problems:

(i) Deteriorated physical and chemical properties of soil; continuous monocropping has resulted in poor soil structure, low pH, shortage of Ca^{++}, Mg^{++} and other minor nutrients, and accumulation of phosphorous (Kim et al. 1987).
(ii) Accumulation of phytotoxic substances; substances such as glutamic acid, alanine, aspartic acid, and glycine secreted from plant residues (leaves, shoots, roots) after harvesting are accumulated and are responsible for poor root growth, leaf chlorosis and wilting symptoms (Lee and Kim. 1985).

(iii) Increased population of soilborne plant pathogens including rootknot nematodes; damage by Phytophthora blight (*Phytophthora capsici* Leonian) is reported to be more than 20% in hot pepper annually. Damage from bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith) and rootknot nematodes (*Meloidogyne* spp.) is on the increase (Kim et al. 1987; Lee and Kim. 1985).

Pests and diseases. The prevailing diseases are anthracnose (*Colletotrichum gloeosporioides* Penz and *P. capsici*), bacterial spot (*Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dowson), tobacco mosaic virus, cucumber mosaic virus, and soilborne diseases such as *Phytophthora* blight and bacterial wilt (Kim et al. 1987; the Korean Society of Plant Protection. 1986). The oriental tobacco budworm (*Heliothis assulta* Guenée) is the most harmful insect pest, followed by aphids, and tobacco cutworm (*Spodoptera litura* Fabricius). Rootknot nematodes and mites are also important (Kim et al. 1987; Korean Society of Plant Protection. 1986).

Varietal. The remarkable increase in yield per unit area of the newly-released F_1 hybrids has led growers to adopt F_1 hybrids instead of local varieties. However, until now, more than 20% of the planted area is still occupied by local cultivars, resulting in low productivity.

Market price. As the demand for hot pepper is always constant, a slight fluctuation in supply leads to severe changes in the market price. A poor crop causes a sharp price rise, whereas over-production causes a sharp price drop, with drastic decrease in farmers' income (Cho and Kim. 1982).

Research and Development

Crop management. Intensive research on methods to attain high yield was conducted in the 1970s. As a result, productivity was increased through the improvement of cultivation methods such as hot bed seedling raising and plastic film mulching (Park. 1983). Presently research priority is given to determining the association of blooming, fruit-setting, and fruit characteristics with environmental factors, such as light and soil moisture (Lee et al. 1982). It is hoped that the results will elucidate the physiological reasons involved in 'soil sickness' and help determine appropriate counter measures. Disease surveys have been conducted in the major production areas. Integrated control methods are being investigated for the effective control of diseases and pests such as late blight, anthracnose, tobacco mosaic virus and nematodes. These methods include the use of resistant cultivars, grafting, and cross-protection with attenuated virus and improved soil and ventilation management in plastic film houses (Kim et al. 1987).

Varietal improvement. Male sterility has been used as a means of F_1 hybrid seed production since the late 1960s (Chung et al. 1971). Genetic analysis of male sterility was conducted. Male sterility was induced by nuclear restitution, and is now commonly used for commercial seed production. At present, basic research on genetic analysis, heritability, genetic correlation, and combining ability of major characteristics is in progress for the breeding of superior varieties (Om and Pyo. 1981). It is expected that varieties with multiple disease resistance to *Phytophthora capsici*, *Pseudomonas solanacearum*, *Colletotrichum gloeosporioides*, *Xanthomonas campestris* pv. *vesicatoria*, tobacco mosaic virus and cucumber mosaic virus will become available soon (Choi and Bae. 1986). A few cultivars with multiple disease resistance have been bred (Horticultural Experiment Station. 1986). Furthermore, varieties with high capsaicin content (0.6-2.0 mg/100 g) and high percent powder yield are being developed (Choi and Bae. 1986).

Production and marketing. To cope with the problem of production fluctuation, the government has recently promoted the crop forecasting service. This allows farmers to make better decisions about crop management and marketing.

Research institutes and researchers. The national research institutes, universities and seed companies involved in research on breeding, physiology and production technology of pepper are shown in the Appendix.

Future Needs

The production of hot pepper has been substantially increased by varietal improvement and cultural methods. In the future the following aspects need to be addressed:

(1) Cultural methods and varietal improvement to prevent flower and fruitdrop caused by high temperature and excessive rainfall in the summer season.
(2) Breeding varieties with high capsaicin content and high powder percentage when processed.
(3) Breeding varieties with multiple resistance to several diseases.
(4) Analysis of causes of soil sickness and methods to resolve it.
(5) Integrated control methods for diseases and pests.

Tomato

Present Status

Production and consumption. Tomato was introduced to Korea about 400 years ago, at about the same time as pepper (Compilation Committee Society of Korean Horticultural Development History. 1980). However, it is considered as a minor vegetable. There are no large-scale production areas; the crop is cultivated on a small scale throughout the country. The cultivation area is 3,000 ha (Table 9) (Ministry of Agriculture, Forestry and Fisheries. 1987). Since the 1970's the field-grown hectarage has decreased, whereas yield per unit area has progressively increased through the use of superior cultivars and improved cultural methods (Ministry of Agriculture, Forestry and Fisheries. 1987).

The year-round demand has led to the differentiation of cropping systems under plastic film houses. The cultivation hectarage under plastic film houses has increased yearly since the 1960s and has reached 1,800 ha in 1986 (Ministry of Agriculture, Forestry and Fisheries. 1987). Plastic house cultivation is now more important than field cultivation in Korea (Tables 9 and 10).

Annual consumption is about 2.3 kg for fresh fruit per capita, and about 0.5 kg for processed products (Ministry of Agriculture, Forestry and Fisheries. 1987).

Table 9. Production and hectarage of tomato in Korea (1978-86).

Year	Open field			Under protection		
	Hectarage (ha)	Yield (kg/ha)	Production (t)	Hectarage (ha)	Yield (kg/ha)	Production (t)
1978	1,827	19,170	35,011	909	30,500	27,728
1979	1,268	44,450	56,345	874	36,510	31,917
1980	1,742	18,270	49,241	852	31,850	27,139
1981	2,510	29,669	74,438	1,078	28,080	30,266
1982	1,978	28,880	57,131	1,303	29,340	38,233
1983	1,192	29,170	34,769	1,516	29,570	44,822
1984	1,038	30,040	32,688	1,572	34,420	54,093
1985	1,387	31,180	43,240	1,648	32,270	53,181
1986	1,117	30,930	34,545	1,827	32,310	59,051

Source: Ministry of Agriculture, Forestry and Fisheries. 1982, 1987.

Table 10. Tomato production in the different provinces of Korea.

Region	Open field (ha)	Plastic house (ha)
Kyungi-Do	287	243
Kangwon-Do	162	28
Chungcheongbuk-Do	53	81
Chungcheongnam-Do	126	335
Chullabuk-Do	35	149
Chullanam-Do	46	170
Kyungsangbuk-Do	140	389
Kyungsangnam-Do	210	391
Cheju-Do	58	42

Source: Ministry of Agriculture, Forestry and Fisheries. 1987.

Cultivation methods and cultural practices. Direct sowing in the field was the only cultivation method until the early 1960s. However, since the late 1960s early maturing culture, in which seedlings are raised in nursery beds and transplanted into the field, has developed. At the same time, late culture in the alpine areas at about 600 m above sea level has also differentiated (Compilation Committee Society of Korean Horticultural Development History. 1980).

Three different cultivation patterns under plastic houses have been developed: late culture, which is seeded in July and harvested from October; forcing culture, which is seeded in September and harvested starting January; and semi-forcing culture, which is seeded in November to January and harvested starting March or April (Table 11) (Compilation Committee Society of Korean Horticultural Development History. 1980). Semi-forcing culture is practiced mainly when pepper succeeds paddy rice in the southern areas. Although the growing method varies considerably depending upon growers and districts, the usual practices are as follows. In the case of early maturing culture, seedlings are raised for about 60 days on the hot bed under plastic houses or tunnels, and transplanted into the field after the danger of late frost has passed. Planting density, although varying with cropping periods, is about 5,000 plants per ha. The crop is usually harvested up to the fourth flower cluster. The approximate amount of fertilizer is: 250-300 kg N; 300-350 kg K; 200-250 kg P per ha. About 15,000 kg of manure and 1,000 kg of lime (hydrated form) are also applied. Herbicides are applied at planting time. Plants are staked with bamboo. Planting beds are covered with polyethylene film to raise soil temperature and to maintain soil moisture. For the control of diseases and pests such as late blight, early blight, gray mold, leafmold, bacterial spot and aphids, chemicals are sprayed approximately 10 times during the growth period. In order to promote fruit-setting and fruit growth, growth regulators such as tomatotone are sprayed to the flower cluster (K.Y. Kang. 1986. personal survey). Plastic houses are covered with additional plastic films and/or straw mats at night to keep heat in the house.

Table 11. Cultivation patterns of tomato in Korea.

Cultivation pattern	Sowing time	Planting time	Harvesting time	Remarks
Forcing culture	September	November	January-June	Under protection
Semi-forcing culture	December	February	March-June	Under protection
Tunnel culture	February	April	May-July	Open field
Early maturing culture	February	April-May	June-July	Open field, seedbed under protection
Highland culture	May	July	September-October	Open field
Late culture	July	August	October-April	Under protection

Source: Compilation Committee Society of Korean Horticultural Development History. 1980.

Marketing. Most products are marketed by collecting merchants who visit each farm and buy the products. Because no major production areas are developed, only a small amount is marketed through the nationwide network of the National Agricultural Cooperative Federation.

Varieties. The preferred cultivars are indeterminate, large-fruited with pink colored and green shouldered fruit. Only F_1 hybrids are cultivated. A total of 38 varieties have been developed by commercial seed companies since 1979 (The Korean Seedling Society, 1986). The major characteristics of the leading varieties are shown in Table 12.

Trade. Consumption of fresh fruits is met by domestic production, while tomato paste for further processing is imported from Taiwan, Portugal, the USA, Japan and Turkey. The amount has been increasing yearly. Only a small amount of fresh fruits are exported, mainly to Hong Kong (Tables 13 and 14) (The National Agricultural Cooperative Federation, 1987).

Table 12. Leading tomato varieties and their characteristics.

Variety	Year of registration	Maturity	Fruit color	Fruit weight (g)	Use	Cultivation type
Suhkwang	1979	Medium	Pink	190-220	Fresh	Forcing or early
Youngkwang	-	Medium	Pink	190-230	Fresh	Field or late
Wolkwang	1984	Early	Pink	190-210	Fresh	Early or semi-forcing
Kwangmyung	1985	Early	Pink	170-190	Fresh	Early or semi-forcing
Nebyung youngsu	1979	Early	Pink	230-280	Fresh	Forcing
Kangyook	-	Early	Pink	200	Fresh	Semi-forcing or early
Kwangsoo	-	-	Pink	210	Fresh	Semi-forcing or early
Nebyungchangsoo	-	Early	Pink	210	Fresh	Forcing or semi-forcing
Poongsaeng	-	Early	Pink	190-220	Fresh	Forcing or early
Poongyoung	1985	Medium	Pink	170-190	Fresh	Semi-forcing or early

Source: The Korean Seedling Society, 1986.

Table 13. Tomato paste import to Korea for processing by year (1970-85).

	Year				
	1970	1975	1980	1984	1985
Quantity of import (t)	2,154	2,373	3,606	4,308	5,107
Price of import (US$/t)	719	783	798	813	756
Total amount (US$1,000)	1,549	1,858	2,877	3,504	3,860

Source: Trade statistics from the Office of Tariff, 1986. (cited in National Agricultural Cooperative Federation, 1987).

Table 14. Fresh tomato export to Korea (1980-86).

Year	1980	1981	1982	1983	1984	1985	1986
Amount (t)	28.5	80.0	123.0	71.9	154.7	251.1	174.1
Value (US$1,000)	11.0	37.0	68.2	44.6	78.7	129.3	86.2

Source: Trade statistics from the Office of Tariff, 1986. (cited in National Agricultural Cooperative Federation, 1987).

Production Constraints

Environment. As the fruits of field-grown tomatoes are harvested in the hot humid months of June and July, fruits are apt to decay due to high temperature and excessive humidity. The unstaked processing tomatoes are particularly vulnerable, as many fruits are in direct contact with the soil. This is the reason why the growing of processing tomato is not economically feasible. In addition, the high temperatures after the rainy season contributes to poor fruit color, cracking and sunscald, leading to decreased yield (Kim, 1984).

Under plastic house cultivation, low temperature and low light intensity during the growth period induce various physiological disorders such as deformed fruits.

Pests and diseases. Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici* (Saccardo) Synder et Hansen) and bacterial wilt (*Pseudomonas solanacearum* (Smith) Smith) are predominant in the continuous cropping area. Late blight (*Phytophthora infestans*), early blight (*Alternaria solanii*) leafmold *Fulvia fulva* (Cooke) Ciferri, gray mold (*Botrytis cinerea*), gray leafspot (*Stemphylium lycopersici*) and bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) are important diseases of the foliage and fruits, particularly when the crop is cultivated under protected culture. The most important tomato viruses in Korea are tobacco mosaic virus (TMV) and cucumber mosaic virus (CMV) (Kang et al. 1981; Korean Society of Plant Protection. 1986).

Varieties. There are many commercial varieties resistant to diseases and these varieties are grown in some parts. However many growers still suffer from disease damage because they are still using susceptible varieties.

Price. Since the production acreage is not controlled, over-production in good years results in a sharp price drops. This leads to a decreased interest among growers in producing more tomatoes thereafter.

Research and Development

Cultivation methods. Research is in progress to study the effect of soil moisture and climatic conditions on blooming, fruit-setting, occurrence of deformed fruits and yield. Studies are being carried out to acquire basic knowledge for the control of diseases and pests by identification of the causal pathogens and pests and their occurrence (Kang et al. 1985, 1981; Kim and Takahashi. 1982).

Varieties. To establish effective breeding programs, studies on the genetic characters of introduced varieties or lines have been carried out. Based on the results of these studies, priority is given to breeding for multiple resistance to diseases, pests and physiological disorders (Kang et al. 1986). In conjunction with an increased demand for tomatoes as a raw material for processing, extensive studies are conducted in cooperation with national institutes and processing companies (Kim and Chung. 1986) on breeding of varieties suitable for dense planting and once-over harvest for non-staking culture.

Research institutes and researchers. The institutes and researchers working on various aspects of tomato improvement are listed in the Appendix.

Future Needs

Most processed tomato products must be imported because it is not feasible to grow processing tomato in Korea because of severe fruitrot, poor color and sunscald caused by high temperatures and excessive rainfall at harvest time. Self-sufficiency in processing tomatoes should be attempted through both cultural management and varietal improvement. It is necessary to breed processing varieties with the following traits: once-over concentrated harvest to save harvesting labor in the non-staking culture; long field storage life; high yield with good quality such as high soluble solids, and sufficient pigment; and tolerance to high temperature, excessive rain, fruit cracking and discoloration and diseases for summer production.

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Appendix. Institutions and private companies involved in pepper and tomato improvement.

Rural Development Administration (RDA)

Horticultural Experiment Station (HES)

- Vegetable Div. 1: Breeding (Juho Chung, Kwansoon Choi, Younghyun Om, Doam Pai
- Vegetable Div. 2: Physiology (Sangkeun Park, Kwangyong Kim, Youngsam Kwon)
- Pusan Branch: Breeding (Kwangyoon Kang, Haebong Chung) Physiology (Juseong Choi

Institute of Agricultural Science (IAS)

- Pathology (Chunghoe Kim)
- Entomology (Sangchan Hahn)

Provincial RDA (8 provinces): Production technology

Universities

Seoul National University: Breeding (Hyokeun Park) Physiology (Hyungu Pyo, Byungil Lee)
Kyungbuk National University: Breeding and Pathology (Byungsoo Kim) Physiology (Wooseung Lee)
Chungbuk National University: Breeding (Jungki Lee)
Kyungsang National University: Breeding (Kwonyuel Chang) Physiology (Jungchoon Park)
Seoul City University: Breeding (Jaebok Park)
Youngnam University: Physiology (Heedon Chung)
Wonkwang University: Breeding (Jinsoo-Kim)
Andong University: Pathology (Euigyu Cho)
Yuanam College: Breeding (Soongjin Kim)

Commercial Seed Companies

Heungnong: Breeding (Ingi Chung, Moonhwan Lee, Pilsik Lee)
Jungang: Breeding (Ilung Yu)
Seoul: Breeding (Yongsu Lee, Youngkwan Cho)
Hahnong: Breeding (Suhngkeun Choi, Jumyun Kim, Chungwhan Ahn)
Shinsin: Breeding (Changsang Yu)

Symposium Discussion

L.L. Black: According to your data, pepper production in Korea increased greatly in 1984 and 1985, but in 1986 production declined dramatically. What was the reason for the decline in production in 1986?

K.Y. Kang: According to my data, pepper production did not greatly increase, but a large amount of dried pepper was imported in 1984 and 1985. We had to import a large amount of dried fruit to make up for the lack in domestic supply caused by crop damage.

Hallard: How do you select for high capsaicin content in hot pepper? Do you use any chemical test procedure to evaluate the material in Korea?

K.Y. Kang: Usually we evaluate the capsaicin contents of hot pepper spectrophotometrically. But for more fine analysis, HPLC is being used. The details of the procedure are available, if you are interested.

504

54

Tomato and Pepper Production and Its Problems in Liberia

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Abstract

Liberia is a humid tropical country in West Africa with climate and soils that are favorable for farming. Shifting cultivation is the dominant farming system throughout the country. Various tropical field crops are grown, such as cassava, sweet potato, cocoyam, yam, corn, cabbage, bitter ball, eggplant, soybean, mungbean, rice, peanut, and others. Tomato and hot pepper play significant roles in the farming systems and are widely grown and consumed as they are important vegetables in the diet of almost all Liberians.

The susceptibility of the varieties grown to various diseases and pests (for example early and late blight, Fusarium wilt, Septoria leafspot, nematodes and viruses) lack of knowledge of adequate management practices, and inadequate supply of good quality seeds are major production constraints. To overcome these problems, the Central Agricultural Research Institute of the Ministry of Agriculture has initiated a research program on these crops with the objectives of increasing production and improving quality through the collection of germplasm; selecting and introducing exotic cultivars; and developing appropriate management practices.

Introduction

Liberia is a small country in tropical West Africa with an area of 111,400 km^2 and a population of approximately two million, growing at roughly 3.0% per annum. The country can be divided into three principal geographical zones: a low-lying coastal belt extending 80 km inland, characterized by mangrove marshes, lagoons and creeks that fill with the tides; an interior tropical rainforest region of hills and plateaus extending to the country's inland border and rising to elevations of 500 to 700 meters; and the Guinea highlands in the far northern part of the country where forest is sparse and mountains rise to 1,500 m (Anon. 1982).

The climate and soils of Liberia are generally favorable for crop production; however, near the coast, there has been considerable leaching and erosion resulting from extremely heavy rainfall. In these areas, the soils tend to be strongly acidic and generally deficient in plant nutrients such as nitrogen and phosphorus. The range of precipitation throughout the country ranges from 1,800 mm in the north of the country to 4,500 mm in the coastal areas. Two distinct growing seasons, wet and dry, are experienced in the country. The wet season extends from April to November with most of the rain falling between August and September. The dry season extends from December to March. The average temperature throughout the year ranges from 15°-37°C, with the maximum usually in March. Relative humidity during the wet season is about 90%, and during the dry season about 87%.

Shifting cultivation is the dominant farming system throughout Liberia. The typical farm, with size ranging from 0.3-30 acres, is a multiproduct farm, producing, through intercropping, a wide range of crops (Anon. 1973). Tomato and hot pepper play important roles in farming

systems. The peasant farmers devote their time and effort almost exclusively to the production of these two crops primarily for domestic consumption as cooked with stews and soups, with any surplus sold in the local market as a source of cash income.

Hot Pepper

Current Crop Situation

Hot pepper (*Capsicum* sp.) is grown throughout the country during wet and dry seasons, as a monocrop, intercropped with other field crops, or as a backyard garden crop. Approximately 91% of 176,400 agricultural households in Liberia (average size of household is 5.6 persons), grow hot pepper, even in small quantities (Anon. 1985). Hot pepper is a very important vegetable and virtually all Liberian dishes contain it. Farmers generally raise seedlings in seed beds and after four to six weeks transplant them in the field at a distance of 75 × 75 cm. Another practice is broadcasting the seeds directly instead of raising seedlings in beds first. Farmers generally weed by hand a few times. Insecticides or fungicides are rarely applied due to inadequate supply, high cost, and the lack of technical know-how. Yields in farmers' fields range from 8-10 t/ha of fresh fruit. Fresh peppers are usually marketed, but during the wet season when pepper is abundant, it is processed into pepper sauce, dry pepper or pepper powder. Local cultivars are mostly grown because of their very pungent flavor which is highly favored by the Liberian consumers. A few introduced cultivars such as Jalapeno, Pusa Jwala and Yatsufusa are also grown. Farmers produce their own seeds from local varieties but seeds of exotic varieties are introduced from Japan, India, the USA and Denmark, and are sold in city markets only. There is no foreign trade of this crop. All the production is marketed and consumed locally.

Production Constraints

Production of hot pepper is hampered by many factors. In the dry season under lowland conditions the high temperatures (36°/37°C), and the shortage of available water for plant growth are the major limiting production factors. In the rainy season, excessive rainfall hampers plant establishment and growth, and fruits are frequently destroyed in the downpour. The high incidence of pests and diseases such as early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), Fusarium wilt (*Fusarium oxysporum* f. sp *lycopersici*), Septoria leafspot (*Septoria apiicola*), anthracnose (*Colletotrichum coccodes*), nematodes (*Xiphinema ifacolum* and *Meloidogyne incognita*) and viruses, particularly potato virus Y and tomato mosaic virus, limit production (Kulkarni, 1985). Although it is a very important vegetable, farmers consider pepper as a secondary crop. Not much attention is given to management practices for the crop, such as fertilizer and pesticide application. Lack of trained personnel in the extension services is also a constraint to production. Poor seed quality and unfavorable environmental conditions during the growth period lead to great yield variability. The lack of adequate storage facilities and lack of knowledge of postharvest technologies are also major constraints. Seasonal price variations make peak season production more risky. Unless programs to promote specialization and trade lead to larger demand and better returns during the peak season, only large holders and risk-takers will be willing to expand pepper production areas. Market and distribution systems are inadequate because of transport and road problems from the farm to the market. Combined with unpredictable prices, they make for great variability in farm returns.

Research and Development

The Central Agricultural Research Institute (CARI) of the Ministry of Agriculture is the only research institute in the country with a systematic vegetable research program which started in 1980 for a period of four years. The program was initially assisted by the Food and Agriculture

Organization (FAO) of the United Nations. Hot pepper is one of the priority crops in the program. The main objective of the program is to increase the quantity and improve the quality of the crop. The pepper program mainly focuses on screening and selection (which is still in its initial stage), germplasm maintenance and the introduction of exotic and local cultivars, screening and selection of promising lines on the basis of yield and other desirable traits such as hotness and flavor, and on the improvement of management practices (date of planting, spacing, fertilizer application, etc). The establishment of a vegetable genebank and a thorough search for suitable parents are top priorities at present. Due to lack of seed storage facilities it is very difficult to maintain the genebank properly. Yields of 12-28 t/ha of fresh fruit was achieved at CARI from the exotic cultivars with good management practices (Table 1). The pepper program is fully supported by the Government of Liberia. A multidisciplinary team consisting of breeders, agronomists, pathologists, entomologists, postharvest technologists, and marketing and socio-economists, aided by extension specialists, is involved in pepper research at the institute. Research on economics marketing, utilization and processing for pepper has not been conducted.

Table 1. Observational trial of exotic hot pepper varieties grown at CARI 1982-83.

Varieties	Days to 1st harvest		Marketable yield (t/ha)	
	Dry season	Wet season	Dry season	Wet season
Fushimi Long Green	98	–[1]	28.4	–
Jalapeno	98	99	21.4	8.2
Takanotsume	98	99	17.8	13.4
Pusa Jwala	98	99	17.5	12.4
Red Chili	93	99	17.5	9.6
Yatsufusa	93	99	14.3	6.6
Long Red Cayenne	93	–	12.9	–
Local	133	137	14.7	8.2

[1]The variety was not included in the wet season trial.

Future Needs

The pepper development program needs more financial support and manpower to carry out research based on farmers' needs, and strong extension services to disseminate the research results and improved production technologies to farmers. It is necessary to establish a breeding program at the research institute to produce better varieties adapted to local conditions, and a national seed committee on vegetables to certify and to ensure production of good quality seeds. The establishment of seed companies and seed stores in selected locations are vital.

Tomato

Current Crop Situation

Tomato (*Lycopersicon esculentum*) is a minor vegetable crop grown mostly in the northern part of the country, especially during the dry season. It is also grown in small quantities in other parts of the country. Approximately 23% out of the 176,400 agricultural households in Liberia grow tomato either as monocrop or as backyard garden crop. Some farmers plant as few as four to five plants. Most of the tomato consumed in the country is imported in the form of pastes from the USA and Hungary. Tomato paste is used for the preparation of many of Liberian dishes and is more important than the fresh fruit. Fresh tomato is of importance especially near the urban centers. Farmers grow mostly local varieties which are very small in fruit size and contain many seeds. A few farmers have introduced seeds of exotic varieties such as Marglobe, Oxheart, Earliana, Homestead, Fireball and others from overseas seed companies. Seeds are generally

broadcast in the field although some farmers raise seedlings in seedbeds and transplant them to the fields after three or four weeks. No staking is done and yield is very poor, generally 2-3 t/ha of fresh fruit. Farmers weed once or twice before harvest. Marketing of locally produced tomato is in the form of fresh fruit.

Production Constraints

The lack of appropriate cultural practices, particularly during the wet season, and the presence of many insect pests, diseases and weeds are the major production constraints on tomato. The varieties grown in Liberia are susceptible to bacterial wilt (*Pseudomonas solanacearum*) early blight (*Alternaria solani*), late blight (*Phytophthora infestans*), Fusarium wilt (*Fusarium oxysporum* f. sp. *lycopersici*), nematodes (*Xiphinema ifacolum* and *Meloidogyne incognita*), and viruses. Poor seed supply and quality is another production constraint. Some farmers import seeds from foreign countries without knowing the adaptability status of the variety imported. Since most of the tomato is consumed in the form of paste, which is imported, farmers are reluctant to give more attention to this crop.

Research and Development

Tomato research at CARI is still at the initial stage. Some were introduced lines from the Asian Vegetable Research and Development Center (AVRDC) and from the University of Missouri in the USA are being evaluated. The imported varieties produced 0.8-5.1 t/ha of fresh fruit at CARI. Research on management practices, economics and marketing, utilization and processing has not yet been undertaken, but will be addressed in the near future. At present the tomato program is fully supported by the Government of Liberia. A multidisciplinary team of research scientists is working in the program.

Future Needs

The tomato program needs more personnel and financial assistance. More research needs to be carried out to find adaptable varieties and to identify appropriate cultural practices for better production. Research on utilization, marketing and processing also needs to be initiated.

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508

55

Tomato and Chili Pepper Growing in Malaysia

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Abstract

More than 1,000 ha are planted to chili in Malaysia. Many varieties are grown but the most common are the local Kulai and Langkap varieties which can yield an average of 12 t/ha. The hectarage planted to tomato is slightly more than 500 ha. The two most popularly grown lowland tomato varieties are Banting and Local White, which can yield up to 17 t/ha. Among more than 50 types of vegetables grown, tomato and chili are the two most expensive to produce, with an estimated production cost of more than US$2,400/ha. Both crops are mainly grown for fresh consumption. A large quantity of tomato sauce, puree, paste, and juice (US$ 2.6 million in 1985) and dried and ground chili (US$ 12.8 million in 1985) is imported into the country. Pests and diseases are the major production constraints. Virus diseases and the fungus *Colletotrichum capsici* are considered the most serious pathogens of chili, whereas fruitborers (*Heliothis* sp.) and fruit flies (*Dacus dorsalis*) are the most devastating pests. On tomato, bacterial wilt and viruses are the major disease constraints and fruitborer the most important pest. Other less important problems are marketing, irrigation, infertile soil, unavailability of good planting materials, and labor shortages. The Malaysian Agriculture Research and Development Institute (MARDI), the major agricultural research agency in the country at the moment, undertakes most of the tomato and pepper research in Malaysia in collaboration with AVRDC, TARC and other international research agencies.

Introduction

Malaysia is a tropical country with a population of about 13.34 million. It is situated between 1° and 7° north of the equator and has an average temperature of 25°-27°C, uniform all year round. Humidity is high (80%-85%). Annual minimum and maximum rainfalls are 1,651 mm and 4,216 mm, respectively. There are two periods of heavy rains, from April to May and from October to December. Temperature and rainfall data of the Ipoh district, one of the major vegetable growing areas are shown in Table 1.

The area under vegetable production is small compared to the area under rubber, cocoa, fruits and oil palm, which are the major plantation crops of the country. In 1985, the area grown to vegetables was 9,340 hectares (Ministry of Agriculture Malaysia, 1980-1985a). Cultivation is undertaken by small-scale growers and market gardeners with an average farm size of one hectare. Sole cropping, mixed cropping and a combination of both mixed and sole cropping are practiced.

Imports of vegetables increased steadily from US$18 million in 1976 to more than US$84 million in 1985 (Ministry of Agriculture Malaysia, 1980-1985b). Current domestic consumption of vegetables is estimated to be approximately 212,360 t (Ariff, 1985).

The present report covers the production of lowland tomato (*Lycopersicon esculentum*) and lowland chili pepper (*Capsicum annuum* L.) in peninsular Malaysia.

Table 1. Temperature and rainfall in the district of Ipoh.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature (°C) (1968-1985)													
24-hr mean	26.5	26.9	27.3	27.3	27.3	27.3	26.9	26.8	26.4	26.3	26.1	26.1	26.8
Mean daily max.	32.8	33.6	33.9	33.5	33.2	33.1	32.8	32.8	32.8	32.2	31.9	31.9	32.8
Mean daily min.	22.1	22.5	23.0	23.5	23.6	23.3	22.8	22.9	22.8	22.8	22.8	22.5	22.9
Rainfall (mm) (1951-1985)													
Mean	152.9	141.9	188.7	251.9	228.7	140.5	153.3	151.5	198.8	298.0	287.3	230.7	2,424.2
Highest	413.0	367.0	408.9	630.2	469.4	390.1	345.7	298.9	389.3	493.3	497.0	437.9	3,323.6
Lowest	15.0	20.3	20.3	95.4	76.4	29.3	39.4	48.8	53.8	92.2	69.9	68.6	1,912.9

Tomato

Current Crop Situation

Production. In terms of total acreage of production, tomato ranks seventh, among vegetables after long bean, sweet potato, chili, Chinese mustard, cabbage, and okra (Government of Malaysia, 1986). A total of 557 ha (approximately 6% of the total area under vegetables) were planted to tomato in 1985, producing 9,469 t of fresh tomatoes valued at US$2.5 million (Ministry of Agriculture Malaysia, 1980-1985a). There was a drastic drop in acreage and production from 1981 to 1982 (Table 2). The high cost of production (estimated at US$2,432 per hectare) might be one factor limiting area expansion (Mohd and Mohd, 1985). The net return is estimated at US$1,588 per hectare which is relatively low compared to other vegetables (Mohd and Mohd, 1985). For example, the net returns from cabbage, mustard and chili are estimated at US$3,352, US$2,232 and US$4,100, respectively.

The leading states producing lowland tomato for the fresh market are Johore with 476 t; Perak with 323 t; and Kelantan with 255 t. These three states produced about 68% of the total lowland tomato in 1985 (Ministry of Agriculture Malaysia, 1980-1985a).

Lowland tomato production in Malaysia is entirely in the hands of small holders. The two popularly grown varieties are Bantng and Local White, which are very susceptible to bacterial wilt (*Pseudomonas solanacearum*) (Melor, 1986). Grafting on resistant brinjal (*Solanum melongena*) rootstock (Lum and Wong, 1976) was recommended to control the disease but was not adopted by the farmers because this method is labor intensive and requires special skills. Subsequently, the Malaysian Agricultural Research and Development Institute (MARDI) introduced six bacterial wilt and heat-tolerant lines developed by the Asian Vegetable Research and Development Center (AVRDC) (Melor, 1986). The characteristics of these lines are shown in Table 3. Foreign commercial cultivars such as Red Cloud, Roma and King Kong were recommended several years ago but only King Kong is being adopted by some farmers in Johore.

An average of 15 t/ha yield is obtained by lowland farmers (Anon, 1981) compared to 35 t/ha obtained in the highlands (Chay, 1987, Highland Farmers Assoc., Malaysia personal

Table 2. Tomato acreage and production in Malaysia, 1980-85.

	1980	1981	1982	1983	1984	1985
Acreage (ha)	2,633	2,208	637	358	579	557
Production (t)	44,761	37,536	10,829	6,086	9,843	9,469

Table 3. Characteristics of lowland tomato lines.

Lines	Plant size	Plant habit[z]	Fruiting	Fruit shape	Fruit color	Fruit wt. (g)	Yield/Plant (kg)	Approx. Yield (t/ha)	Reaction to bacterial wilt[y]	Remarks
Local cultivars										
Banting	Short	D	Heavy	Slightly flattened	White (immature) light red (ripe)	29-37	0.7-1.0	18-19	HS	Fruit color not attractive
Local white	Moderate	SD	Heavy	Round	White (immature) red (ripe)	35-100	0.72	10	S	Yield can reach 28t/ha
Introductions from AVRDC										
MT 1	Moderate	SD	Heavy (150-190 fruits/plant)	Round red (ripe)	Green	35-40	1.9	33	R	Uniform ripening
MT 2	Moderate	SD	Heavy	Slightly flattened	Green shoulder red (ripe)	50-55	1.6	30	R	–
MT 3	Moderate	SD	Heavy	Slightly flattened	Green shoulder red (ripe)	50-60	1.4	27	R	Uniform ripening
MT 5	Moderate	SD	Heavy	Round	Light green (immature) red (ripe)	50-55	1.2	23	R	–
MT 6	Moderate	SD	Heavy	Slightly oval	Light green (immature) red (ripe)	35-45	1.7	32	R	Uniform ripening
MT 10	Moderate	SD	Heavy	Round	Green (immature) red (ripe)	35-45	1.1	30	R	Plants not very bushy

Source: Hassan, and Hong. 1983. [z]D = determinate. SD = semideterminate. [y]R = resistant; S = susceptible; HS = highly susceptible

communication). Both organic and inorganic fertilizers are used. The most common inorganic fertilizer used is the granulated complete fertilizer 15:15:15 (Anon. 1981) at the rate of 800 1,350 kg/ha. Chicken dung is the most popular organic fertilizer and approximately 14 t/ha is used (Anon. 1981). There is no standard recommended fertilizer practice.

Tomato is often intercropped with other vegetables and many farmers practice crop rotation with no fixed pattern, even though rotating tomato with cabbage has been shown to produce the highest return per unit input (Haron. 1986).

Seed production. The majority of the farmers save their own seeds from one planting to another. Only a small amount of seed is imported, mainly from Taiwan and Thailand. In 1984, 80 kg of tomato seed was imported (Rahmat and Chua. 1985). At present, there is no commercial seed production.

Consumption. Consumption of fresh tomato is relatively low, compared to some other types of vegetables (Table 4). The per capita consumption for lowland tomato was estimated at 1.111 kg, for the year 1985, an increase of only 5.2% from 1982. During the same period, a 52% increase in consumption was observed for the highland tomato, from 0.828 kg in 1982 to 1.259 kg in 1985. Approximately 100 t of tomato ketchup are produced daily, much of which is consumed within the country (Husin Zakaria. 1987. MARDI, Serdang, Selangor, personal communication). It is produced by more than 60 tomato processing factories, four of which, Nestle, Kimball, Yeo Heap Seng, and Gan Limited, handled about 45% of the total production.

Table 4. Per capita consumption of some common vegetables in 1983.

Vegetables	Comsumption (kg/yr)
Cabbage	2.7
Green mustard	2.5
Long bean	3.2
Cucumber	3.1
Lady's finger	1.1
French bean	1.3
Eggplant	2.4
Water convolvulus	1.7
Chili pepper	2.9
Tomato	1.0

Source: Fama, 1984.

Marketing. Most tomatoes produced are marketed as fresh fruit. The marketing pattern is farmers collectors truckers wholesalers - retailers consumers. By far the most prevalent is selling by consignment in which tomatoes are consigned by the farmers through local collectors or transport agents (or truckers) for sale in the terminal market with prices determined at the market. The price fluctuates throughout the year due to seasonality in both supply and demand. In 1985, the fluctuation ranged from US$0.22 to US$0.72 per kilogram (Azmi Mohd. 1987. FAMA Headquarters, Kuala Lumpur, personal communication).

Import and export. The total imports of processed tomato products in the form of puree, paste, concentrate and sauce for 1985 were valued at more than US$2.6 million. In 1985, Malaysia spent US$488,600 on imports of fresh tomato (Table 5), mainly from Thailand. However a substantial amount of locally grown fresh tomato, from both the lowlands and highlands, were also exported (Table 5), mainly to Singapore. Malaysia supplies 96% of the total fresh tomato imports of Singapore (Anon. 1983).

Table 5. Imports and exports of tomato and tomato-related products by Malaysia in 1985.

Item	Import		Export	
	Quantity (t)	Value 1000 (US$)	Quantity (t)	Value 1000 (US$)
Fresh tomato	2,462	488.6	6,986	988.4
Tomato purees, paste and concentrate	2,823	2,387.8	3	2.2
Tomato juice	203	167.1	–	–
Tomato sauce	73,669 liter	74.0	2,550,465 liter	2,493.8

Source: Ministry of Agriculture, Malaysia, 1980-1985b.

Problems and Constraints

Pests and diseases. Pests and diseases are the most serious production constraints. Bacterial wilt (*Pseudomonas solanacearum*), early blight (*Alternaria solani*), black leafmold (*Cercospora fuligena*), anthracnose (*Colletotrichum capsici*), Sclerotium wilt (*Sclerotium rolfsii*), bacterial spot (*Xanthomonas campestris* pv. *vesicatoria*) (Mah. 1987) and viruses, such as cucumber mosaic virus, tobacco mosaic virus, tomato spotted wilt virus, tomato mosaic virus and potato virus Y (AVRDC. 1984; Noraini. 1984; 1986; 1987; Fujisawa et al. 1986; Mah. 1987; Ong and Ting. 1977) have been reported on tomato in Malaysia. However, only bacterial wilt, early blight, black leafmold and viruses are of economic importance (Mah. 1987. MARDI, Kelang, personal communication). Bacterial wilt is the most widespread and destructive disease and total crop loss is not uncommon (Mah. 1987). Black leafmold is increasingly prevalent on tomatoes grown in the lowlands of Malaysia (Mah. 1987). Fruit flies and fruitborers are the dominant pests.

Lack of adapted varieties. Most tomatoes are produced in the mountain regions such as the Cameron Highlands. Part of the reason for slow expansion of lowland acreages is the lack of varieties adapted to lowland cultivation, resistant to the major diseases, and with acceptable yield. Varieties suitable for processing are non-existent.

Other problems. More fertile soils in the country have been utilized for plantation crops. Only marginal land is usually available for vegetable production and inputs and management skills are needed to produce the crop economically. Because of the wide range of soils, fertilizer recommendations are not entirely satisfactory and farmers apply fertilizer according to their own experience or follow recommendations of the supplier (Anon. 1981).

Research and Development

Varietal improvement. A breeding program was initiated in 1968 at the Faculty of Agriculture, University of Malaya (UM) emphasizing bacterial wilt resistance (Graham et al. 1977). Research conducted over a nine-year period resulted in the introduction of three tolerant lines namely FP-1, FP-2 and FP-5, the seeds of which were made available for large-scale planting. However, farmers' acceptance of the varieties was poor due to their small fruit size.

With limited resources and manpower, MARDI has opted to collaborate with AVRDC and the Tropical Agricultural Research Centre (TARC) in Japan to expedite the progress of its tomato varietal improvement program. Bacterial wilt screening techniques have been developed by MARDI (Anon. 1987). MARDI started receiving AVRDC materials in 1974 (Siti et al. 1980). More than ten years were spent in evaluating the materials and after several selections, MARDI has finally recommended six heat-tolerant and bacterial wilt-resistant lines (MT 1, MT 2, MT 3, MT 5, MT 6, MT 10) which outperform the local cultivars Banting and Local White (Melor. 1986).

Not much breeding is done to produce varieties resistant to other diseases. However evaluations of germplasm for resistance to nematodes (Graham et al. 1977), viruses and early blight are conducted (Mah and Melor. 1982).

The Department of Genetics, National University of Malaysia (UKM) (Johari and Mahir. 1986; Apandi and Mahir. 1986) is involved to a limited extent in a screening program for resistance to tomato mosaic virus. At the Agricultural University of Malaysia (UPM) screening is conducted to identify tomato genotypes that can take up potassium more efficiently, which should ultimately help to reduce fertilizer cost.

Pest and disease control. Chemicals for the control of important diseases, such as early blight and black leafmold are evaluated by MARDI. Presently mancozeb is the recommended fungicide for early blight and benomyl for black leafmold (Mah. 1987).

The use of systemic insecticides such as prothiofos, profenofos and methiocarb before and after transplanting has shown to reduce the incidence of tomato spotted wilt virus to a tolerable level (Aziz. 1986. MARDI, Bertam. personal communication).

MARDI has been evaluating insecticides for effective control of fruit flies and fruitborers. Fenvalerate has been shown effectively to control fruitborers.

Postharvest research. The present practice, whereby tomatoes are packed tightly in bamboo baskets and transported on lorries to the market outlets, has resulted in substantial postharvest losses. Storage of tomato is deemed necessary especially where there is a glut on the market. Postharvest research by MARDI has resulted in the recommendation of a packaging technology involving precooling and storage temperature requirements, and recommendations as to harvesting stage and ripening induction procedure.

Future Needs

Processing varieties suitable for cultivation under Malaysian lowland conditions need to be developed because of the substantial amount of money which is spent yearly to import the raw materials for the local processing industry. Research to resolve the bacterial wilt problem must be continued and intensified. International cooperation with research bodies such as AVRDC and TARC, which have interests in developing tomato technologies suitable for the tropics, should be intensified.

Chili Pepper

Current Crop Situation

Production. Chili pepper (*Capsicum annuum* L.) is one of the most important vegetables grown in the lowlands of Malaysia. The crop leads all other vegetables grown in Malaysia in terms of value and total acreage. From 1980 to 1985, the acreage planted to chilies fluctuated between 1,100 and 1,500 ha (Table 6).

Table 6. Total acreage, production volume and value, and ex-farm price of chili produce in Malaysia, 1980-85.

Item	1980	1981	1982	1983	1984	1985
Acreage (ha)	1,357	1,513	1,065	1,115	1,275	1,153
Production (t)[a]	16,284	18,156	12,780	13,380	15,300	13,836
Exfarm price (US$/kg)	0.58	0.73	0.76	1.06	0.92	1
Production value (US$ '000)	9,444.7	13,253.9	9,712.8	14,182.8	14,076.0	13,836

[a]Based on an average yield of 12 t/ha.

Perak is the leading state in chili production with 3,144 t in 1985 (Ministry of Agriculture Malaysia, 1980-1985a) with major production areas in the Kinta Valley near Ipoh and in the Langkap and Batang Padang areas near Tapah. The state of Kelantan ranks second, followed by Kedah, Terengganu, and Johore. These five states accounted for about 81% of the 1985 production (Table 7).

The yield of chili per hectare is fairly stable from year to year. However great fluctuations are observed from season to season from as low as 5 t/ha up to as high as 11.5 t/ha (Anon. 1981). Farmers opinions as to the cause of the fluctuations cite poor weather conditions, increased pests and diseases and scarcity of water (Anon. 1981). In the dry season, with good management practices, yields can reach 20 t/ha (Leong, 1985). Two types of chili are grown, the long and slender Cili Besar and Cayenne type (*Capsicum annuum* var. *annuum*), and the highly pungent and smaller Cili Padi (*Capsicum annuum* var. *aviculare*). The first type is economically more important.

The average farm size is 0.25 ha (Anon. 1981). Chili is planted all year round either as a monoculture or polyculture, the latter in the form of inter or relay cropping. Monoculture is more popular. Chili is intercropped with immature coconut, oil palm, rubber and pineapple, or it is planted as a relay crop to cabbage and other leafy vegetables (Leong, 1985). The growing period can reach up to six months from sowing to last harvest (Anon. 1981).

The cost of production is estimated at US$2,140 per hectare, most of which is spent on pest and disease control, manuring and harvesting. The net income from chili production is estimated at US$4,100 per hectare for a season of six months and it is a highly profitable vegetable when yields are reasonable and prices are favorable. Prices of chilies fluctuate from year to year (Table 3) but tend also to fluctuate widely from month to month within the year. Prices are especially high during the wet season because of the increased incidence of diseases and flower abortion (Leong, 1985).

Chili has one of the highest per capita consumption among the vegetables grown, which was estimated at 2.90 kg per capita in 1984.

Table 7. Acreage distribution of chili pepper among the eleven states of peninsular Malaysia in 1985.

State	Acreage (ha)	Major production areas
Perak	262	Districts of Ipoh and Tapah
Kelantan	235	Districts of Kota Bahru and Pasir Mas
Johor	121	Districts of Kulai
Terengganu	142	Scattered throughout the state
Kedah	175	Scattered throughout the state
Pahang	79	Scattered throughout the state
Pinang island	53	Scattered throughout the state
Selangor	55	Scattered throughout the state
Melaka	20	Scattered throughout the state
N. Sembilan	9	Scattered throughout the state
Perlis	2	Scattered throughout the state

Seed production and supply. Approximately 780 kg and 90 kg of chili seeds were imported in 1983 and 1984 respectively (Rahmat and Chua, 1985) mainly from Thailand and Taiwan. There is no explanation available for the drop in imports. At present, there is no commercial seed production.

Cultivars. The two commonly planted cultivars are Kulai and Langkap. Currently MARDI is promoting several higher-yielding local selections (Leong, 1985) (Table 9). The selections were made from locally grown cultivars.

Table 8. Varieties of lowland chili.

Cultivars	Pungency	Av. fruit size (cm)	Av. plant height (cm)	Av. yield (kg/plant)	Remarks
Local cultivars					
Kulai	Very pungent	12.0 × 1.5 (long and thin)	60.0-180.0	0.5-1.5	Thin mesocarp
Langkap	Not pungent	(11.0-12.0) × 2.0	80.0-100.0	0.5-0.8	Thick mesocarp
MARDI Selections[z]					
MC 4	Not pungent	(8.0-9.0) × (2.0-2.5)	60.0-70.0	1.0-1.5	Ripens in flushes
MC 5	Pungent	(12.0-13.0) × 1.5	100.0-120.0	1.5-2.0	Long productive period
MC 6	Fairly pungent	13.0 × 2.5	75.0-95.0	0.7	Fruits contain few seeds
MC 7	Not pungent	9.0 × 3.0	70.0-90.0	0.7	Fruits contain few seeds
MC 10	Pungent	11.0 × 1.2	70.0-80.0	0.5	

Source: Leong 1985 [z]Currently being promoted

Crop management. On mineral soils, farmers often apply 3 to 6 t/ha of chicken dung one week before transplanting. About 2-2.5 t/ha of complete fertilizer 15:15:15 is applied as basal and top dressing at monthly interval. Seedlings are raised in shaded seedling beds and transplanted 4-7 weeks after sowing. Between rows spacing varies from 60-180 cm and between plant spacing from 45-80 cm. Weeding is mainly done manually (Leong, 1985).

Imports and exports. Import and export of chilies and chili-related products by Malaysia is shown in Table 9. Malaysia provides more than 90% of Singapore's requirement for fresh chili with more than 5,000 t of fresh chilies valued at more than US$1.2 million exported to Singapore every year (Mohd and Mohd, 1985). Malaysia also imports fresh and dried chili and chili products from India, Thailand, Taiwan and the People's Republic of China, with a total value exceeding US$11.6 million. Thailand is the main supplier of fresh chilies. The import of dried chili is valued at approximately US$9.2 million. India and Thailand are the major suppliers of ground chili.

Table 9. Import and export of chili and chili-related products by Malaysia, 1981-85.

Items	1981		1982		1983		1984		1985	
	Import (t)	Export (t)	Import (t)	Export (t)	Import (t)	Export (t)	Import (t)	Export (t)	Import (t)	Export (t)
Fresh chilies	1,026.5	6,243	926.1	5,915	1,485.4	5,623	3,357.5	5,407	5,150	7,316
Dried chilies	13,354.7	216	12,344.8	102	16,262.8	98	12,599.2	63	12,403	83
Ground chilies	269	7,147	209	1,121	298	1	259	2	371	4

Source: Ministry of Agriculture, Malaysia (1980-1985b).

Problems and Constraints

Pest and diseases. Pests and diseases are the most important constraints to successful production, as cited by more than 80% of the vegetable farmers interviewed by MARDI in 1981

(Anon. 1981). In 1984, the Federal Land and Development Authority (FELDA) tried to grow chili on a large scale in their oil palm scheme, but failed because of high disease and pest incidence which resulted in 95% yield loss (Rahmat and Tang. 1985).

Diseases affecting chili in Malaysia includ. (in order of importance): virus diseases caused by chili veinal mottle virus (CVMV), cucumber mosaic virus (CMV), tomato spotted wilt virus (TSWV) and tobacco mosaic virus (TMV); bacterial wilt (*Pseudomonas solanacearum*); anthracnose (*Colletotrichum capsici*); Cercospora leafspot (*Cercospora capsici*); basal rot (*Sclerotium rolfsii*) and leafblight (*Choanephora cucurbitarum*) (Noraini. 1984; 1986; Fujisawa et al. 1986; Mah. 1987). Damage due to viruses usually ranges from 10 to 15% in the case of late infection and may reach 60% in the case of early infection (Ong et al. 1980; Noraini. 1984). Bacterial wilt is serious when chili is planted continuously on the same field.

Anthracnose is devastating particularly in the wet season. In an epidemic situation, reduction in yield of 10 to 60% has been reported (Mah. 1985). The incidence of anthracnose was shown to be reduced by barrier crops (Mah. 1987). However, fungicide sprays still remain the best control method.

The most important pests are fruit flies (*Dacus dorsalis*) and fruitborers (*Heliothis* spp.) (Aziz. 1986. MARDI. Seberang. Prai. Penang. personal communication).

Nutrient deficiencies. Deficiency symptoms associated with lack of Fe, Mn and B which also affect yield sometimes occur when chili is planted on marginal soils such as peat, tin-tailing and bris soils (Vimala and Kho. 1985; Zaharah and Vimala. 1985). Water availability is also scarce in tin-tailing and bris soils due to their lower water-holding capacity.

Varieties. The varieties available are low-yielding, susceptible to diseases, and not uniform. Varieties suitable for dried chili are lacking.

Marketing. The supply is generally low. The price of chili is unstable and is usually tied up with the problem of seasonality in both supply and demand in the wet season. The seasonal influx of fresh chili from Thailand also affects the demand for local chili. Market outlets are not always secured.

Other problems. The high degree of postharvest losses, lack of proper storage and transport facilities, high transport costs and poor quality account for the high margins demanded by the market intermediaries to justify the risks associated with the crop. Inadequate market information makes matters worse.

Although not of prime importance, other constraints also affect chili production. Costs of production are high for chili, which is a slightly more delicate crop than tomato, good varieties are scarce, and there are labor shortages. As a result of these problems and the risks of chili cultivation, farmers often have difficulty securing sources of credit.

Research and Development

Varietal development. Notable varietal improvement has been achieved resulting in the recommendation of MC4, MC5, MC6, MC7 and MC10 by MARDI (Leong. 1985). Further improvement of yield, maturity, and fruit quality is currently under research at MARDI (Anon. 1987).

Efforts are also under way at the Agriculture University of Malaysia (UPM) to produce genetically superior varieties suitable for the fresh market and for processing (as dried chili and ketchup). Attempts to improve the yield further by researchers at the University of Malaya (UM) has led to the identification of two hybrid crosses (Irian × CM 31 and CPK × 0110-1) which showed significant heterosis in yield potential (Mak. 1987. Department of Genetics. University of Malaya. Kuala Lumpur. personal communication).

The development of virus-resistant varieties is in progress. MARDI scientists have incorporated CVMV resistance, derived from *Capsicum annuum* (MARDI Acc. No. 170) into

local susceptible cultivars. An intensive multiple virus resistance breeding program has been initiated for CVMV and CMV. Two combinations have been identified as potentially resistant materials. A project of a similar nature has also been started by breeders at UKM.

Studies on anthracnose have indicated that all the highly pungent Cili Padi genotypes (*Capsicum annuum* var. *aviculare*) possess resistance (Mah. 1985; Chew. 1986). Several advanced materials in which the resistance gene or genes have been incorporated are being evaluated for agronomic performance.

Disease and pest management. Currently, basic studies on the identification of chili viruses, their epidemiology and their effect on the host are being pursued vigorously at MARDI and UPM. An integrated virus management team consisting of several researchers within MARDI is actively conducting research to develop effective control measures for the different viruses. The same integrated management concept is also being evaluated in the farmers' fields by scientists from UPM. Another project funded by the International Foundation for Science is designed to evaluate cultural practices intended to control virus diseases, such as the use of reflective mulches, the cultivation of protective or barrier crops, the use of mineral oil sprays, and combinations of these techniques. Studies on the biology and host-parasite relationship of anthracnose are being pursued by UPM.

Research on fruit flies is presently confined mainly to the screening of effective insecticides. Basic research on the lifecycle, taxonomy and the identification of possible predators is being pursued by scientists at UPM and MARDI.

Nutritional requirements. MARDI has developed equations that predict nutrient removal by chili which make it possible to estimate the amounts of nutrients to be applied at various levels of production (Vimala et al. 1985). A specific fertilizer recommendation for very sandy bris soil has also been formulated (Zaharah and Vimala. 1985). At UPM an 'NPK predictor' to determine the nitrogen and potassium requirements for chili has been developed (Jabar et al. 1982).

Postharvest research. Research on improvement of storage conditions and artificial ripening is being conducted at MARDI. The best harvesting time for the degreening treatment is when the fruits start to turn purple or red.

Marketing. To assure market outlets, the Federal Agricultural Marketing Authority of Malaysia (FAMA) has been encouraging direct trading to supplement contract farming. To expand the existing market and to develop new market outlets, FAMA is implementing the so-called Market Promotion Program. FAMA is also trying to establish appropriate quotas on imports to help stabilize prices. The study of market potential is another step taken by FAMA to help define optimum production by local growers. FAMA has also initiated the establishment of standards and grades in conjunction with the Standard Institution and Industrial Research of Malaysia (SIRIM), in addition to the introduction of appropriate packing technologies.

Future Needs

There is a great need for a concerted effort to develop and improve the crop. Past experience has shown that the existing uncoordinated efforts by individual scientists to improve the crop to suit the local environment has led to little progress. It is suggested therefore that an active crop improvement group, involving scientists from both research and academic institutions as well as from the private sector, be set up at the national level.

A larger portion of the research funds and efforts available should be channelled into research on pest and disease control. Varieties suitable for processing must be developed at the earliest possible time. Small, reliable and inexpensive machines and equipment should be tested or modified to improve the efficiency of farm operations.

Researchers and institutions involved in pepper improvement are listed in the Appendix.

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Appendix: Researchers currently working on tomato and chili in Malaysia.

Name	Organization	Area of Research
Melor Rejab	MARDI, Jln. Kebun, Kelang, Selangor	Breeding
Chew Boon Hock	MARDI, Serdang, Selangor	Breeding (chili)
Mah, S.Y.	MARDI, Jln. Kebun, Kelang, Selangor	Pathology
Ho, B.L.	MARDI, Jln. Kebun, Kelang, Selangor	Bacteriology
Mohd. Roff, M.N	MARDI, Jln. Kebun, Kelang, Selangor	Virology
Mohd Shukor, N.	MARDI, Cameron Highlands, Pahang	Breeding (tomato)
Leong, A.C.	MARDI, Pontian, Johore	Agronomy
Vimala, P.	MARDI, Jln. Kebun, Kelang, Selangor	Nutritional Requirement
Aziz Atta, M.	MARDI, Bertam, Pulau Pinang	Entomology

Name	Organization	Area of Research
Syed Abd. Rahman	MARDI, Cameron Highlands, Pahang	Entomology
Mak Chai	Univ. of Malaya, Kuala Lumpur	Breeding (chili)
Ahmad Mahir	Univ. Keb. Malaysia, Bangi, Selangor	Breeding (tomato)
Noraini Samad	Univ. Agric. Malaysia, Serdang, Selangor	Virology
Cheah, C.H.	Univ. Agric. Malaysia, Serdang, Selangor	Breeding (chili)
Mohd. Md Ali	Univ. Agric. Malaysia, Serdang, Selangor	Agron. & Physiol. (chili)
Jabar Kamal	Univ. Agric. Malaysia, Serdang, Selangor	Fertility (chili)
Sariah Meon	Univ. Agric. Malaysia, Serdang, Selangor	Pathology
Zakaria Sidek	Univ. Agric. Malaysia, Serdang, Selangor	Virology (chili)
Inon Sulaiman	Univ. Agric. Malaysia, Serdang, Selangor	Virology (chili)
Kamaruzaman Sijam	Univ. Agric. Malaysia, Serdang, Selangor	Bacteriology (chili)
Hiryati Abdullah	Univ. Agric. Malaysia, Serdang, Selangor	Bacteriology
Isnin Bujang	Univ. Agric. Malaysia, Serdang, Selangor	Breeding (tomato)

Symposium Discussion

J.W. Scott: What are the sources of tomato late blight resistance you mentioned?
N.M. Shukor: They are PI 162679 from AVRDC germplasm collections and West Virginia Accession 700 from USDA.

N.S. Talekar: (1) From where do you import your pepper? (2) How serious is *Liriomyza* sp. on tomato in Malaysia?
N.M. Shukor: (1) Dried chili pepper are imported from India and China. (2) Not very serious. The most serious pest is fruitborer.

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56

Tomatoes and Peppers in Mexico: Commercial Production and Research Challenges

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Abstract

Peppers *Capsicum annuum* and tomatoes *Lycopersicon esculentum* are together the most important vegetables in Mexico, in terms of acreage, hand labor, value and export. Relative importance can be inferred from the size of the Mexican population (close to 80 million), the daily use of the crops at every social level, and their importance in foreign trade. The combined effect of Mexico's tropical location and the variety of available agricultural areas ranging from sea level to over 2,000 m, allows year-round production of the two crops, both for local consumption and export. Winter production is located on both coasts, whereas summer production is on the central plateau. Most research is done by the National Institute of Agricultural Research (INIFAP) which has a large and active pepper germplasm bank at the Bajio Experiment Station.

National annual production of tomato is close to 2 million t on 73,000 ha. Most of the tomato production for fresh-market, processing and seed production comes from Sinaloa in the northwest coastal region of the country. The region produces high yields of good quality fruit, because of the long harvest periods and effective cultural practices such as hand-transplanting and staking. The summer supply for the huge fresh market of Mexico City and the surrounding metropolitan area (17 million people) is produced within a 300-km radius, which includes high-altitude valleys. Small-scale local production is undertaken in virtually every state. Foliar diseases, pinworm, leafminer and fruit firmness are the main research challenges.

More than 30 commercial types of peppers are continuously marketed in the area, but local consumption is restricted to pungent types. Pasilla and Ancho types supply most of the dry pepper market and are produced in the temperate central valleys, whereas Jalapeño and Serrano, the leading types for fresh production, can be produced in areas where the climate is warmer. Bell peppers (sweet peppers) are grown mostly for export to the USA. Wild populations of *C. annuum* and *C. frutescens*, known as Piquin or 'bird-pepper' are found in several coastal locations or frost-free inner valleys and are marketed fresh or dry. Resistance to tobacco etch virus and *Phytophthora capsici* found in landraces and Piquin accessions, has been successfully used in breeding programs worldwide.

Introduction

Taken together, peppers (*Capsicum* spp.) and tomatoes (*Lycopersicon esculentum*) are the most important vegetables in Mexico, in acreage, hand labor, value and export. They are used daily in the Mexican diet at every social level. The tropical environment and scattered growing areas from sea level to over 2000 m, allow year-round production of the two crops, both for local consumption and export.

The use of these two crops in Mexico goes back to ancient times, and they have always been linked. Tomatoes are ground or chopped, and mixed with hot peppers, onion, salt, and so on for 'salsas'. The ingredients of 'salsa', vary according to region, but hot, pungent peppers are always part of it. In green salsas, *Physalis ixocarpa*, or 'tomatillo', is substituted for tomato. *L. esculentum* and *C. annuum* originated in South America, but both were domesticated in Mexico in early times (Rick, 1976; Pickersgill, 1971). Wild forms of *L. pimpinellifollium*, *L. esculentum*, var. *cerasiforme*, *C. annuum*, var. *glabriusculum* and *C. frutescens* are commonly found in many places, and their special flavor is widely acceptable.

Many different commercial types of hot and sweet pepper exist in Mexico. Pepper contributes flavor, color, aroma, and condiment to the very rich Mexican cuisine. It has played a key role in tradition, folk medicine, and gastronomic diversity. Selection for flavor preference and local use has been carried out for centuries, and a study of the evolution of domestic peppers in Mexico would be instructive. Thorough studies have already been made of the role of peppers in Mexican culture and tradition, and work has been done on their use in religion, as tribute in ancient times, and as a folk medicine (Long-Solis, 1986).

Distribution in Mexico

In winter, the two crops are grown in the low altitude valleys along both coasts. By contrast, summer production is from high altitude valleys in the center of the country. Pepper and tomato are produced in four major areas (Figure 1).

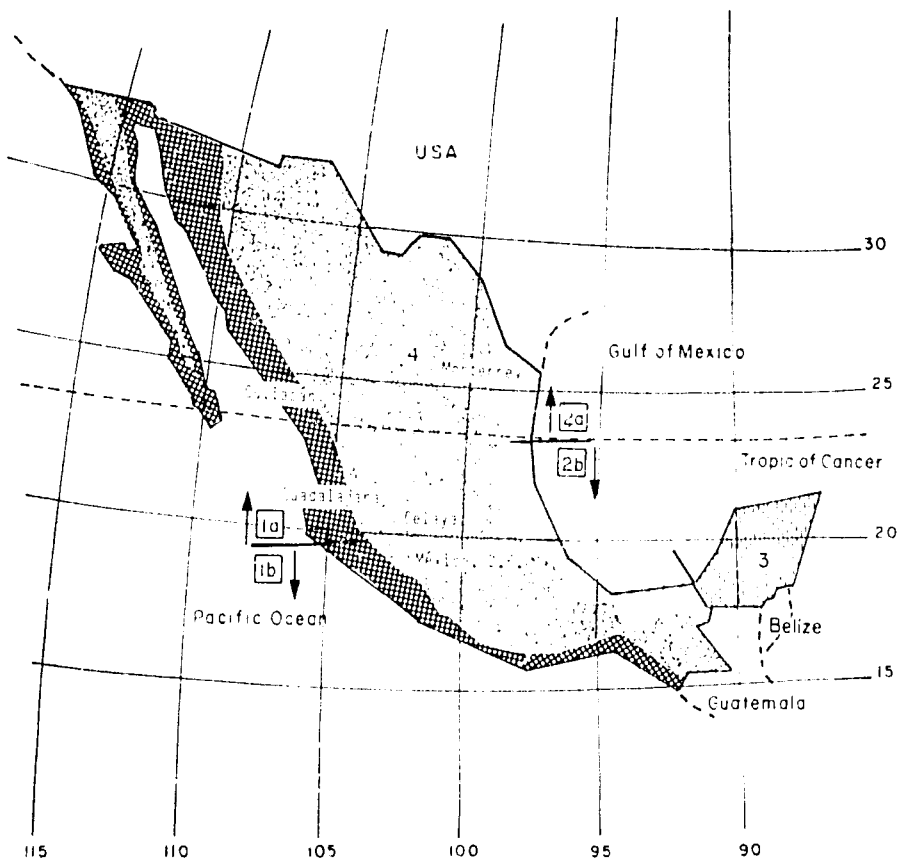

Figure 1. Tomato and pepper distribution of Mexico.

West Coast

Region 1a, comprises the northern west coast from about parallel 20° N up to the US border. This region has dam-irrigated valleys and is characterized by frost-free winters, deep soil and optimum growth temperatures. Most of the fresh-market tomato, bell peppers, cucumbers, melons, and eggplant, which are exported to the US during the winter are produced there, as well as most processing tomatoes. This region also plays an important role in the winter supply of Ancho and Serrano peppers for the Mexican market. Hot temperatures (35 to 40° C), high moisture and heavy rainfall at the peak of the rainy season (600 mm), precludes any commercial harvest from June through November. The main harvesting period is December to June.

The southern west coast from Michoacan to Chiapas, makes up Region 1b. Corn, melons, watermelons and other staple crops for domestic use are commonly grown here. The region has good potential for tomato and pepper production, because of favorable weather and soil, and plentiful water and hand labor. The bulk of vegetable crops in the region is grown for winter harvest with a main harvesting period from December to June.

East Coast

Region 2a, the northern east coast, is similar to the lower Rio Grande Valley of Texas, which has a frost risk and is not sufficiently warm for winter production of peppers and tomatoes. The harvest period coincides with that of south Texas, thus depriving this area of export opportunities. The limited production of tomatoes and peppers is for local consumption. The main harvesting periods are May June and October November.

Region 2b is the southern east coast. The gulf coast region, south of the Tropic of Cancer, has commercial winter production of tomatoes and is also the traditional Serrano and Jalapeño pepper producing area during winter months. The main harvesting period is from December to May. Heavy tropical rains, high temperatures, low yields, poor quality and severe disease and insect problems make summer production unprofitable.

Yucatan Peninsula

Region 3 has many features in common with Florida, but temperatures are generally higher and frost is absent. The main harvesting period is from December to May. Production of both crops is for the local markets. The two crops are not yet grown for export, primarily because of the small landholdings under cultivation, and because of social factors. The peninsula, in spite of troublesome soil management problems, has the agricultural potential to become an important supplier of tomato and pepper in the winter.

Central Plateau

Region 4 consists of two main high mountain ranges (sierras) which run along and close to the east and west coasts. Several valleys with a variety of different agroclimatic niches and ranging from 1,000 to 2,000 m in altitude are located between the sierras. Valleys with winter temperatures cold enough for frost are located in the northern half of the plateau and above 2,000 m, whereas the low altitude southern valleys experience what is dubbed 'permanent spring' because of their constant mild, frost-free weather. In most of this region the rainy season is from June to early October. Most of the agricultural production is rainfall-dependent and is devoted to staple crops, such as corn. Vegetable crops, including tomatoes and peppers, are grown under irrigation and represent most of the summer and fall production of the country. The main harvesting period is from June to September or from October to March in some low southern valleys.

Most fall-harvested Jalapeño peppers are from Chihuahua State. The typical Mexican peppers, Ancho, Mulato, and Pasilla, are grown across a long north to south stretch of the country from

Zacatecas to Guanajuato. Fresh-market tomatoes are produced year round in this area, with fall and winter production in the low valleys south of Mexico City, and spring and summer production in medium to high-altitude valleys. Areas which used to produce processing tomato areas no longer do so, because of low yields which are attributed to virus diseases. However, the excess production of fresh-market tomatoes is sold to processors.

Production and Export

Tomato

Growing areas, average yields, and national production figures are presented in Table 1 and probably include both fresh-market and processing tomatoes. The main producing states and their corresponding shares in area and production are presented in Table 2. In the last 10 years the total acreage has fluctuated between 61,000 and 77,000 ha, with an average yield of about 25 t/ha. More than 50% of the total acreage is in the northwest coastal region near Sinaloa (Region 1a, Figure 1). Sinaloa produces about 1.3 million t of tomatoes annually on 31,000 ha and average yields of 42 t/ha are obtained. The region leads in export, domestic production and processing. The importance of the northwest coast (Region 1a) becomes evident when the export market is considered. In winter and spring, 94% of exports come from Sinaloa, and during

Table 1. Tomato production in Mexico.[z]

Year	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
1977	61.7	15.8	974
1978	65.4	21.3	1,394
1979	77.4	20.2	1,565
1980	69.5	19.0	1,321
1981	61.8	17.4	1,075
1982	56.5	23.2	1,313
1983	63.0	23.4	1,472
1984	68.1	23.1	1,574
1985	70.1	25.4	1,779
1986	73.0	26.3	1,925

[z]Modified from Union Nacional de Productores de Hortalizas (UNPH), 1987b

Table 2. Tomato production areas in Mexico.[z]

Region	State	Area (%)	Production (%)
1.a	Sinaloa	43	66
1.a	Baja California Norte	4	2
1.a	Sonora	2	2
1.b	Michoacan	4	2
2.b	Tamaulipas	10	4
2.b	Veracruz	5	2
4	Morelos	3	3
4	Guanajuato	3	2
4	Hidalgo	3	2
1 to 4	22 other states	23	15
	Total	100	100

[z]Contribution by States, 1986 season. Modified from UNPH 1987b.

the fall, exports come exclusively from the northern Baja California. In 1987 Sinaloa exported 359,161 t and Baja California Norte 52,141 t. The United States imports about half of its tomato requirements, mostly from Mexico. The importance of Mexican tomatoes in the winter market of the USA is presented in Table 3.

Table 3. Mexican share of winter-spring fresh market tomatoes in the USA.[z]

Year	Total USA winter-spring consumption ('000 t)	% imported	% USA imports from Mexico
1978	737	50	99
1979	728	43	99
1980	773	40	99
1981	723	35	98
1982	758	32	98
1983	789	36	99
1984	723	42	99
1985	823	39	98
1986	745	45	98
1987	807	45	98

[z]Modified from UNPH 1987b.

Peppers

The statistics for peppers are not very reliable, because they are expressed in two different ways: as 'pungent' and 'nonpungent' (peppers and sweet peppers) or as 'dry and green peppers'. However some pungent types such as Ancho and Pasilla (Figure 2) are marketed as either dry or green peppers. Current figures do not specify which peppers are included in which group. Official figures for 'green peppers' (Table 4) give a yearly acreage of over 60,000 ha, with a mean yield of 9.1 t/ha. The individual contribution per state is given in Table 5. A noticeable omission from this table is Tamaulipas State, the main Serrano producer. The different ratio of percent area production of Veracruz and Oaxaca (12.7 and 14.6) in contrast with Chihuahua (7.16), may be explained by the widespread use of new improved, high-yielding Jalapeño cultivars in Chihuahua, in contrast with high-quality but low-yielding creole varieties in Oaxaca and Veracruz.

The most accurate statistics are available for exported peppers, because of a special permit which has to be presented at the US–Mexican border. Bell peppers, which are grown mostly for export, have shown a steady increase in production in recent years, from 42,709 t in 1982-83 to 97,109 t in 1986-87. Most of the US import needs are covered by Mexican produce, although the share taken by pepper in the US winter market is lower than that achieved by tomatoes (Table 6).

Table 4. Fresh green pepper production in Mexico.[z]

Year	Area ('000 ha)	Yield (t/ha)	Production ('000 t)
1977	49.8	9.7	482
1978	55.9	9.5	531
1979	57.9	8.6	498
1980	60.7	8.7	531
1981	45.4	8.9	405
1982	66.3	8.4	554
1983	48.5	9.3	449
1984	51.3	11.0	566
1985	78.1	8.2	639
1986	63.5	8.4	536

Includes many different kinds of peppers. [z]Modified from UNPH 1987b.

Table 5. Fresh green pepper production by state, 1986 season.[z]

Region	State	Area (%)	Production (%)
1.a	Sinaloa	17	22
1.a	Nayarit	6	8
2.b	Veracruz	12	7
2.b	Oaxaca	14	6
4	Chihuahua	7	16
4	Zacatecas	12	13
4	Guanajuato	6	6
4	San Luis Potosi	5	6
4	Puebla	4	3
1 to 4	22 other states	17	13
	Total	100	100

[z]Includes many different types of peppers. Modified from UNPH 1987b.

Table 6. Mexican share of winter-spring fresh bell peppers in the USA.[z]

Year	Total USA winter consumption ('000 t)	% imported	% USA imports from Mexico
1978	131	39	95
1979	137	36	94
1980	149	45	96
1981	130	32	92
1982	145	40	94
1983	130	33	92
1984	139	36	93
1985	166	46	95
1986	176	49	96
1987	185	50	96

[z]Modified from UNPH 1987b.

Figure 2.
Some commercial peppers grown in Mexico: (a) used fresh and dried: 1a. Chipotle, 1b. Jalapenō; 2a. Ancho, 2b. Poblano; 3a. Pasilla, 3b. Chilaca. (b) dried usage only 4. De Arbol; 5. Guajillo. (c) fresh usage only: 6. Serrano; 7. Peron; 8. Caloro; 9. Dulce (bell).

Pungent peppers, in contrast with bell peppers, are exported year round, although 72% of the total export is in winter and spring. Serrano and Jalapeño are exported throughout the year. Pepper exports for the last 10 years are presented in Table 7. The trend to export is generally increasing. Jalapeño, which is mostly exported in cans, is not included in agricultural export statistics and the even increasing USA demand of processed Jalapeños, has prompted the Mexican government to stipulate a condition of the export permit by the canning industry to provide enough product for the domestic demand. Nobody can predict, least dares to face, the consequences in Mexico from running out of Jalapeños.

Table 7. Pungent fresh and dry pepper export to the USA, 1978-87.[z]

Year	Type of pepper exported ('000 t)					
	Jalapeño	Serrano	Anaheim	Caribe	Pasilla	Others[y]
1978	1.9	1.2	1.8	1.2	0.08	5.0
1979	2.1	1.0	–	1.4	0.1	4.4
1980	2.6	1.1	0.4	2.9	0.01	1.0
1981	2.2	1.4	0.6	0.4	0.2	4.1
1982	7.6	1.2	0.6	0.5	0.2	5.4
1983	4.0	2.0	0.3	0.2	0.3	7.4
1984	3.0	1.5	0.3	0.2	0.6	29.6[x]
1985	6.1	3.0	1.4	0.7	1.0	5.4
1986	4.9	2.5	1.2	0.7	1.2	3.4
1987	5.7	3.1	2.5	1.9	1.3	2.3

[z]Modified from UNPH 1987a, 1987b [y]Poblano, Calcro, Cubanelle, Ancho, Cayenne, De Arbol, Seco, Fresno, Guajillo, Cascabel, Chilaca, Hungarian, Cherry, Mirasol, Piquin, Negro, Puya, Bola, Chipotle, Güerito. [x]There is no logical explanation for this figure.

Cultivation Practices

Tomato

Tomato production techniques vary somewhat from region to region. In most parts of the country, ground tomatoes are grown in rows 1.8 m to 2.5 m apart, with plants spaced 30 cm to 1 m. Direct seeding or transplanting using traditional seedbeds are standard procedures, except in Sinaloa where seedlings are grown under plastic greenhouses.

Sinaloa's traditional competitive edge has been based on harvesting pink or vine-ripened tomatoes. This is accomplished by trellising the plants between agave or plastic strings, supported by thick wooden stakes. This requires huge inputs of hand labor. About 20,000 ha of staked tomatoes are grown annually in Sinaloa, which far exceeds the hectarage of pole tomatoes in any other single region in the world. Indeterminate tomatoes are pruned to two stems, because increased fruit size is a well known response of two-stem pruning. Only two growing points are allowed and all suckers below the first cluster of flowers are removed. The weekly removal of side branches, above the first truss, is practiced for as long as the exuberant foliage growth permits.

However, determinate cultivars now occupy the largest hectarage of staked tomatoes. Pruning has changed accordingly. All leaves and growing points are suppressed below the first flower truss, but a light pruning is made above it. Several growing points are allowed in contrast to the two in the traditional method for indeterminate types.

In the early season (August to September plantings), temperatures are 35° to 40°C with 90% to 100% RH at Sinaloa. To allow extra ventilation under these extreme conditions, growers remove all leaves at ground level up to 10 cm. Upper leaves are removed on the side of the row with lower solar exposure, uncovering fruits to be harvested within one month to decrease incidence of gray wall fruit disorder. Leaf removal is claimed to promote earliness and to facilitate control of foliar diseases.

The vine-ripened tomatoes are harvested at the breaker stage, 95 to 105 days after transplanting. They are harvested daily for 60 days in the case of determinate cultivars, and for 90 days if indeterminate hybrids are used. In contrast, mature green tomatoes are usually harvested four times at 10-day intervals. These fruits are artificially ripened by ethylene. The production cost is greatly reduced and a firmer fruit is thus obtained in this way, though with inferior color and flavor.

Cultural practices, including pruning techniques, recommended cultivars and registered chemicals for insect and disease control, are updated yearly by regional experiment stations (Silvas et al. 1987).

Tomato paste for export to the US, Canada and other countries is obtained from high-quality processing tomatoes produced in Region 1a under standard Californian growing techniques (Sims et al. 1979), some including machine harvesting. For domestic consumption, a large share of tomato paste production comes from leftovers of fresh-market fields.

Peppers

Peppers are usually transplanted, and only seldomly they are direct-seeded. Due to the diversity of types, regions, and economic status of growers, different systems for producing transplants are to be found, ranging from very rudimentary seedbeds, ground-built as a series of 1 m × 1 m squares covered with dry corn stalks for frost protection, to seedling production under plastic greenhouses, where temperature, irrigation, pests and diseases and fertilizers are controlled. No matter what seedling raising technique is used, all transplanting is done exclusively by hand.

Distance between rows and plants varies according to individual plant sizes; traditional Mexican types tend to have large plants, and thus low population density. Bell pepper types and others grown for export have short, compact plant structure, which allows planting of two rows per bed. Peppers grown during the rainy season require deep rows to facilitate water runoff from the base of the plant so that wilt, caused by *Phytophthora capsici*, can be minimized. This practice is mandatory for Region 4. Flat rows result in poorly drained fields and complete loss due to wilt is common.

Harvesting is always manual at the mature green stage (for fresh fruit) or at the fully ripe stage (for dried fruit). Dehydrating methods vary from sun-drying, to the use of commercial dehydraters. Sun-drying is used in small enterprises where family members provide the labor required to turn the fruits daily until they are fully dry. Dehydrators, which blow hot air under a slow moving belt on which fruits are placed, are used by large commercial operations.

Cultivars

Tomato

Ace and San Marzano were the standard cultivars for fresh and processing tomato in the Central Plateau (Region 4) for many years. On the west coast (Region 1a) fresh-market cultivars mostly reflect the Florida releases of the 1960's such as Indian River, Manapal, Tropic, Homestead, and others; Walter, Florida MH-1, and Hayslip, released in the 1970's; and currently Floradade, Sunny, Carmen, Contessa, Mountain Pride, Pole Boy, Pole King, etc. Cultivars found to be successful on the west coast are tried in the rest of the country, where local preference decides the prevalence of one or another. Mexican releases, such as Culiacan 1, Culiacan 360, Pacifico and Humaya, have never had a significant share of the market.

Lassen and Alta are the main processing cultivars, representing about a fourth of the total hectarage of processing tomato. Other processing cultivars such as UC-82B, E-6203, and Red Stone, are also used for the fresh-market. Processing tomatoes used for such purpose are

collectively called 'Saladez tomatoes', a generic derivative from Saladette, a cultivar no longer in use. There is a growing trend towards preparing homemade salsas with these kinds of tomatoes.

Landraces can be found in the local markets. They are usually fasciate. Wild plants of *L. esculentum* var. *cerasiforme* and *L. pimpinellifolium* are commonly found and their fruits are preferred for certain local dishes. They are not commercially produced, but have been successfully used in breeding programs.

Pepper

A particular classification used in one country does not necessary apply to other countries. Classification of peppers in India (Muthukrishnan et al. 1986) or the US (Smith et al. 1987) does not apply to the diverse Mexican types. The main Mexican peppers and their common growing techniques have been described (Laborde and Pozo. 1984) and this information is summarized in Table 8.

Some commercially grown types are presented in Figure 2. Ancho and Pasilla are the most popular dried types, respectively named Poblano and Chilaca if used fresh. Jalapeño is called Chipotle when smoke-dried. Two others used exclusively dried are De Arbol and Guajillo. Those used only fresh are: Serrano, Peron, Caloro and Bell. The last two are grown mostly for the export market.

The major peppers commercially grown in Mexico are grouped in Table 8 by their market destination: (a) national consumption and export, and (b) exclusively for export. Cultural practices are not included in Table 8, even though they form the subject of a large research effort by INIFAP. The lack of proper plant selection in the field has led to a large variability within the landraces. The National Institute of Agricultural Research (formerly INIA, now INIFAP, from its acronym in Spanish), has released improved cultivars from these landraces. In most cases, mass and pedigree selection for a number of generations has been necessary before releasing improved cultivars. A total of 21 improved cultivars are described with complete pedigree information (Pozo. 1981). The most common ones are: Jarocho and Papaloapan (Jalapeño type); Cotaxtla, Veracruz S-69, Tampiqueño 74, Panuco and Altamira (Serrano type); Verdeñe, Esmeralda, 1020 (Ancho type); Apaseo, Salvatierra (Pasilla type); V-2, and Roque (Mulato type); Loreto and Real Mirasol (Guajillo type); Uxmal (Habanero type). Improved peppers have been immediately adopted by the growers. There is ample evidence that Tampiqueño 74 was used in every growing region and replaced all landraces within less than four years of its release. Genetic erosion was prevented by preservation of the original collections. Uniform fruit type and high fruit quality have been the main factors in the success of Tampiqueño 74 and other improved Mexican cultivars. Some Jalapeño types released by American seed companies have become the dominant cultivars in some Jalapeño-producing regions such as Chihuahua, because of their very high and uniform yield, although their quality and pungency do not compare with the traditional types. For bell peppers and other common US pepper types, only American cultivars and hybrids are used.

The pepper seed trade in Mexico is quite unique. Seed distribution of most of the Mexican types is undertaken by brokers who produce their own seed or buy it from selected growers. The big brokers partially finance commercial production and provide the seed.

Marketing of Pepper and Tomato

The export trade consists mostly of fresh winter products to the United States, although a small amount of peppers is exported on a year-round basis. Fresh tomatoes and peppers are shipped by refrigerated trucks to the closest US border where they are distributed according to their destination. Many growers have their own brokers. To control export production, the total regional acreage is agreed by the local grower's associations, and consolidated for all the country, by the National Confederation of Vegetable Growers (UNPH, acronym in Spanish).

Table 8. Major peppers commercially grown in Mexico.

Type	Pungency	Adaptation[z]	Use
A. National consumption and export			
Jalapeño	Mild/hot	Warm (2b, 4, 1a)	Mature green, fresh, in salsas Mature green, canned. Most popular use Ripe, dried by smoke, called 'chipotle'
Serrano	Hot	Warm (2b, 1a, 4)	Mature green, fresh, in salsas
Ancho	Mild/hot	Temperate (4, 1a)	Mature green, fresh, stuffed or in slices also called 'Poblano' or 'Cuaresmeño'. Ripe, dry. Very popular
Mulato	Mild/hot	Temperate (4)	Same as ancho, but ripen brown, not red.
Pasilla	Mild	Temperate (4)	Mature green, fresh. Called 'Chilaca', for slices. Ripe, dry. Widely used.
De Arbol	Very hot	Temperate (4)	Ripe, dry. Special flavor for hot salsas
Piquin	Very hot	Warm (2a, 2b, 1b, 1a, 3)	Collected from wild plants. Fresh or dry use Mostly *C. annuum*, but some *C. frutescens* in regions 1b, 2b and 3. Called 'bird pepper'
Various dry	Very hot	Temperate and warm (1 thru 4)	Costeño, puya, cascabel, mirasol, guajillo, bola, negro, etc. are hot peppers sold only as dry peppers Marketing volume is much less than ancho, mulato, pasilla or arbol, but are mandatory for many special dishes
Habanero	Very hot	Warm (3)	Exclusively grown in Yucatan Peninsula. The only *C. chinense* grown in Mexico. The name is Spanish, not Mayan, suggesting recent introduction. Consumed only fresh, mature green or ripe
Manzano	Very hot	Cold (4, only above 2000 m)	The only *C. pubescens* commercially grown in Mexico. Produced at very high altitudes, above where no other *Capsicum* can survive because of low temperatures. Probably a recent introduction
B. Exclusively for export			
Bell	Sweet	Warm (1a, 4)	Fresh, in salads, limited local consumption
Various fresh types (Cubanelle, Fresno, Caloro, Hungarian, Anaheim)	Sweet and hot	Warm (1a, 4)	Fresh, appear very seldom in local markets

[z]Numbers and letters refer to regions in Figure 1, and are listed according to their commercial importance.

Production plans, and corresponding acreage proposals, receive final approval from the Ministry of Agriculture which enforces them through a system of export permits, distributed and controlled by UNPH.

There is no equivalent control for the production for local consumption. Acreage and product availability may fluctuate widely from year to year. The national market is dominated by three main centers of distribution: Mexico City, Monterrey, and Guadalajara (Figure 1), each affecting large regions of the country such as central and south, northeast, and west, respectively. The combined population of these three cities, including their close dependant suburbs, is over 20 million people, roughly a quarter of the Mexican population. Price fluctuations in all other cities are affected by these three main marketing centers.

Production Constraints

The factors limiting tomato and pepper production vary between the different growing regions. The most relevant information is summarized in Table 9. Emphasized here are those problems where international cooperation would be extremely helpful.

The relative importance of the limiting factors is ever-changing. Although tomato fruit firmness has always been studied by the national breeding programs, it has become a critical factor in recent years, particularly in Sinaloa where tomatoes are produced for export to the USA. Florida mature green tomatoes, which are paler and less tasty and whose ripeness has been induced by ethylene, arrive firmer to the consumer and command higher prices than the better flavored and colored vine-ripe tomatoes.

Diseases are very important in both crops. A number of different viruses have been the most devastating constraints both for tomato and pepper. A 60% reduction in tomato yield has been attributed to viruses in the Bajio area at the center of Region 4 (Garzon, 1984). As a consequence the hectarage has been reduced to less than 3,000 ha today from 13,000 ha in 1974. A similar situation has been recorded for peppers in the winter production area of Tampico, Region 2b. Research efforts have concentrated on the identification of the viruses

Whereas pests are a serious economic problem only for tomato and not for pepper, recent research dealing with insect control of tomato has been strongly influenced by the ever-lower tolerances of chemical residues in vegetables. The year-round presence of pests favored by the absence of winter frosts, the pests' short lifecycles and tolerance of or resistance to certain insecticides, has forced researchers to look for new approaches. Priorities have shifted from chemical control to integrated pest management (IPM). The natural levels of parasitism and predators are very high, and positive results have been obtained in Sinaloa for processing tomatoes (Alvarado, 1987). After monitoring pinworm, fruitworm, armyworm and leafminer populations and their corresponding parasitism levels during the 1986-87 season, more than 900 ha out of a total of 2,200 ha were grown under IPM, without a single chemical application. Five to nine applications had been common in previous years. A joint effort by growers, industry and INIFAP is under way to implement the IPM program for both fresh and processing tomatoes in Sinaloa.

Research Institutions

In many developed countries a large part of the agricultural research effort is based in the university system, and the extension service is linked to or derives feedback from the university system. Teaching and research are mutually dependent , and so they have a continuous feedback.

Mexico, like many other developing countries, does not follow this pattern. Teaching institutions are virtually void of research, mostly because of lack of funds and an overload of teaching assignments rather than because of a lack of qualified researchers. Thus agricultural research activities of the country are led unchallenged by federal government agencies. The National Institute of Agricultural Research (INIA) was recently merged with the Research Institutes of Forestry and Livestock, to become INIFAP. In spite of its federal status it was subdivided in 1987 into 31 partly independent state research centers, though some national

Table 9. Limiting factors of production and research projects.

Problem	Evident since	Main regions of occurrence[z]	Solution to the problem[y]	Suggested goals of research[x]
Tomato				
Plant pathogens				
Late blight (*Phytophthora infestans*)	50s	1a, 4	Forecast	G.R.[y]
Early blight (*Alternaria solani*)	50s	All	Partial	G.R
Powdery mildew (*Leveillula taurica*)	80s	1a	Partial chemical control	Efficient chemical control and G.R
Bacterial spot (*Xanthomonas campestris* pv *vesicatoria*)	80s	1a	None	G.R.
Bacterial speck (*Pseudomonas tomato*)	80s	1a	None	G.R.
Curly top virus	70s	1a	None	Positive virus and vector identification
'Virus Permanente del Tomate'	70s	4	Partial	G.R., IPM
Tobacco etch virus	80s	1a	Partial	G.R., IPM
Tomato spotted wilt virus	80s	1a	None	G.R.
Insects				
Armyworm (*Spodoptera exigua*)	50s	All	Promising (in region 1a)	IPM
Leafminer (*Liriomyza sativae*)	50s	All	Promising (in region 1a)	IPM
Fruitworms (*Heliothis zea*)	50s	All	Promising (in region 1a)	IPM
Pinworm (*Keiferia lycopersicella*)	60s	1a	Promising (in region 1a)	IPM and G.R.
Quality				
Fruit firmness	80s	1a	Limited postharvest management	Breeding
Pepper				
Plant pathogens				
Bacterial spot (*Xanthomonas campestris* pv *vesicatoria*)	80s	1a	None	G.R.
Pepper wilt (*Phytophthora capsici*)	50s	4	Resistance	G.R.
Tobacco etch virus	70s	2b	Partial	G.R.

[z]Regions refer to those of Figure 1. [y]Based on research results obtained in Mexico. [x]G.R. = genetic resistance; IPM = integrated pest management

coordination is still in effect. The main research teams for tomatoes and peppers are located in Sinaloa, Tamaulipas and Guanajuato States. Information on research projects and other INIFAP activities in tomato and pepper can be addressed to: Dr. Eliseo Redondo, Vegetable Crops Leader, Apdo. 112, Celaya, Gto. 38000 Mexico.

There are no formal joint research projects on tomato and pepper with international research institutions of the sort conducted with CIP on potato, and with CIMMYT on wheat and corn.

Private research is carried out by international companies. Seed companies usually limit their activities to generation advance during winter time. Although they may select a particular

line with outstanding performance under Mexican conditions, the development and evaluation of lines or hybrids are conducted elsewhere. Research in the private tomato industry has been addressing local production problems and has provided outstanding contributions to integrated pest management as well as new locally adapted cultivars.

Limited project oriented collaboration with foreign research organizations does occur, such as a joint venture with the University of California at Riverside to investigate tomato pinworm. More such international efforts are needed.

Growers' Associations

The importance of the export market for tomatoes and peppers cannot be ignored. Much of the credit for export success goes to the National Confederation of Vegetable and Fruit Producers (UNPH) which was created in 1962. It has acted as a link between local growers' associations and different government agencies dealing with export permits and regulations. Its careful yearly growing projections have been instrumental in keeping a proper balance between supply and demand. Twenty-four regional agricultural associations representing a total of 238 local growers associations are affiliated with the UNPH, involving a total over 22,000 individual growers. An important UNPH contribution has been to promote, counsel and advise growers on how to organize locally for cooperative efforts aimed at export. Additional information about UNPH or its specialized crop groups can be obtained from: UNPH, Apdo. 712, Culiacan Sinaloa, Mexico.

Potential Contribution of Mexico to the International Community

Organizations such as the Asian Vegetable Research and Development Center (AVRDC) should play an active role in evaluating, promoting and helping to preserve national germplasm collections, and in considering joint ventures with national research organizations. Considering its unique situation, Mexico should be a logical non-Asian partner country.

The factors contributing to the outstanding position of tomato and pepper in Mexico are: Mexico's position as a domestication center for both crops, (in pepper only for *C. annuum*); available wild germplasm and landrace cultivars, sources of resistance to insects and diseases of international importance, aggressive predators and parasites of major pests resulting from thousands of years of cultivation; commercial production under a wide range of social, economic, and technological conditions; different climatic conditions which emulate any growing condition in the world; ample research facilities throughout the country; and a well organized confederation of growers' associations that currently provide significant economic support for research projects.

Germplasm evaluation for sources of resistance to environmental stresses, pests and diseases is of prime importance. A continuous, but limited, effort since 1976 by INIA (now INIFAP) on germplasm collection and evaluation led to the establishment of a large pepper germplasm collection at the Bajio Experiment Station. An active duplicate of most of Dr. Paul G. Smith's collection is kept there. A grant from the International Board of Plant Genetic Resources (IBPGR) provided extra support for *Capsicum* collections in Mexico (IBPGR, 1983). Examples of contributions made by the germplasm so far collected are sources of resistance to *Phytophthora capsici*, and tobacco etch virus. These sources are currently used in breeding programs in other countries.

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Symposium Discussion

G.Y.H. Grubben: (1) Which proportion of the area and production is accounted for by small farmers? (2) Why is there no national seed production if all conditions are so favorable?
J.A. Laborde: (1) There are small farm operations both for pepper and tomato in most agricultural areas. They may be located next to big farm operations, but represent well below 30% of the area and production. (2) For a reason we call 'Malinchismo' which means 'better trust foreigners rather than nationals'.

D.J. Schuster: Have the tomato landraces from Mexico been evaluated for insect or disease resistance?
J.A. Laborde: No, not in a systematic way. Some have been evaluated for fruit-set at high temperatures.

N.S. Talekar: What is the status of pinworm damage in the southern or more tropical areas of Mexico?
J.A. Laborde: It is not yet of economic importance as it is along the northwest coast.

E.C. Tigchelaar: What is the status of tomato virus diseases in Mexico?
J.A. Laborde: In central Mexico (Bajio area) 'permanente virus' has been so severe that the acreage has been reduced from over 15,000 ha to 2,000-3,000 ha. Along the Pacific Coast, south of region 1-A at Autlan Jal., similar damage has occurred. Integrated pest management has given promising results by controlling vectors.

R.L. Villareal: (1) Are you growing US varieties of tomatoes and bell pepper in the Culiacan Valley? (2) What are the major vegetable research centers/institutes in Mexico?
J.A. Laborde: (1) All important tomato and bell pepper varieties in the Culiacan Valley, as well as in the rest of the country, are US varieties, mostly hybrids. (2) INIFAP, the former National Institute of Agricultural Research.

H.C. Wien: Why does the fasciated tomato type persist in local varieties?
J.A. Laborde: The large, fasciated tomatoes of Oaxaca are locally used because of their particular and pleasant flavor. Dr. Villareal mentioned a similar situation in the Philippines.

536

57

Present Status and Prospects for Increased Production of Tomato and Pepper in Northern Nigeria

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Abstract

Tomato (*Lycopersicon esculentum* Mill.) and pepper (*Capsicum* spp.) are indispensable constituents of the daily diet of over 100 million Nigerians. They are used mainly in the preparation of soups and stews which are essential complements to staples based on cereals and rootcrops. Although the two crops are widely grown in Nigeria, the major areas of production are in the Northern Guinea savanna ecological zone between latitudes 10°N and 12°30'N. Currently, about 50,000 and 77,000 ha of tomato and pepper, respectively, are under cultivation. Yearly production is approximately 600,000 and 695,000 t, with average yields per hectare of 12 and 9 t of tomato and pepper, respectively. Factors contributing to the low yields are the genetic limitations and poor adaptation of many currently grown varieties to local environmental conditions; suboptimal levels of inputs, such as fertilizers, and inadequate control of weeds at critical stages of plant growth; diseases, especially leafspots (*Septoria lycopersici* and *Alternaria solani*) on tomato, rootknot nematodes (*Meloidogyne* spp.), vascular wilts, leaf curl virus for both crops, and pepper veinal mottle for pepper. Aphids and whiteflies are important pests in both crops, while the fruitworm, *Heliothis* spp., can substantially reduce marketable yield of tomato. Based on the recently developed technologies for increased production of the two crops, 20-60 t of tomato and 12-15 t of pepper can be attained. In on-farm trials, average net returns for tomato production were 33 to 95% above those obtained under traditional practices. Similar trials are planned for pepper. The prospects for expanded production are enormous, and producers and processors intend to exploit the possibilities.

Tomato

Tomato, *Lycopersicon esculentum* Mill., probably was introduced into Nigeria either by Portuguese trade missions to Africa and freed slaves from the West Indies, or by the later European merchants and colonizers (Tindall, 1977; Villareal, 1978, 1980). From southern Nigeria, the crop probably dispersed through the northern parts of the country. It has now become an integral part of the diet of most Nigerians and an important source of cash to a large number of farmers, middlemen and processors.

Current Crop Situation

Climatic data of major production areas. Tomato is cultivated principally in southwestern and northern Nigeria (Figure 1) between latitudes 10° N and 12° 30' N in the Northern Guinea and Sudan Savanna ecological zones. These areas are characterized by a distinct wet season from either April or May to September or October, and a distinct dry season from October to March (Figure 2) when production is possible only under irrigation. Rainfall in the area varies

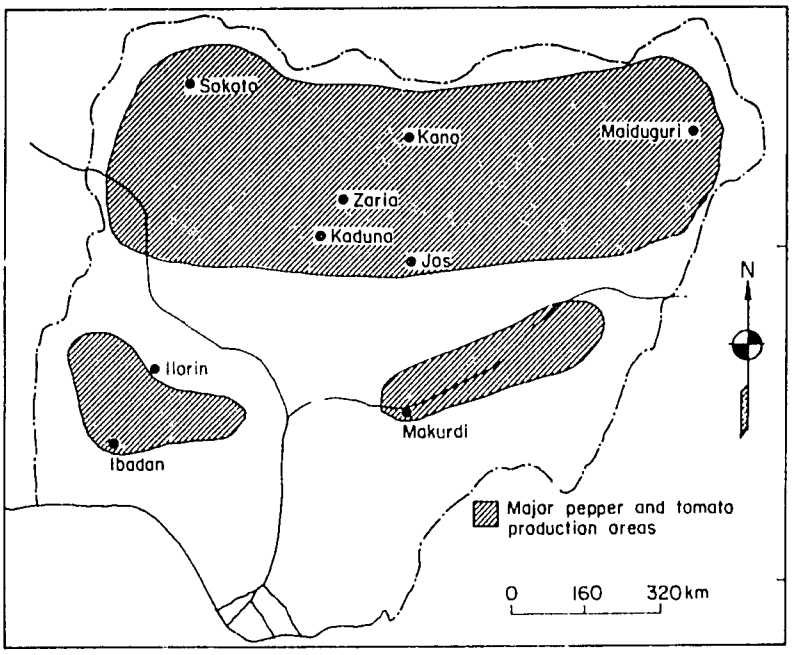

Figure 1. Major pepper and tomato producing areas of Nigeria.

from about 600 to 1,300 mm, with one peak in July or August. Temperatures are tropical throughout the area, mostly with night temperatures above 21.1°C and day temperatures higher than 32.2°C (Quinn, 1974). During the dry season there is a three to four-month period when night temperatures may fall below 15°C.

Production status. An estimated 225,000 t of tomato were produced yearly on 25,000 ha between 1973-1977 (Villareal, 1980). Current production is estimated at 600,000 t from 50,000 ha. Local demands have not been met from local production and considerable importation of tomato paste is needed to augment local production (Federal Office of Statistics, Lagos, 1985). The greatest production occurs between October to February, during the coolest part of the year. There is very little production between March and June due to high temperatures. A sizeable crop is produced between June and September. Yields vary greatly between and within seasons. The FAO (1984) has estimated an average national yield of 11.4 t/ha. It is generally well known, however, that yields are higher in the northern parts of the country than in the southwest (Figure 1) where tomato is also grown (Denton and Swarup, 1983). Yields from farmers' fields are not available, but on well managed small irrigated holdings, over 60 t/ha is readily attained. In a ten-year multilocational trial in northern Nigeria, average yields of 48.1 t/ha during the wet and 56 t/ha during the dry seasons were obtained (Quinn, 1980).

It has been estimated that it costs between US$ 491 to US$ 908 and US$ 1,286 to 1807/ha to produce tomato during the dry and wet seasons, respectively (IAR Cropping Scheme Report for 1978 and 1985). The higher cost for the wet season is due to the extra costs of mulching or staking, control of foliage diseases and sorting of rotted fruits. Tomato is the most important vegetable in a vigorous north-south trade in Nigeria. Its production offers employment to a large number of small-scale producers who sometimes make gross margins of up to N2,700

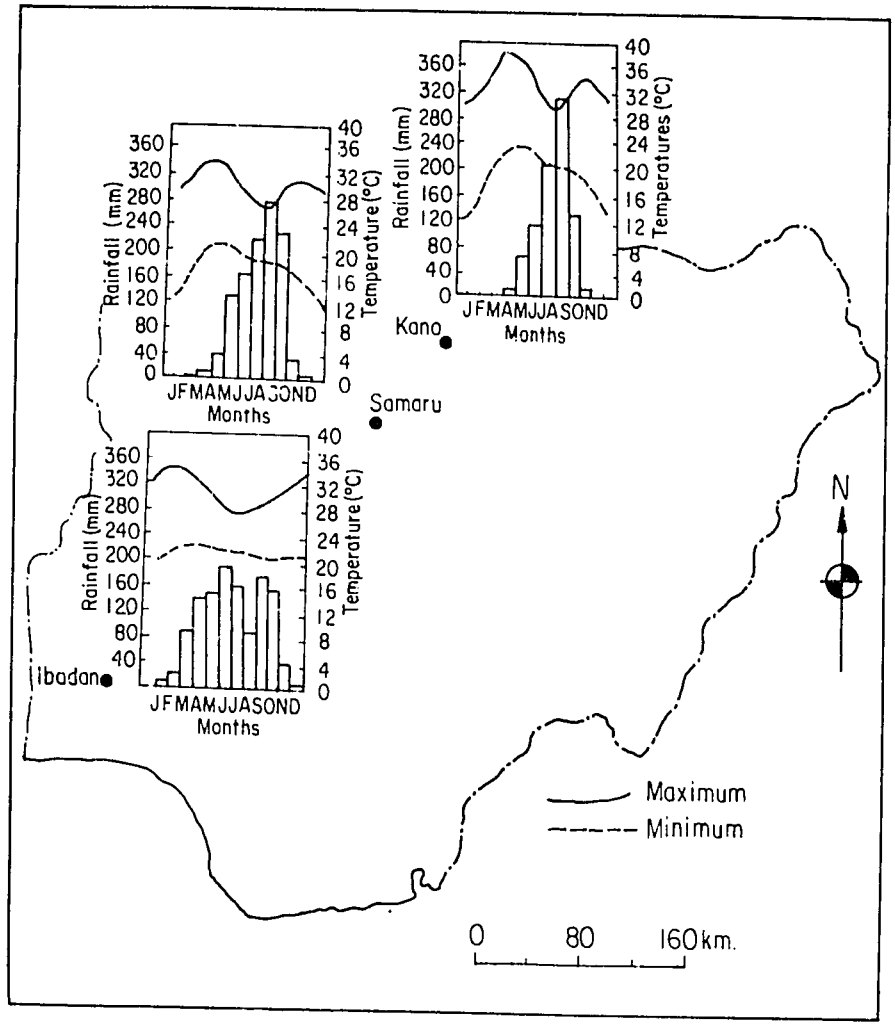

Figure 2. Annual rainfall and temperature (maximum and minimum) for three sites in Nigeria where pepper and tomato are produced commercially.

(US$ 3,000)/ha. A large number of people are also engaged in transportation, packing, sorting and sale to consumers. The production of the crop for the three processing companies located in various parts of northern Nigeria, also provides employment and revenue to local, state and national governments.

Cropping systems and cultural practices. Most of the tomato crop is transplanted. Direct seeding is a recent introduction which has not gained popularity. Traditionally, tomato and other vegetables, including carrot, onion, pepper, okra, spinach (*Amaranthus* sp.) and eggplant, are grown in mixtures in holdings rarely exceeding 0.1 ha. The proportion of tomato in the mixture varies depending on the proximity of major roads and large towns, and on market forces.

Most soils of the area are deficient in nitrogen and phosphorous. Traditionally farmers use high rates of organic manure in the form of poultry droppings, cow dung and homestead wastes for fertilization of fields where vegetables are grown. Because of inadequate supply of organic manure, most farmers now rely either partly or solely on complete inorganic fertilizers, such as 15:15:15, 20:20:0, or 20:12:9 or single superphosphate (18% P_2O_5), calcium ammonium nitrate (26% N) or urea (46% N).

The wet season crop is either grown on ridges or on raised beds and is usually staked or mulched. The dry season crop is grown either on the side of ridges or in sunken beds. Small holdings traditionally were watered manually by the shadoof system. Now, however, most holdings employ engine-driven pumps. Spacings vary from 45-60 cm in a row and 60-90 cm interrow. Plant densities in excess of 48,000 plants/ha have been recommended, but farmers usually plant lower populations.

The tomato is a poor competitor and unchecked weed growth causes about 68% loss in yield (Sinha and Lagoke, 1984). Weed control is usually manual, although metribuzin (Sencor), diphenamid (Enide), and other herbicides are used more frequently. Chemical weed control offers a better alternative than manual control, which may be scarce at times of peak demand.

The wet season crop is protected by four to six fungicide sprays applied weekly in the wetter areas and every 10 days in the relatively drier regions. Fungicides most commonly used are mancozeb (Dithane M45), captafol (Difolatan) and benomyl (Benlate). Insect control, especially of fruitworm, is usually adequate with two sprays of insecticides such as carbaryl (Sevin, Vetox) and synthetic pyrethroids (Cymbush, Ambush). Rootknot nematodes in the seedbed are controlled by soil treatment with nematicides or nonspecific soil sterilants such as dazomet (Basamid) and carbofuran (Furadan).

Harvesting is done by hand. Fruits are picked at mature green, breaker stage or vine-ripe, stages depending on the distance to the market. At least four pickings are normal. Fruits are transported in palm frond baskets or wooden or plastic crates.

Marketing and processing. There is much trade in fresh tomato between the northern and southern areas of Nigeria, which involves several middlemen. Processing firms sell their products through their appointed agents. One firm makes a blend of tomato and pepper called Tomapep with two degrees of pungency. Two firms originally relied on considerable importation of puree. Nigerian puree is mostly retailed in small tins of 100-225 g each.

Utilization patterns. Only a small proportion of the tomato crop is eaten raw. Most of it is consumed in cooked form with onion and pepper in soups and stews. Average per capita consumption is estimated at 9.13 g per annum, which is about 18% of the average consumption of vegetables (Olayide et al. 1972). A small proportion is used for catsup and canned foods.

Cultivars and seed supply. In southwestern Nigeria, local indeterminate selections are preferred to recently introduced ones because of higher fruit-set and tolerance to viral diseases. In northern Nigeria, local selections are only widely grown during the wet season. The following seven introduced processing cultivars are currently recommended: Roma VF, Ronita, Piacenza 0164, Gamad, Gemed F, Marzanino and Harvester. Three fresh-market tomatoes, viz. Enterpriser, La Bonita and Ife 1 are also recommended (Quinn, 1980). In addition to these, some hard tomatoes, such as Earlystone, are also widely grown. In recent years, Roma VF and Ronita have dominated the market. These cultivars (Table 1) are adapted only to the cool and dry part of the year which lasts only for three to four months. Hybrids, especially from California and Italy, are being evaluated but no hybrid seed company exists in Nigeria.

Traditionally, farmers saved their own seed which invariably came from unmarketable fruits. There is not an articulated national program on vegetable seed production and commercial growers have yet to establish one. Limited production of foundation seed is organized by research institutes and other government agencies. There is a considerable annual seed importation from Italy, Holland and Denmark; some seeds from this trade have been found to be adulterated.

Foreign trade. Nigeria relied on heavy importation of tomato paste/purees which reached a peak of 23,711 t in 1977, valued at US$ 21,613,500 (Table 2). In monetary terms, the highest drain in foreign exchange due to importation (13,247 t valued at US$ 38,250,554) was in 1978. Twenty-three countries, mostly European, were engaged in this trade, with the Federal Republic of Germany, France and Italy together accounting for about 8,000 t. Importation has been

Table 1. Some important cultivars of tomato grown in the northern Guinea and Sudan savanna zones of Nigeria.

Cultivar/Line	Year introduction	Source
Chef	1973	Petoseed Co. California & USDA, Beltsville, Maryland
Chico	1967	Texas A & M, Texas
Cirio 56	1968	Stazione Agraria Sperimentale Bari, Italy
Earlystone	1974	Petoseed Co., California
Enterpriser	1967	USDA, Beltsville Maryland
Euromech	1977	Peto Italiana, Italy
Gamad	1968	Hazera Seeds Ltd. Haifa, Israel
Gemed F	1972	Hazera Seeds Ltd., Israel
Harvester	1967	FMC Corp., California, Peto Italiana & USDA
Ife 1	1967	IAR & T, Ibadan Nigeria
Ife 1 P	1974	IAR & T, Ibadan, Nigeria
La Bonita	1968	Texas A & M
Laurano	1976	Tanzi Armando, Parma, Italy
Marmande Extra	1967	Ohlsens Enke Denmark
Marzanino	1967	Stazion Sperimentale, Parma, Italy
Napoli VF	1973	FAO, Rome; Petoseed Co
Pavebo	1974	Raci Sementi, Italy
Piacenza 0164	1967	Instituto Nazionale, Rome, Italy
Roma VF	1973	Royal Sluis, Netherlands
Roma	1968	IARI, Delhi, India
Roma VFN	1973	Peto Italiana, Italy
Ronita	1967	Station d'Amelioration des Plantes, Monfavet, France
Rossol	1971	Station d'Amelioration, Monfavet, France & Ohlsens Enke, Taastrup, Denmark

Source: Quinn, J G. 1980

Table 2. Imports of tomato puree paste, 1972-80.

Year	Quantity (kg)	Value (US$)
1972	24,318	259,783
1973	566,997	270,874
1974	394,333	423,890
1975	2,238,138	2,687,144
1976	17,049,000	15,808,000
1977	23,711,000	21,613,500
1978	13,247,000	38,250,554
1979	1,958,303	2,756,152
1980	3,943,063	3,701,694

Source: 1972-1980 Nigeria Trade Summary, Federal Office of Statistics, Lagos, Nigeria

considerably reduced in recent years with only 2.9 t imported in 1985 (Federal Office of Statistics, 1985.)

Constraints

Environmental factors. The rainfall pattern is highly seasonal in most regions of Nigeria (Figure 2). During the rainy season, heavy downpours and high relative humidities are inimical to tomato production. Except during the October-February when night temperatures are usually low (Figure 2), high temperatures often militate against good growth and yield of the tomato (Table 3). Overcast skies during the wet season reduce net assimilation rate of the tomato. During the dry season the dust-laden atmosphere (harmattan), also reduces available sunshine and the dust deposition on the plants may reduce plant metabolism.

Table 3. Marketable fruit yields of tomato cv. Harvester transplanted on 12 occasions between August 1968 and July 1969 at Samaru, northern Guinea savanna of Nigeria.

Date transplanted	Yield t/ha
August 13, 1968	33.4
September 14, 1968	39.2
October 14, 1968	28.6
November 12, 1968	33.2
December 9, 1968	30.9
January 14, 1969	11.3
February 17, 1969	9.3
March 3, 1969	1.5
April 1, 1969	2.0
May 7, 1969	14.8
June 4, 1969	31.6
July 1, 1969	38.7

Source: Quinn (1974).

Pests and diseases. Pests and diseases in the seedbed, in the field and after harvest result in significant yield losses (Erinle, 1979; Denton and Swarup, 1983). The most important pests are whiteflies (*Bemisia tabaci* Gennadius), aphids, especially *Myzus persicae* Sulzer, and fruitworm (*Heliothis armigera* Hübner). Whiteflies and aphids are of special importance because they are vectors of virus diseases of tomato and pepper (Alegbejo, 1986; Ladipo and Roberts, 1977; Lana and Adegbola, 1977).

As elsewhere, the tomato crop in Nigeria is plagued by a large number of diseases caused by bacteria, fungi, nematodes and viruses. The two most important bacterial diseases are bacterial spot (*Xanthomonas campestris* pv. *vesicatoria* (Doidge) Dowson) and bacterial wilt (*Pseudomonas solanacearum* E.F. Smith). The latter often severely limits areas where tomato can be produced. Leaf diseases caused by fungi severely affect tomato production during the wet season. The most important are Septoria leafspot (*Septoria lycopersici* Speg.), early blight (*Alternaria solani* Sorauer) and leafmold (*Fulvia fulva* (Cooke) Cif. (*Cladosporium fulvum* Cooke). Late blight (*Phytophthora infestans* (Mont) de Bary) is endemic in high altitude areas but has also been reported at 686 m (Erinle and Quinn, 1980). Nematodes, mostly species of *Meloidogyne* (rootknot) are important in certain regions. Pepper veinal mottle virus disease is widespread (Ladipo and Roberts, 1977) but probably not as damaging as leaf curl, which is most prevalent during the warm and dry months.

Fusarium and sclerotium wilts are important in many areas. Two races of *Fusarium oxysporum* f. sp. *lycopersici* have been reported. Most of the currently grown cultivars are susceptible to race 2 (Erinle, 1982). *Sclerotium rolfsii* causes severe losses (Wokocha, 1984), especially where tomato follows either groundnut (peanut) or cowpea.

Pre- and postharvest fruit losses caused principally by sunscorch, *Geotrichum candidum* Link ex Pers., *Aspergillus niger* v. Tieghem, *Rhizopus stolonifer* Ehrenberg ex Fr. Lind and *Fusarium* spp. severely plague producers (Onesirosan and Fatunla, 1976; Erinle, 1983; Okoli, 1986). Farmers sometimes adopt a no-risk strategy by harvesting before fruits attain the mature green stage; however, there is attendant loss in quality.

Management and varieties. Though the small-scale intensive growers of tomato have attained a generally high level of management, further advances in terms of age of transplants, fertilizer application, watering regime, optimum spacing, crop protection, and etc. need addressing. Lack of adaptation to high rainfall, high humidity, heat, and resistance to leaf diseases are crucial areas of concern.

Socioeconomic and marketing factors. There is a considerable interplay of market forces which affects tomato production in Nigeria. In one large irrigation scheme primarily designed to produce wheat, farmers did not follow crop rotation recommendations because they preferred to produce a poor crop of tomato rather than a good crop of wheat, because cheap wheat imports resulted in weak demand for locally produced wheat. In some years, a glut in tomato production occurs and in the absence of processing outlets to absorb the surplus, farmers become discouraged and switch over to the production of less perishable vegetables like carrot and Irish potato. Physical infrastructures, principally roads, efficient transport systems and suitable storage facilities are not always ideal to sustain and increase production.

Utilization. There is need for further diversification of tomato uses other than in traditional stews and soups. Eating of raw tomato is still largely regarded as European. Other uses may develop with increasing industrialization.

Funding of research. Research is hampered by grossly inadequate funding. Less than 1% of the country's gross national product is spent on applied research in science and technology, of which agriculture forms a component. Funding in horticulture is less when compared to other agriculture activities. For example, only about 0.3% of the investment in agriculture was allocated to horticulture by Federal and State governments between 1976-1980 (Ojehomon, 1983).

Research and Development

Varietal development. At least three centers (research institutes universities) have active breeding programs to develop locally adapted tomatoes. Commercial establishments only are importing and screening cultivars. Disease resistance to bacterial wilt and Septoria leafspot, and developing heat tolerant lines are principal goals of the breeding program at the Institute for Agricultural Research, Samaru, Zaria, where breeding started in 1982. Advanced breeding lines, especially CL 119-1-2-0, CL 143-0-4B-1-0-0, CL 8d-0-1-1-0-0-0 and CL 32d-0-1-1-p-0-0-0 from AVRDC, have formed the bulk of the materials being used in an attempt to incorporate resistance to bacterial wilt in commercial lines. Excellent sources of resistance to Septoria leafspot have been identified in the USDA accessions.

Management. Advances in plant establishment practices, levels of fertilizer and frequency of application, spacing, mulching, staking, crop protection, etc. have been made but more adaptive trials need testing under farmers' conditions. Many of the research findings have been tailored to small-scale producers, but there is now a need to focus attention on the intermediate producers as well.

Economics and marketing. All that has been done in this regard is evaluation of recommended practices at the farmer's level to demonstrate profitability. Few or no marketing studies have been conducted and price shifts in the commodity are not even monitored on a systematic basis. Compared to the work done on cereals, oilseeds and rootcrops, much remains to be done on tomato.

Utilization and processing. Collaboration with industry has not been strong. There is a need to foster this relationship for the greater utilization of the crop.

Funding. Funds are difficult to obtain. One tomato project, screening for tolerance to heat, is currently being supported by a commercial firm. Some firms support research on testing of pesticides on the crop. International support for research and production is nil.

The institutes and researchers working on tomato improvement are shown in Appendix I.

Future Needs

1. Research funding is the greatest limiting factor in tomato improvement in Nigeria as the funds provided to research institutes by government barely cover personal emoluments.
2. Greater national, regional and international collaboration is needed. Unlike the situation with respect to staple crops, there are no organized links between research workers on tomato. Researchers rarely know of developments within their own regions let alone on a global basis. In view of the global importance of tomato as a food and industrial crop, an international newsletter on this crop would be highly desirable.
3. There is a need for intensified adaptive research and stronger extension services.
4. Storage and preservation should be given greater attention, especially improved facilities at the grassroots level.
5. Greater access to publications at affordable prices would be of immense assistance to workers in foreign exchange-starved countries like Nigeria.

Pepper

Peppers, *Capsicum* spp., are thought to have been introduced into Nigeria from the New World. Two main species, *Capsicum annuum* L. and *C. frutescens* (sweet pepper and hot pepper or chili) are widely grown. Most of the production is utilized in the preparation of stews and soups but export of chili, mostly to Europe, is currently a lucrative business.

Current Crop Situation

Production and consumption status. Nigeria is the largest producer of pepper in Africa, accounting for about 50% of the African production. According to 1983 FAO estimates, production was 695,000 t of green chili and pepper obtained from an area of 77,000 ha, giving an average yield of about 9 t/ha. On farmers' fields, yield varies from 2.5 to 10.5 t/ha fresh fruits of sweet pepper. These yields are low when compared to 18 to 36 t/ha of fresh fruits in developed countries. Yields of hot pepper range between 0.5-4.5 t/ha (personal communication). On-station yields of hot peppers as high as 9 t/ha and 14 t/ha of sweet pepper (cv. California mild) have been reported (Adigun et al. 1987; Adigun et al. 1983).

The hot pepper has received a new boost in production following the reactivation of export in the commodity. Cost of production is about US$ 440 to 770/ha, a good proportion of which is due to weeding and harvesting.

Consumption of pepper accounts for about 20% of the average vegetable consumption per person per day. It is used as a spice in various food preparations. The large-fruited, less pungent peppers are ground with tomato and onion in the preparation of stews and soups. Other uses are in medicinal preparations, flavoring and coloring certain food preparations and for stuffing and in salad dishes (sweet pepper). A body of folklore has been built around pepper consumption and a popular adage says 'a sound body emanates from a generous pepper intake'.

Climatic data of major production areas. Pepper production occupies similar climatic zones as tomato production (Figure 1). There is a sizeable production in the rainforest area and derived savanna of southwestern Nigeria where mostly the chili and small-sized types of the mild forms are prevalent. The bulk of the country's production is found, however, in the savanna zones to the north.

Cropping systems and cultural practices. These are very similar to those for tomato. The crop is mostly grown rainfed, but a sizeable crop is also produced under irrigation. In contrast

to tomato production, the crop neither requires staking nor mulching, and little or no crop protection inputs are currently used. Herbicides are not widely used in pepper production and two to four hoe-weedings are usually done, depending on the season and the site.

Marketing and processing. There is a sizeable fresh fruit trade in sweet pepper. For chili, the crop is dried and stored on flat rooftops until required for sale. The produce is bagged in jute or propylene bags in 20-40 kg units and marketed. There are two processing outlets which make a tomato paste pepper blend for use in stews and soups.

Cultivars and seed supply. There are currently no recommended cultivars of pepper in Nigeria. Over 200 local selections are grown throughout the country. Certain forms of chili are identified with some important areas of production, e.g. Funtua peppers (Table 4). Introduced cultivars of sweet pepper such as California Wonder, Bell Boy, Anaheim and Yolo Wonder are also grown. Seed supply is largely the responsibility of each grower. No commercial seed companies produce pepper seeds. Government agencies produce small quantities of foundation seed.

Table 4 Characteristics of some important local selections of chili pepper.

Selection[z]	Fruit characteristics	Market description of fruit
Dan Mayere	Pendant, slim, 3.7 × 0.8 cm Average fresh weight 0.7 g	Fairly good appearance but tends towards loose seed
Dan Tsiga	Erect, very short and with blunt tip, 2.0 × 0.6 cm. Average fresh weight 0.3 g	Good quality, some pungency. Very acceptable on world market.
Kashin Burgu	Erect, short and with blunt tip, 2.0 × 0.8 cm Average fresh weight 0.6 g.	Reasonably good appearance, tends towards loose seed
Kimba	Erect, smooth with blunt tip, 3.5 × 0.8 cm Average fresh weight 1.2 g.	Good appearance
Sakarahoh	Pendant, smooth with acute tip, 3.5 × 0.8 cm. Average fresh weight 0.7 g.	Virtually unacceptable on the world market
L 2155	n.a.[y]	Tends towards loose seed
L 2190	Pendant 3.7 × 0.8 cm Average fresh weight 0.6 g.	Unacceptable on the world market. Dandicut type which would grind to an unattractive appearance.
L 2096	n.a.	Suitable for grinding but probably low in pungency.

[z]All possess a compact to semibushy growth habit. [y]n.a. = information not available

Foreign trade. Nigeria was an important exporter of whole, dried chili, which rated well on the world market. Most exports went to the United Kingdom. By 1954, about 1,000 t were exported. Exportation declined, however, to about 150 t/annum during the first half of the 1970's. Since 1976, exports have been minimal. Many Nigerian chili tend towards loose seed, and a few that do combine good appearance, heat and other qualities are not competitive on the world market. Between 1966 and 1977, annual average prices of Nigerian chili moved from £167 to £1,100, CIF United Kingdom. During 1979, local prices of Nigerian chili suitable for export were N910 and N1,130/t. The market prices in the UK for chili from elsewhere were in the range of £800 to £1,100/t ex-store. The two currencies had about the same value at that time.

Constraints

Environmental factors. Environment probably does not play as crucial a role in pepper production in Nigeria as it does with tomato. Except for the three to four months during the coolest time of the year when growth is severely retarded temperature is usually adequate. Heavy rainfall and overcast skies can, as in the case of tomato, result in adverse effects on growth, fruit-set and fruit quality (Purseglove, 1977; Opoku-Asiama et al. 1987). Most varieties of sweet pepper mature towards the end of the rains in the savanna and fruit scorch can be very severe. Thus the best sweet peppers are grown under irrigation during the cooler part of the dry season. Chili seems to perform better during the wet season.

Pests and diseases. Insect pests (aphids and whiteflies in particular) are major limiting factors, particularly as they are vectors of important virus diseases such as pepper veinal mottle virus and leaf curl diseases. They are controlled largely by the use of insecticides. Rootrots, nematodes and wilts also are important, especially in hydromorphic soils where rotation is neglected. Fruits of many introduced *C. annuum* peppers suffer considerably from sunscorch and or infection by *Colletotrichum* species.

Management. Pepper, being a hardy crop, is often grossly neglected. Seedlings are often overgrown before transplanting. Although the use of organic manures traditionally offsets much of the nutritional deficiencies of soils on which the crop is grown, the dearth in supply and periodic shortages of inorganic fertilizers often predispose the crop to a slow start. Like tomato, peppers are poor competitors and unchecked weed growth throughout the life cycle can result in an 86-90% reduction in potential yield of chili pepper (Adigun, Lagoke and Karikari, 1987). Pre-and post-transplanting herbicides have been shown to be a better alternative than manual weed control. Being a cash crop, farmers usually relegate its cultivation and care to periods when demands on their time from tending the staple crop allow for it. The high labor cost is one major constraint in the production of this crop, especially for picking the chili fruit.

Varietal factors. Many of the varieties being grown are rather limited in their genetic potential as well as in varietal traits such as fruit shape size, color, capsaicin content and so on. There has not been a serious effort to collect and screen a large collection of germplasm and no active breeding programs exists.

Socioeconomics and marketing. A good marketing system is in operation but the price a consumer pays at the end of the trade is often dictated by the number of middlemen through whose hands the commodity has passed. It is not uncommon for prices to appreciate 300% between the time of initial and final purchases. This may occur in just a few months.

Utilization. This has been outlined in the previous discussions. Further usage of the products will occur as processing facilities and urbanization develop.

Research and Development

Only the Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria (Appendix I), has an on-going program on pepper improvement. Some improved selections have now been obtained and breeding work on sweet pepper is in progress. There are considerable difficulties in collecting germplasm from various parts of the country and maintaining it for further use. Meanwhile, numerous projects are being undertaken on varietal evaluation, use of fertilizers, spacing, weed control with herbicides, and pest and disease control. Only sporadic efforts are being made, however, in the areas of economics, marketing, processing and utilization. Funding remains a severe limiting factor. At present there are no externally funded projects and international support for research and production is nonexistent.

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Appendix I. Institutes and researchers working on tomato and pepper improvement

Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria (tomato and pepper)

P.G. Eruotor, Ph.D.	– breeder (tomato)
S.G. Ado, M.Sc.	– breeder (pepper)
I.D. Erinle, Ph.D.	– plant pathologist (tomato)
M.D. Alegbejo, Ph.D.	– plant virologist (tomato, pepper)
I.I. Uyah, Ph.D.	– entomologist (tomato)
P.S. Chindo, M.Sc.	– nematologist (tomato)
S.T.O. Lagoke, Ph.D.	– weed scientist (tomato)
A.J. Adigun, M.Sc.	– weed scientist (tomato, pepper)
E.B. Amans, M.Sc.	– agronomist (tomato)
J.G. Bodunde, M.Sc.	– physiologist (tomato)
I.S. Adeoti, M.Sc.	– agricultural engineer (tomato)

National Horticultural Research Institute, Ibadan (tomato)

L. Denton, Ph.D.	– breeder
N.J. Usoroh, Ph.D.	– weed scientist
M.O. Ogunlana, Ph.D.	– entomologist
I.A. Oladiran, M.Sc.	– plant physiologist

Obafemi Awolowo University, Ile-Ife (tomato)

T. Fatunla, Ph.D.	– breeder
I.L. Ladipo, Ph.D.	– virologist
B.O. Adelana, Ph.D.	– agronomist

Symposium Discussion

J.C. Girard: Do you consider Septoria leafspot as a major disease of tomato in your country?
I.D. Erinle: Yes indeed. Septoria leafspot is the most widespread and most damaging leaf disease of tomato during the wet season.

R.T. Opeña: There are some Septoria leafspot resistant cultivars and/or germplasm available, eg from H. Laterrot's program (INRA). Have they been tried in Nigeria? Why was Septoria resistance not given high priority in the University of Wisconsin program in Nigeria?
I.D. Erinle: We have not tested any of Laterrot's lines as far as I know. We have, however, tested a number of USDA Beltsville materials obtained from Dr. Barksdale and some resistant lines have been identified. The University of Wisconsin program was a short-lived program and did not go into research on Septoria leafspot.

P. Rosset: You mentioned that onion as intercrop with pepper offers pest control benefits. Which pests are adversely affected by onion?
I.D. Erinle: Mostly thrips, aphids and whiteflies.

A. Sajjapongse: Population density of 48,000 plants/ha is rather high. We have found that yield was not significantly increased when population density was higher than 20,000. With the population of 48,000 plants/ha what is planting space that you recommended?
I.D. Erinle: The currently recommended spacing is 45 x 60 cm for determinate tomatoes which form the bulk of our widely grown cultivars. In fact we get responses beyond this but we consider around 48,000 plants a good compromise.

J.Y. Yoon: Can you elaborate on the present situation of weed control and related research work in pepper cultivation in Nigeria?
I.D. Erinle: In Nigeria weed control is usually manual but we have tested pre- and post-transplanting herbicides and some, e.g. metribuzin at 0.5 kg/ha, have shown good results. Linuron mixtures with alachlor or metolachlor, oxadiazon and diphenamid, all followed by supplementary hoe weeding at six weeks after transplanting, have combined effective weed control with high chili pepper fruit yields and performed better than metribuzin.

A. Sajjapongse: In our trials, metribuzin at the rate of 0.75 kg/ha completely killed both sweet and hot pepper plants. Obviously, the herbicide is very injurious to the crops.

Tomato and Pepper Production in the Philippines

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Abstract

Tomato is probably one of the most important vegetables in the Philippines. In 1986, the total area planted was 17,490 ha with a production of 143,888 t. It is commonly grown in the lowland rice paddies during the dry season. The crop is grown throughout the country but the bulk of production is concentrated in the northern regions (Ilocos provinces). Supply and prices fluctuate widely from the dry season to the wet season and can increase as much as 10 times.

Processed tomato and tomato products are widely used in the country. The processing industry is still at the developmental stage so that the country imports tomato paste worth US$4,024,486. More research and development work is conducted on tomato than any other vegetable. Presently, the main research priority is the development of varieties resistant to bacterial wilt and viruses and with good fruit-set under warm temperature (25°-30°C). Studies are also directed to growing tomato during the rainy season under low elevation conditions to help stabilize the supply throughout the year. Pepper is a minor vegetable crop in the Philippines. Hot pepper on the other hand, is more commonly consumed and is grown in most parts of the country. However, there is a need to increase the utilization of the product to improve the demand and to encourage more production.

Tomato

Current Crop Situation

Production. A total area of 17,490 ha were planted to tomato in 1986 with the major production areas in Ilocos, Central Luzon and Southern Tagalog regions (Table 1). Most areas are planted during the dry and cool season (October-January), following the rice crop after the rainy season to take advantage of the residual soil moisture and light rains which may occur (IPB, 1987a).

For the past 15 years (1972-86), production showed a steady increase in area and value except in 1982 when a decrease in area resulted in a corresponding decline in production (Table 2). Although a tremendous increase in value was observed in 1986, this is attributed to the artificial price increase of the crop due to drastic monetary devaluation during this period.

Climatic data of major production areas. Tomato is normally grown in the low elevations towards the end of the rainy season during the cool months of the year (October to January). In the major lowland tomato production regions (Ilocos), the average day temperature during the growing months (October to January) is 28°C. Mean minimum and maximum temperatures are 23.5° and 32.4°C, respectively (Figure 1). Later plantings, even with sufficient irrigation are characterized by low fruit-set due to increasing day and night temperatures towards the months of April and May. Very few farmers grow tomato during the wet season (June to September) because of adverse weather conditions such as frequent rains, high temperatures and high

Table 1. Tomato production areas in the Philippines, 1986.

Region	Area planted (ha)	Production (mt)	Value ('000 US$)
Ilocos	5,780	4,275	13,050.15
Cagayan Valley	1,120	5,594	1,417.11
Central Luzon	2,450	17,763	3,212.95
Southern Tagalog	2,380	22,340	5,302.74
Bicol	920	4,376	1,040.57
Western Visayas	1,400	12,348	1,747.56
Central Visayas	1,000	2,750	531.67
Eastern Visayas	150	1,717	432.45
Western Mindanao	230	928	205.47
Northern Mindanao	1,090	14,910	3,318.28
Southern Mindanao	700	3,400	658.19
Central Mindanao	270	3,487	622.53
Total	17,490	143,888	31,566.67

Sources: Statistical Handbook in Agriculture. Agricultural Crops Summary. Bureau of Agricultural Economics, Dept. of Agriculture. Republic of the Philippines, 1986

Table 2. Volume of tomato production in the Philippines, 1972-86.

Year	Area (ha)	Quantity (kg)	Yield (kg/ha)	Total value (US$)
1972	15,770	81,133,800	5,144	4,049,188.66 (0.05 kg)
1977	18,550	145,900,000	7,865	9,520,234.60 (0.07 kg)
1982	15,210	127,340,000	8,372	5,554,447.70 (0.04 kg)
1986	17,490	143,888,000	8,226	31,566,666.67 (0.22 kg)

Source: Statistical Handbook in Agriculture. Agricultural Crops Summary by Region. Bureau of Agricultural Economics, Dept. of Agriculture. Republic of the Philippines, 1986

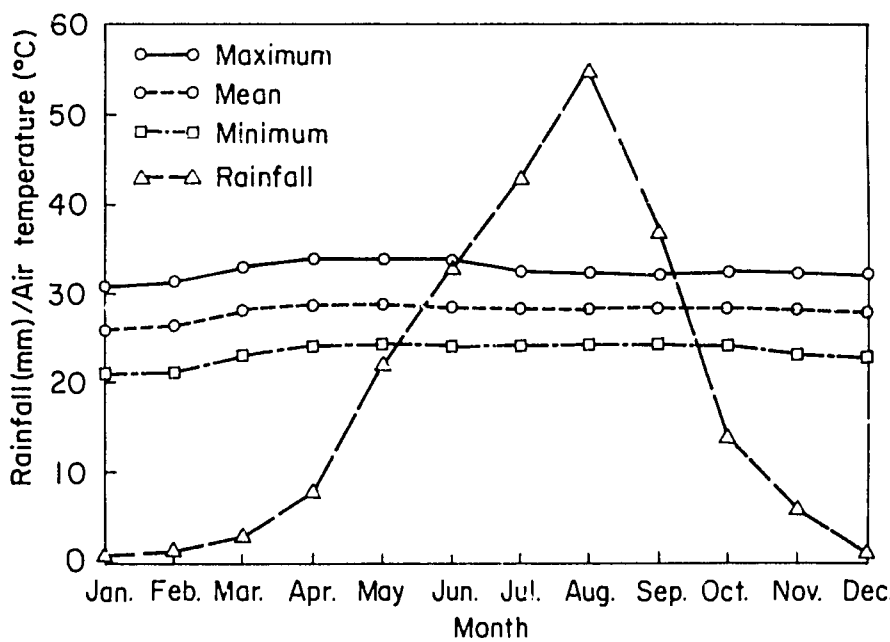

Figure 1. Air temperature minimum, maximum, mean (°C) and average rainfall (mm) in Ilocos region. (Pangasinan tomato growing areas show similar temperature and rainfall patterns.)

humidity. Rainfall is at its peak in August, reaching around 50 cm. The poor performance of tomatoes in many places throughout the country during the wet season (June to September) is caused by high night temperature and humidity which inhibit fruit-setting, and promote diseases which reduce plant growth, yielding ability and fruit quality. In addition, the frequent occurrence of typhoons during this time severely affects the crop. The country is struck by an average of 19-20 typhoons per year. However, there are areas in the Mindanao region where there are practically no typhoons hence a considerable share of fresh-market tomato is produced there during the whole year-round (Deanon and Villareal, 1988).

Cropping systems and cultural practices. Fresh-market tomato is commonly planted in upland areas. Processing tomato, on the other hand, is grown as a monocrop in Pangasinan and Ilocos Norte after the rice crop to reduce infection by bacterial wilt and to make maximum use of idle rice paddies which are usually not planted to rice from September to April (Villareal, 1986; Villareal and Beltran, 1986). Production of processing tomato is closely supervised by the processing companies starting from the planning and scheduling of harvesting. The farmer provides the land, labor and management of all operations while the company gives the material inputs needed (i.e. seeds, fertilizers and pesticides). All inputs provided are subtracted after the delivery of the products.

For processing tomatoes which are planted after the rice crop, fertilization rate is 136.5 kg N, 90 kg P and 180 kg K per hectare using complete (14-14-14), urea (46-0-0), and muriate of potash (0-0-60). Basal fertilization (45.5 kg N, 90 kg P and 60 kg K) is done during the second and fourth week after transplanting. Furrow irrigation is also commonly applied. Chemical control of pests is only employed whenever necessary (IPB, 1987b).

Staking of tomato is only practiced in some parts of Mindanao and Benguet province (high elevation areas) where the indeterminate fresh-market varieties are grown. Mulching with dried rice stalks is commonly done by farmers to help conserve moisture and to control weeds. Pruning and training of plants, however, have not become popular because of the high labor cost involved.

Cultivars and seed supply. The commonly grown fresh-market and processing tomato cultivars in the country are listed in Table 3. Many of the fresh-market cultivars bred at the UPLB College of Agriculture and the Bureau of Plant Industry are of the determinate type, heat tolerant and are planted in the upland areas of the country. They have resistance to bacterial wilt (*Pseudomonas solanacearum*), leaf mold (*Fulvia fulva*) and gray leaf spot (*Stemphylium* spp.) (IPB, 1985).

In 1975, the Philippine Seedboard approved cv. Improved Pope, a variety developed by the Bureau of Plant Industry. Since then, it has been the dominant variety used for tomato production. It is grown in the favorable off-season climate of the midelevation areas of northern Mindanao (Misamis Oriental) and shipped to other parts of the country. In 1976, the Philippine Seedboard approved cv. Marikit, a variety developed by the UPLB College of Agriculture, Institute of Plant Breeding. It is an all-season cultivar, has determinate growth and shows resistance to bacterial wilt, leaf mold and Septoria leaf spot. In 1986, the Philippine Seedboard released cv. UPL Tm-6 (Maigaya), an open-pollinated, determinate cultivar which was developed by J.R. Deanon, Jr. of the Institute of Plant Breeding. Maigaya is considered as an off-season tomato suited for growth during the rainy season. It bears small, pink fruits and has resistance to bacterial wilt biovar III (IPB, 1987a). It has an estimated yield of 34.05 t/ha during the dry season and 20.89 t/ha during the wet season.

A native cultivar, Nagcarlan, is grown in Southern Luzon where growers plant during the early part of the rainy season. It is small-fruited, exhibits tolerance to bacterial wilt and sets fruit fairly well during the rainy months.

Two determinate hybrid cultivars, namely Panag-ulan and Bonanza, were commercially released in 1986 by the East West Seed Company for wet season planting. It was the first time that hybrid tomatoes were grown on a commercial scale in the Philippines. The yield of Panag-ulan during the wet season was 54% to 109% higher and that of Bonanza 57% to 157% higher

Table 3. Commonly grown tomato varieties in the Philippines.

Cultivar	Description
A. Fresh-market (IPB. 1985)	
Marikit	an open-pollinated variety developed by the UP College of Agriculture; determinate, vigorous and moderately resistant to bacterial wilt (mixtures of all biovars), shows intermediate drought and waterlogging resistance; fruits are relatively soft; average yield is 25 t/ha during the dry season and 13 t/ha during the wet season.
Marilagan	open-pollinated variety developed by the UP College of Agriculture; indeterminate, resistant to bacterial wilt (biovar III), spotted lady beetle; moderately resistant to gray leafspot, heat-tolerant; intermediate drought and waterlogging resistance; fruits are relatively soft; yield ranges from 25-30 t/ha.
VC-11-1 UG	a determinate type developed by the UP College of Agriculture; moderately resistant to bacterial wilt (biovar II); intermediate heat tolerance; resistant to drought and waterlogging
Improved Pope	determinate type developed by the Bureau of Plant Industry which has become popular because of its ability to withstand transport damage; resistant to bacterial wilt (biovar III), intermediate drought tolerance.
Maigaya	an all-season open-pollinated determinate variety developed and released by the Institute of Plant Breeding, UPLB; resistant to bacterial wilt (biovar III), early maturing and tolerant to waterlogging and moisture stress; crimson colored fruits; yields 34 t/ha (dry season) and 20.89 t/ha (wet season).
Nagcarlana	farmer's variety which has become popular in Southern Luzon; determinate, sets fruit fairly well during the rainy season.
Bonanza	F_1 hybrid developed by the East West Seed Company (EWSC); determinate, early fruiting, moderately field resistant to foliage diseases, and bacterial wilt; fruits are high round, firm, thick-fleshed, and deep red; postharvest life is longer; average fruit size is 38 g.
Pan[illegible]ulan	F_1 hybrid developed by the EWSC; determinate; early fruiting, moderately resistant to gray leafspot, higher level of resistance compared to Bonanza; fruits are oblate, firm, thick-fleshed, and develop a deeper red color; postharvest life is intermediate between Bonanza and Improved Pope.
Marglobe	imported indeterminate open-pollinated variety which is commonly planted in Benguet province; fruits are oblate and large.
Walter	imported indeterminate open-pollinated variety which is planted in the highlands of Benguet and Mindanao areas; fruits are large, uniform green.
B. Processing Tomato (Villareal. 1988b)	
Peto 95-43	an imported open-pollinated variety grown in Central Luzon, determinate, vigorous, with concentrated fruit-set, fruits are round, firm; yield ranges from 30-35 t/ha, susceptible to bacterial wilt and foliage diseases like leafspot and powdery mildew.
UC-204	an imported open-pollinated variety grown in Central Luzon; determinate, vigorous, fruits are oblate; yield ranges from 32-35 t/ha; susceptible to cracking.

Table 3. Continued.

Cultivar	Description
VF 134-1-2	the most popular open-pollinated variety grown in Central Luzon; determinate, very vigorous with concentrated fruit-set; fruits are very firm but have the tendency to become blotchy and puffy; yield ranges from 35-40 t/ha.
Bronco	the major processing tomato cultivar grown in the northern part of the country (Ilocos); fruits are relatively small but deep red in color; high TSS content.
BPI-TM P-1	originated from AVRDC (CL 2784-1-1-4); determinate, fruits are round, relatively soft, intense red in color, resistant to cracking, high TSS content; yields 36 tons/ha.

than Improved Pope. In the dry season, Bonanza and Panag-ulan exceeded Improved Pope by 70%-83% and 79% to 123%, respectively (Rasco, 1987). Tomatoes planted in the high elevation areas (Benguet province) are commonly of the indeterminate type, such as Marglobe and Walter.

A few farmers produce their own seeds but most of the seeds of the open-pollinated freshmarket tomato cultivars are produced by the Institute of Plant Breeding of the UP College of Agriculture and by the Department of Agriculture with the participation of selected private growers. Hybrid seeds, on the other hand, are produced by the East West Seed Company. However, information on their selling volume is not available.

Cultivars grown for processing are mainly introduced from the United States and AVRDC (Villareal, 1988b). The processing plant in Central Luzon uses the imported cultivars Peto 95-43, UC-204 and VF 134-1-2 while that of Ilocos Norte uses Bronco (Ilocandia 4). Yields range from 26-50 t/ha. In 1986, the Bureau of Plant Industry officially released CL 2784-1-1-4, an introduction from AVRDC, popularly known as Mapula.

The processing sector imports certified seeds from reliable seed companies. A small amount of seed is presently produced by the processing firms on a trial basis and for use in case of seed shortage due to importation problems.

Marketing and processing. The marketing systems for fresh-market tomato in the Philippines can be described as follows:

a) Direct selling: products are delivered to local markets and sold directly to consumers or to retailers.
b) Selling through wholesalers: the produce is brought to trading centers in the towns or cities where wholesale buyers compete for the produce. These wholesale buyers then sell the produce to either the retailers in the locality or to other towns or cities. In some cases where transportation facilities are adequate, the wholesale buyers go to the areas of production to buy the produce.
c) Selling through consignment/commission: the produce is brought to a trading firm which has facilities for storage. The firm then sells the produce for a commission previously agreed upon.

Tomato processing, on the other hand, is confined mainly to the production of tomato paste. At present, there are two processing plants in the country, one in Central Luzon and another in the Northern Ilocos province. Together they process the produce from 1,500 ha. As of now, however, these plants have not attained their maximum capacity so that the country still imports tomato paste to meet the requirements of food processors.

Utilization patterns. Tomato plays a major role in the diet, particularly that of the low income group. It is often used as a fresh ripe fruit in salad preparations together with other vegetables such as onions, lettuce, pechay and mustard (Knott and Deanon, 1967). It is also commonly consumed cooked with fish or meat or with other vegetables such as eggplant, bitter gourd, cowpea, string beans and many others (Villareal, 1980).

In the processed form, tomato is used mainly as a sauce for sardines, beans and meat products or as a salted preparation of very small shrimps (alamang) or small fish (bagoong), and also as tomato ketchup.

Foreign trade. The country imports tomato in the form of puree (paste) and concentrate amounting to US$4,224,486 (Bureau of Agricultural Economics, 1986). At times when the supply is abundant (February to April), the fresh and chilled tomatoes of the large-fruited cultivars grown in the highlands are exported to Pakistan, Hong Kong, Singapore and Brunei.

Production Constraints

Environmental. Too much rainfall, frequent typhoons and high night temperature limit the production from May to October (wet warm season) because of reduced fruit-set, plant growth, yield and fruit quality.

During the dry season the lack of irrigation facilities limits production and mainly the small-fruited local varieties are planted. Very few growers have irrigation systems which can help in delaying planting to escape the glut. Cold storage to delay ripening is seldom practiced because it is too expensive.

The big-fruited, relatively sweeter tomatoes for export (e.g. Marglobe, Walter, etc.) can only be produced profitably in the limited highland areas (Benguet province) where the temperature is lower. However, these production areas are limited and not much expansion can be expected.

Diseases and insect pests. Tomato is prone to diseases and insect pests which decrease yield, sometimes causing total crop failure. Most of the varieties grown are susceptible to these (Knott and Deanon, 1967; Villareal, 1980).

Bacterial wilt, caused by *Pseudomonas solanacearum*, is one of the most serious problems of tomato growers in the Philippines (Valdez, 1985). Farmers are now adopting the practice of growing tomatoes after rice to minimize infection (Villareal and Beltran, 1986; IPB, 1987b). Several cultivars, including Marikit, Marilag and Maigaya, have become popular because of their resistance to the pathogen (Valdez, 1985; IPB, 1985, 1987a). Damping-off (*Rhizoctonia* spp., *Phythium* or *Phytophthora* spp.) is a problem in the seedbed and is controlled by soil sterilization and by drenching the seedlings with fungicides such as captan or thiram (Knott and Deanon, 1967; NCT, 1987). Fusarium wilt (*Fusarium oxysporum*) is a problem in the highlands and can be overcome by planting disease-resistant varieties. Early blight (*Alternaria solani*) is common in the northern parts of the country and is controlled by spraying mancozeb every two weeks. Leafcurl and tomato mosaic viruses become more prevalent, particularly during summer. Rootknot nematodes (*Meloidogyne* spp.) are prevalent in all tomato production areas. The planting of resistant varieties is recommended (Valdez, 1979).

Fruitworm (*Heliothis* sp.) are controlled by spraying thiodan twice a week and aphids (*Aphis* spp.) by spraying with malathion, thiodan or diazinon. Spider mites (*Tetranychus truncatus*) are more prevalent during the summer. They can be controlled by spraying the plants with either carbaryl or diazinon (Knott and Deanon, 1967).

In addition, tomato is prone to certain physiological disorders like blossom-end rot, sunscald, blotchy ripening, cracking and puffiness.

Management. Growers are reluctant to adopt improved cultural practices which need additional inputs because they add to the high cost of production. Only the contract growers of the processing firms have guaranteed minimum returns for their produce.

Research and Development

Varietal improvement. The scientific effort to develop ideal tomato varieties for tropical areas such as the Philippines has a long history. While the Asian Vegetable Research and Development Center (AVRDC) has the most significant and successful work in recent years, attempts by local scientists long precedes the establishment of AVRDC (Rasco, 1987; Villareal, 1988a). For years, the breeding program at the UP College of Agriculture, particularly at the Institute of Plant Breeding, has been geared towards the development of varieties which are resistant to diseases (notably bacterial wilt, Septoria leaf spot, leafmold, tomato mosaic virus) and with high temperature fruit-set. Foreign cultivars are collected and are being evaluated for horticultural characteristics. Germplasm maintenance and breeding works are also being carried out at the institute. Results of the breeding efforts have led to the release of several varieties like Marikit, Maigaya, and Marilag which have resistance to different biovars of bacterial wilt and can produce fruits under high temperature conditions. Private seed companies are also involved in tomato improvement. In 1986, the East West Seed Company released two off-season cultivars namely Panag-ulan and Bonanza.

Research at the national level is coordinated by the Philippine Council for Agriculture and Natural Resources Research and Development (PCARRD) with the help of the Department of Agriculture (DA) and headed by a project coordinator. New varieties developed by the institutes/companies are tested for four to six seasons at different locations and are recommended for commercial production following a cultivar release scheme of the Philippine Seedboard (Villareal, 1988a).

Breeding for processing tomatoes, however, is still in its initial stage. The varietal improvement of processing tomatoes has led to the development of processable, although bacterial wilt susceptible, varieties (IPB, 1987b). Researchers at the Institute of Plant Breeding have been supporting and coordinating with the two processing companies of the country in carrying out variety trials and cultural management studies.

Others. Cultural management studies with emphasis on fertilization have been conducted by the IPB, but recommendations have not yet been issued to the farmers.

Presently no formal studies on economics and marketing are being conducted by government agencies except for monitoring activities on production and prices together with other vegetables to serve as a guide to traders and consumers. Similarly there are no studies on utilization except those by processing companies who are investigating the processing qualities of the different varieties that are grown.

Future Needs

Tomato is an important component of the Filipino diet, therefore, ensuring its steady supply throughout the year is an urgent need. This could be made possible through the development of lines better adapted to local conditions. Importation of processing tomato products could be minimized, if not totally eliminated, if processing tomatoes can be more extensively grown in the country. While they can already be grown during the cool, dry season in the northern provinces in the country, problems of low yield and poor quality continue to plague the industry. A vigorous tomato research program is imperative. Economics and marketing strategies should also be well studied to improve production efficiency.

Externally Funded Projects

Presently there are no externally funded research and development projects for tomato.

Pepper

Current Crop Situation

Production, cultural practices and seed production. Hot pepper (*Capsicum annuum* L.) is a minor crop in the Philippines. Production is limited to very small, scattered areas only. It is grown throughout the year because it is more tolerant to frequent rains and sets fruit well at high temperatures. Production statistics on this crop are not available. The demand for hot pepper is however increasing and the crop may become important in the future.

Sweet pepper (*Capsicum annuum* L.), on the other hand, is grown in larger production areas. The main growing area is in Ilocos, in the northern part of the country (Table 4). The average temperature of this area during the growing season (December-February) is 26°C with a minimum of 19°C and a maximum of 33°C, which is slightly lower than in the major tomato production areas. The rainfall distribution is similar to that of the tomato growing areas. Other growing areas are Southern Tagalog and Eastern Visayas. During the last nine years, there has been practically no change in the area planted (Table 5). Sweet pepper is usually planted as a monocrop both in the upland and lowland areas during the cool months of the year (December-February) after the rainy season. In the lowlands it is planted after rice. Seedlings are produced on seedbeds and transplanted when about a month old. Heavy manure is applied (10 t/ha) whenever available, one week before planting, and a complete fertilizer at planting. Side-dressing with nitrogen and potassium fertilizers is recommended every two weeks up to 60 days after transplanting.

Table 4. Production areas of sweet pepper in the Philippines.

Region	Area (ha)	Production (kg)	Value ('000 US$)
Ilocos	370	1,285	447.21
Cagayan Valley	20	27	6.16
Central Luzon	30	27	8.31
Southern Tagalog	260	854	355.62
Bicol	50	91	25.32
Western Visayas	100	125	44.43
Visayas	210	201	98.78
Eastern Visayas	80	419	170.38
Western Mindanao	40	45	20.28
Northern Mindanao	140	198	77.71
Southern Mindanao	110	280	105.62
Central Mindanao	40	54	17.06
Philippines	1,450	3,606	1,376.88

Sources: Statistical Handbook in Agriculture. Agricultural Crops Summary. Bureau of Agricultural Economics, Dept. of Agriculture, Republic of the Philippines, 1986

Table 5. Volume of sweet pepper production in the Philippines.

Year	Area (ha)	Quantity (kg)	Yield (kg/ha)	Value (US$)
1977	1,470	6,540,000	4,448	1,528,787.88 (0.23/kg)
1981	1,460	3,534,000	2,420	899,413.49 (0.25/kg)
1986	1,450	3,606,000	2,486	1,376,880.00 (0.38/kg)

Sources: Statistical Handbook in Agriculture. Agricultural Crops Summary by Region. Bureau of Agricultural Economics, Dept. of Agriculture, Republic of the Philippines, 1986

Cultivars and seed supply. Very few cultivars of sweet pepper are grown in the Philippines. The most widely grown is Sinagtala, a locally developed, open-pollinated cultivar. It has big fruits and is highly adapted to the local conditions. Based on rating scheme developed by the plant pathologists of the Institute of Plant Breeding, the cultivar was found to be moderately resistant to tobacco mosaic virus, bacterial wilt and also shows moderate reaction to thrips, aphids and fruit rot. However, it is susceptible to sunscald, waterlogging and moisture stress (IPB, 1985). In the highlands (Benguet province) imported varieties like California Wonder and Yolo Wonder are also grown. These lines are not well adapted to low elevation planting and are also highly susceptible to bacterial wilt.

Most hot peppers cannot be accurately identified as cultivars because they are mixtures resulting from the seed production employed by the growers themselves. The most commonly grown variety is Matikas, developed and bred by the UP College of Agriculture. It is popular among the farmers because of its high-yielding ability and early maturity. It is resistant to bacterial wilt and moderately resistant to tobacco mosaic virus (TMV- yellow and green strains) (IPB, 1985). The fruits are very pungent. Recently, another cultivar named All Season developed and bred by the UP College of Agriculture, was released. It is more tolerant to bacterial wilt and has good fruit-setting ability and large fruits.

Many growers are producing their own seeds and only a few use imported certified seeds for planting. However, there is no information available on the volume of seed produced and imported. The Institute of Plant Breeding of the UP College of Agriculture produces seeds of locally developed cultivars for sale directly to growers. Seed supply for imported sweet pepper is mainly from seed houses which import the seeds.

Marketing and processing. There are no regular established marketing outlets in the region. The farmer has the option to sell directly to consumers at the local market, sell to wholesale buyers or sell to middlemen who go to the farm.

Only a small amount of sweet pepper is processed, mostly as an ingredient in pickled vegetables and to a lesser extent as preserved fruit in brine solution. There is a growing demand for processed hot pepper for use as hot sauce, either as a pure pepper product or mixed with banana or tomato.

Consumption and utilization. Hot pepper is usually eaten cooked with meat, fish or other vegetables and as the main ingredient in hot sauce and in pickles. Sweet pepper is usually consumed cooked with other vegetables, meat and fish, although small amounts are also eaten fresh with other vegetables as salads. It is also processed into sauces or as pickled products.

Foreign trade. The foreign trade on this crop is minimal, amounting to only about US$18,000 for the year 1986 for fresh fruits exported mainly to Hong Kong and Indonesia.

Constraints in Production

Environmental and varietal. Sweet pepper production under low elevation conditions (Ilocos and Central Luzon) is limited by high temperatures to a short growing season starting from November to January. The lack of varieties adapted to high temperatures is the major constraint in production. Most of the big-fruited varieties have been imported from temperate countries which, however, can only be grown in the highlands or in the lowlands during the dry and cool season. There has been very little work conducted regarding crop improvement and cultural management.

Insect pests and diseases. In the rainy season, diseases are the major problem. The most important diseases of pepper include bacterial wilt (*Pseudomonas* sp.), leafspot (*Cercospora capsici*), anthracnose (*Colletotrichum* sp.) and fruitrot (*Colletotrichum capsici*). Viruses are prevalent year-round in all production areas (Knott and Deanon, 1967).

Socioeconomic situation and marketing. The low demand for sweet pepper is attributed to some degree to high prices and the marketing aspect has always been a significant constraint in vegetable production in the country. The highly seasonal production is attributed to the inherent characteristics of the crop and to the established cropping practices in the major production areas which grow vegetables only at certain months of the year. The grower's share of the income is quite low because of the lack of an organized marketing system by the growers themselves. The insufficient information on prevailing daily prices in the different market centers accounts for the wide discrepancies in prices paid by the consumers (Deanon and Villareal, 1988). The lack of proper packaging materials, poor transportation and storage facilities also account for a great deal of postharvest loss.

Research and Development

The Institute of Plant Breeding of the UP College of Agriculture is the only institute engaged in hot as well as sweet pepper improvement. For years, the breeding program has been geared towards the development of varieties with acceptable processing qualities combined with resistance to diseases, specifically bacterial wilt, root-knot nematode (*Meloidogyne incognita* race 1), leaf mold (*Cladosporium fulvum*) and tobacco mosaic virus (yellow and green strains). This has led to the development of cultivars like Sinagtala (sweet pepper), Matikas and All Season (hot pepper) with improved yield, maturity and resistances to the major pests mentioned above. Since not all of these traits have been combined in a single variety, there is still a pressing need to continue research.

Future Needs

While there is an increasing demand for this vegetable, more research and development work is necessary to produce pepper varieties better adapted to the Philippines. The present cultural practices followed by the farmers also need to be improved.

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Appendix. Institutes and researchers working on tomato improvement.

Institute of Plant Breeding, College of Agriculture, University of the Philippines at Los Baños, College, Laguna

a) Prof. Jose R. Deanon Jr.Breeding	– Breeding
b) Dr. Ruben L. Villareal	– Breeding and cultural management
c) Dr. Eufemio T. Rasco Jr.	– Breeding
d) Ms. Josefina O. Narciso	– Breeding
e) Ms. Virgina P. Roxas	– Breeding and cultural management
f) Ms. Marilyn M. Beltran	– Cultural management

Department of Agriculture (Bureau of Plant Industry)

a) Ms. Adoracion Virtucio	– Varietal testing

Symposium Discussion

G.Y.H. Grubben: (1) It appears that poor soil structure and low fertility in the paddy fields after rice are the primary causes of poor growth and low production of tomato. Has there been any research on this? (2) Do low-input tomato growers intend to buy expensive improved commercial seed?
J. Soriano: (1) I do not discount the possibility of soil compactness contributing to low yields. As far as I know there has been no research on this. (2) The low-input growers will buy expensive improved seeds if they have an assurance of good markets that guarantee good returns. The willingness of the contract growers of processing tomato to buy expensive seed is a good example of this.

R.T. Opeña: Please explain the slight but still discernible difference in the general climate of production for pepper vs tomato, i.e., why are peppers grown more under cooler conditions than tomato? Is this varietal in nature or is it a reflection of general differences in climatic requirement between the two crops?
J. Soriano: It seems that the sweet pepper has a lower temperature requirement than tomato. The data on climate refers to the major region where pepper is grown and the pepper referred to in the production statistics is more likely that of the sweet pepper.

J. Soriano: It seems that the sweet pepper has a lower temperature requirement than tomato. The data on climate refers to the major region where pepper is grown and the pepper referred to in the production statistics is more likely that of the sweet pepper.

N.S. Talekar: Do you use the same cultivar for utilization of pepper as leafy vegetable and fresh fruit? What is the effect of defoliation on the fruit yield?

J. Soriano: The cultivar commonly used for leafy vegetable is the small-fruited hot pepper cultivar. Fruit yield is drastically reduced but there is not much need for their fruits because hot pepper of this variety is not used commercially in large amounts. There is now a growing demand for hot pepper sauce. Probably when the demand for hot pepper becomes high and stable there will be a separate production for leaf and fruit.

Major Disease Problems of Tomato Production and Their Control in the Sudan

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Abstract

Vegetable production in the Sudan, especially tomato and pepper, is gaining importance, both for local consumption and for export. More than 50,000 acres are grown to tomato. Several cultivars of tomato have been introduced and acclimatized throughout the Sudan, including canning types such as San Marzano, Roma, Romano and Strain B, and salad types such as Pearson, Money Maker, Early Pack and others. However, tomato throughout the country suffers from leaf curl virus disease, transmitted by the cotton whitefly *Bemisia tabaci*, from infestation with the rootknot nematode *Meloidogyne javanica*, and recently from powdery mildew. Leaf curl virus disease can result in more than 70% yield reduction. In the absence of a commercial tomato cultivar with resistance against this virus, control is achieved by integrating various approaches, including both cultural and chemical. Rootknot nematodes can be controlled by growing tomato on heavy clay and by the use of resistant commercial tomato cultivars like Nemared and Monte Carlo.

Introduction

The Sudan covers an area as big as India, some one million square miles. The total cultivable area, rarely exceeds eighty million ha, however only one tenth of this, or eight million ha is actually under cultivation. The climate is mostly arid in the northern part, extending to subtropical or tropical in the south. Accordingly, rainfall varies from a few millimeters per annum in the extreme north, to more than 800 mm in the extreme south, averaging 400-600 mm in the central plains where most of the cultivable area exists. In the north the temperature is typical of an arid climate, ranging between 10°-15°C (mean minimum) and 25°-30°C (mean maximum) during the winter period of November-February, between 20°-25°C (mean minimum) and 40°-45°C (mean maximum) during the summer period of March-June, and somewhere in-between during the rainy period of July - September. In the southern less arid part of the country, however, the gap between minimum and maximum temperatures is much smaller. The relative humidity is about 5% or less in the extreme north, with almost no rainfall, and around 20%-30% or 60%-80% in the central and southern parts respectively. The soil is either riverain or volcanic; while the riverain can be either sandy or silty, the volcanic usually varies from pure sand in the western region to alluvial in the south, with heavy clays in the center and east. Soil pH is mostly neutral or alkaline, around pH 7-8 (Tothill, 1952). Among the important crop plants grown throughout the Sudan are fiber crops (mainly cotton), oil crops (groundnut and sesame), cereals (sorghum and wheat), as well as vegetable crops such as tomato, onion, eggplant, hot and sweet pepper and several cucurbits. These are often exported to Europe, the Far East, and some Arab countries.

The production of tomato and pepper is gaining increasing importance in the Sudan, both for local consumption and for export. The total area grown to tomato under irrigation exceeds 50,000 acres. Most cultivars are introduced. The most important are the canning types such

as San Marzano, Roma, Romano and Strain B, and salad types such as Pearson, Heinz, Early Pack and Money Maker. On the other hand, the area under pepper is considerably lower with fewer varieties grown. Both crops are, however, produced by smallholders who employ relatively poor crop management practices. In addition, diseases and pests often further aggravate the situation, especially in the case of tomato.

Tomato Production and Its Disease Problems

Three major pathogens are known to affect tomato production in the Sudan: leaf curl virus (TLCV) transmitted by the whitefly *Bemisia tabaci* Genn.; powdery mildew; and rootknot nematodes, mainly *M. javanica*. Of these, TLCV is of relatively greatest importance because of its geographically wider occurrence throughout the country. Powdery mildew has recently become important in the northern regions of the country.

TLCV Disease. Symptoms caused by the leaf curl virus are yellowing, leaf curling and blistering, reduced leafsize, shortened internodes, flower shedding and poor flower bearing. Severe epidemic outbreaks have been reported from Sudan, affecting all the commercial tomato cultivars introduced from the USA, Europe, and the Far East (Yassin and Abu Salih, 1972), and severely reducing yield. Yield losses of up to 75% have been reported (Yassin and Nour 1965a). Although affecting tomatoes year round, the leaf curl disease constitutes a bottleneck to the production of summer tomato in many of the tomato producing counties, when unusually severe outbreaks are quite often encountered (Yassin and Nour, 1965b). A geminivirus with a particle diameter of 10-15 nm has been associated with tomato yellow leaf curl virus (TYLCV) infection of tomato in Israel (Russo, Cohen and Martelli 1980) and with the tomato leaf curl disease in the Sudan (Russo and Dafalla, 1982, personal communication). It has been suggested that the leaf curl diseases in Sudan and Israel are caused by the same virus, or perhaps by strains of the same virus.

Since the host range of both the virus and its vector is wide, it is impracticable to control the disease by eradication of alternative hosts. Furthermore, since resistant commercial cultivars are not yet available and since the foci of primary infection in any field are widely scattered and numerous, with a random pattern of spread (Yassin and Abu Salih, 1977), roguing of infected plants is not advisable. The only possible control measures against the leaf curl disease are as follows:

Use of high-yielding or disease-resistant cultivars. Yassin and Nour (1965a) observed an early maturing tomato cultivar, Pearl Harbour, which escapes the disease. This cultivar is, however, no longer grown commercially. Other cultivars such as Heinz, Pearson and the FAO series of cultivars, were shown to give relatively high fruit yield in certain seasons despite their susceptibility to the leaf curl virus under the conditions of Hudeiba or the Gezira (Yassin and Abu Salih, 1972, 1976, Yassin et al. 1982).

Use of relevant cultural practices. Fresh crop mulch such as wheat straw, placed near young tomato seedlings, significantly reduced incidence of tomato yellow leaf curl in Isreal (Cohen, Madjar and Hanein 1974). It was suggested that the mulch offers shade as well as shelter to the vectors, thus keeping them away from the tomato seedlings, and consequently offering protection against leaf curl infection in the early stages of tomato growth. However, the procedure seems to be impracticable in the Sudan, where farmers are rather reluctant to dispose of crop residues for the sake of mulch. Crop interplanting has been considered as an alternative. Yassin and Abu Salih (1977) postulated that crops known to be hosts of the vector but nonhosts of the virus, such as sweet Lubia bean (*Lablab purpureus* (L.)), when interplanted with tomato in the field, might attract the vector and hence reduce TLCV incidence in tomato.

Use of insecticides and oil sprays. Details of tests with insecticidal sprays for the control of the tomato leaf curl disease in the Gezira region have been reported (Yassin, 1975). Insecticides

recommended for use on vegetable crops, such as Dimethoate 80% and formothion 25%, were found to be effective in reducing disease incidence and increasing fruit yield significantly. Since the highest rate of infection usually occurs in the early stages of tomato growth (up to 12 weeks after planting), insecticide applications have to be started before transplanting and continued for several weeks afterwards (Yassin, 1975). Insecticidal applications are now widely practiced. Recently, the use of pyrethroids has become popular, not only in the Sudan (Dafalla, 1983) but also in the United Arab Emirates (Abu Salih, 1984, personal communication) to control tomato leaf curl disease

Mineral oils have been shown to be effective in the control of virus diseases (Calpouzos, 1966; Russel, 1970). Singh, Sastry and Sastry (1974), were the first to use mineral oil against tomato leaf curl virus in India. In the Sudan, promising results with mineral oils have been obtained, resulting in reduced disease incidence, as well as increased tomato fruit yield (Yassin and Abu Salih, 1975; Yassin et al. 1982).

Rootknot nematodes. Rootknot nematodes are widely distributed in river silt along the Nile's banks and also in light alluvial soils in the western and southern part of the country (Yassin, et al. 1970; Decker et al. 1980; Yassin 1974; Yassin and Zeidan 1979; 1982). In the Gezira area where river silt soils are predominant, many crop and weed plants are affected by nematodes, especially vegetables. A total of five nematode species have thus far been identified (Decker et al. 1980), but the most important are *M. incognita* and *M. javanica* (Yassin 1974). While *M. javanica* can inflict heavy damage (especially on tomato and tobacco) in the north part of the country, *M. incognita* is more prevalent in the south, both on tomato and eggplant (Yassin 1974). Various control practices to protect tomato against *M. javanica* have been investigated. Among the most important are:

1. The use of resistant cultivars, such as Nemared, Monte Carlo and Healam (USA), Rossol and Marsol (France) and Romita (Italy) (Sasser and Kirby 1979). These cultivars have been tested under Sudan conditions and found suitable;
2. Planting on heavy clay, such as that of the Gezira or of the eastern Sudan rainlands, whenever possible, because nematodes do not thrive in heavy clay. It is thought that root exudates which favor hatching and infectivity do not move freely under these conditions;
3. Rotation with nonhosts such as cotton and groundnut which are immune to *M. javanica* and *M. incognita*, and with pepper which is immune to *M. javanica* (Yassin and Zeidan, 1982);
4. The use of cultural practices, such as deep ploughing and dry fallow, to kill nematodes by desiccation and starvation;
5. The use of nematicides such as Nemacur, Furadan, DD, etc. (Yassin, 1974; Yassin and Zeidan, 1982; Yassin, 1984b); however, this practice is not generally recommended because of health hazards and the high cost involved.

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Symposium Discussion

R.T. Opeña: We have previously tried several times to send seed materials to the Sudan and neighboring countries. However, there was more failure than success, thereby discouraging further attempts. Do you have any alternative way to get the flow of materials going more smoothly?

A.M. Yassin: You can correspond with me directly (address in the list), or with our national coordinator for horticultural research, Dr. A.A. Geneif (same address). We appreciate your sestained efforts.

V.P. Roxas: Is cracking an important problem in tomato production in your country?
A.M. Yassin: Yes, because of our very dry, hot weather (relative humidity is about 20% and temperature more than 30°C at the time of tomato planting). Our main problem is heat tolerance and we hope AVRDC or other organizations can help. The other problem is leaf curl virus.

60

Tomato and Pepper Production and Improvement in Thailand

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Abstract

Pepper is the most widely grown vegetable crop in Thailand. 'Bird pepper' and chili occupy about 60,000-80,000 ha of the total vegetable and flower growing area of about 400,000-450,000 ha. In 1985, the total production of pepper was about 116,501 t from a harvested area of 58,159 ha. However, production is not enough for local consumption, and about 1,000-3,000 t of dried chili are imported each year. For the local diet, pepper is more important than tomato.

The tomato growing area is only one-seventh that of pepper. Even though the area is small, tomato's economic importance is the same as pepper's. Production of tomato is mainly for local markets, processing plants, and F_1 seed production. In 1985, the total production of tomato was 93,986 t from a harvested area of 8,277 ha. Production of tomato satisfies the local demand. About 1,300-3,200 t of tomato products are exported each year. The main constraints on tomato production are leaf curl virus, bacterial wilt, late blight and inadequate performance at high temperatures. Programs for improvement of varieties for heat tolerance, disease resistance, and good processing qualities are under way in many institutions and seed companies.

Pepper

Production

Pepper is one of the most important ingredients in the Thai diet. The two major types of pepper in Thailand are 'bird pepper' and chili. Bird pepper, called 'Prik Khi Nu' in the Thai language, is the most pungent of all peppers and has small, short, and fruits with erect pedicel. There are two bird pepper species, *Capsicum annuum* and *C. chinense*. Chili, called 'Prik Chi Fa' in the Thai language has low to high pungency and large, long and elongated fruits with pendant pedicel. The three chili species are: *Capsicum annuum*, *C. chinense*, and *C. frutescens* (Worayos, 1986). Bird pepper and chili cover more of the total vegetable growing area in the country than any other vegetables (Ministry of Agriculture, 1985). The total vegetable growing area is about 400,000-450,000 ha. In 1985, the total harvested area of pepper was 58,159 ha of which 40,231 ha was bird pepper and 17,928 ha chili (Table 1). The production of chili shows a declining trend, probably caused by import of low-priced chili from India. The total production of bird pepper was 80,714 t, and that of chili was 35,787 t, in 1985 (Figures 1 and 2). The main production areas of bird pepper and chili are in the west, northeast, and northern regions (Figure 3).

There are two types of cropping systems for chili and bird peppers: upland and paddy land pepper. Upland pepper is grown on terraces on hillsides, almost all of which are rainfed. The planting is in June or July and harvest is from October to January. Paddy land pepper is grown after rice, usually on irrigated paddy fields. It is planted in October or November and harvested from January to April. All pepper is transplanted. Transplanting of upland pepper is practiced

Table 1. Total harvested area of pepper, 1981-85.

Crop	Harvested area (ha)				
	1981	1982	1983	1984	1985
Bird pepper	41,104	40,902	38,007	41,906	40,231
Chili	36,380	32,388	22,094	24,560	17,928

Source Ministry of Agriculture 1985

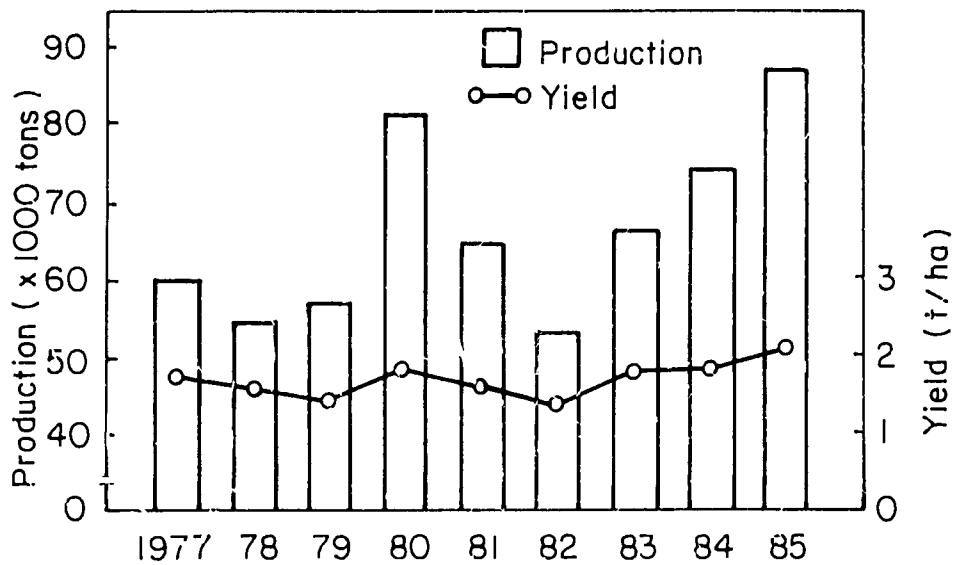

Figure 1. Total production and yield of bird pepper in Thailand. 1977-1985.

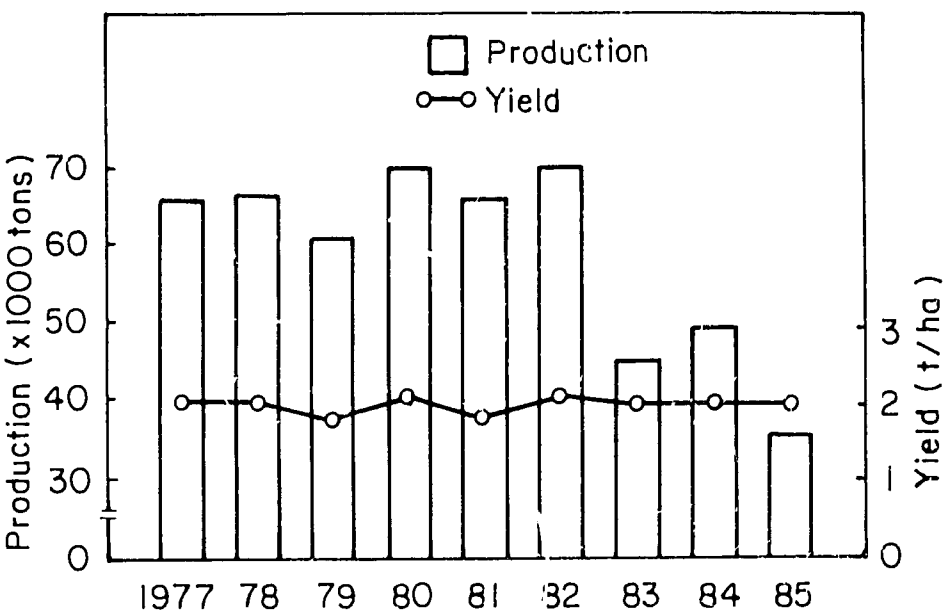

Figure 2 Total production and yield of chili in Thailand 1977-1985.

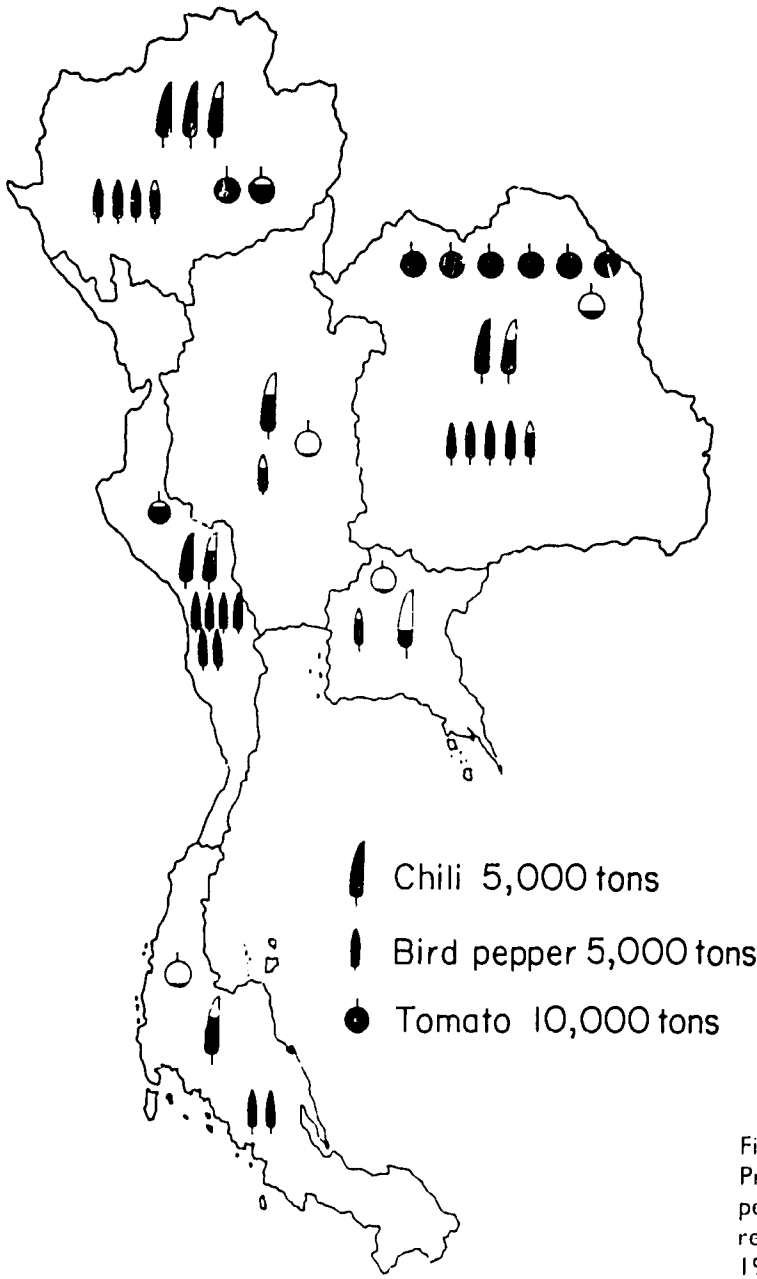

Figure 3.
Production of chili, bird pepper, and tomato in six regions of Thailand, in 1985.

after the rain because there is no irrigation of any kind. A spacing of 50 × 50, 50 × 30, or 60 × 70 cm is used. Hired laborers are required for transplanting. Fertilizer is usually not applied on upland pepper. Weeding and insecticide application are the only other management practices. Upland pepper receives very low management inputs compared to paddy land pepper. Paddy land pepper usually produces higher yields. Harvesting of upland pepper requires high labor input and very often, when the price of pepper is low, fields are not harvested at all.

The collection of pepper germplasm has been supported by the IBPGR. A total of 79 accessions have been collected in Thailand (Worayos, 1986). Three species identified were, *Capsicum annuum*, *C. chinense*, and *C. frutescens*. There are some unclassified accessions.

which possibly include *C. pubescens* and *C. baccatum*. Both the Chiang Mai University and Khon Khan University have collections of hot pepper germplasm.

Varieties and Seed Supply

All local varieties are open-pollinated and most of them have not been improved by either government or private sectors. Imported hybrid varieties have been tested in the farmers' field by seed companies. Hybrid varieties are not yet grown by farmers. Huaysiton 1 is the only variety of pepper released by the Department of Agriculture (Ministry of Agriculture, 1977). This variety has been selected from Chinda, a local variety. It has higher yield and better fruit quality than other local varieties and is widely used by farmers. Khon Khan University has released an improved hot pepper variety, Prik Wee which bears fruit in clusters. The variety has not yet been accepted by farmers because the plant is short (about 30-50 cm) and difficult to harvest. Most farmers produce their own seeds. Only a very small amount of pepper seed is imported (Table 2). Two seed companies, the East West Seed Company (a foreign company) and the Chia Tai Company (a local company), are involved in varietal improvement of hot pepper. Their main objective is the development of hybrid varieties for the local environments. Although at present, the market for seed in Thailand is very small, the companies expect to expand it through F_1 hybrid varieties.

Import and Export

Thailand imports large quantities of pepper each year (Table 3). The import of pepper has been increasing in the last few years, while export is declining.

Table 2. Import of pepper seeds into Thailand (1983-85).

Crop	1983		1984		1985	
	Quantity[z]	Value[y]	Quantity	Value	Quantity	Value
Pepper	0.63	14.46	0.91	17.92	0.14	3.1

Source: Ministry of Agriculture, 1985. [z]Quantity: ton. [y]Value: US$ 1,000

Table 3. Export and import of fresh and processed pepper (1983-85).

Crop	1983		1984		1985	
	Quantity[z]	Value[y]	Quantity	Value	Quantity	Value
Export						
Chili (dried)	327	710	1,867	1,902	957	882.8
Other pimento	23	6.9	1	1.5	9	18.2
Import						
Chili (dried)	2,901	2,600.9	1,095	1,180.5	1,876	2,501
Other pimento	120	130	9	22.6	26	73

Source: Ministry of Commerce, Bangkok, Thailand. [z]Quantity: ton. [y]Value: US$ 1,000

Economic Analysis of Income

The per capita income in Thailand was US $560 in 1984, which is low compared with that of developed nations, such as the United States, which was US $13,567 (Office of the National Economics and Social Development Board, 1986; United Nations, 1986). However, it is slightly higher than in the Philippines and Indonesia which are US $459 and US $447, respectively.

The major proportion of farmers' income is from crops. Approximately 84% of the income is derived from crops and only about 14.7% from livestock (Center for Agricultural Statistics,

1986) (Table 4). Pepper represents about 0.62 % of the total farm income (Table 5). Although the average income from pepper may be low, it is an important source of cash income for farmers. Farmers in the northeast can earn up to US$ 485.1/ha of profit (Table 6) (Office of the National Economics and Social Development Board, 1986). Pepper production is attractive to farmers, although they usually have no choice in the type of land they use for peppers. This is often the upland rainfed areas which cannot be used for other crops (particularly tomato) because of the distance to the tomato processing factories.

Table 4. Cash farm income per farm per crop year 1982/1983.

Region	Livestock	Crop	Other	Total
Northeast	100.26[z] (22.7)[y]	336.67 (76.15)	5.06 (1.15)	442.09 (100)
North	73.34 (9.30)	708.67 (89.87)	6.56 (0.83)	788.56 (100)
Central	175.71 (11.86)	1,297 (87.52)	9.17 (0.62)	1,481.88 (100)
South	124.14 (18.97)	512.69 (78.34)	17.59 (2.69)	654.42 (100)
Average of whole country	109.86 (14.71)	629.3 (84.24)	7.86 (1.05)	747.02 (100)

Source: Ministry of Agriculture, 1985. [z]Unit: US$/farm. [y]The number in brackets is the percentage of cash income from the agricultural sector by type of various income sources.

Table 5. Cash farm income per crop per farm (1982/83).

Crop	Region				Average of whole country
	Northeast	North	Central	South	
Onion	0.24[z] (0.07)[y]	14.82 (2.09)	– –	– –	4.00 (0.64)
Shallot	0.76 (0.22)	2.85 (0.40)	7.03 (0.54)	– –	2.33 (0.37)
Garlic	0.50 (0.15)	77.14 (10.98)	0.44 (0.03)	– –	20.59 (3.27)
Chili	0.68 (0.20)	6.88 (0.97)	9.75 (0.75)	0.40 (0.08)	3.89 (0.62)
Garden vegetables	4.67 (1.38)	19.57 (2.76)	45.72 (3.52)	12.94 (2.52)	17.01 (2.70)
Other crops	329.82 (97.98)	587.41 (82.89)	1,234.06 (95.16)	499.35 (97.40)	581.4 (92.40)
Total	336.67 (100)	708.67 (100)	1,297.00 (100)	512.69 (100)	629.30 (100)

Source: Ministry of Agriculture, 1985. [z]Unit: US$/farm. [y]The number in brackets is the percentage of cash farm income.

Table 6. Production costs and profit on upland pepper in Northeast Thailand.

Cost	Cash	Non-cash	Total
Variable cost			
1. Labor	121.9[z]	55	176.9
2. Field supply	8.8	3.1	11.9
3. Opportunity cost	–	18.8	18.8
Total variable cost	130.7	76.9	207.6
Fixed cost			
1. Land	29.4	66.3	95.7
2. Depreciation	–	10.0	10.0
Total fixed cost	29.4	76.3	105.7
Total cost of production	160.1	153.2	313.3
Yield (kg/ha)			5,931.3
Total income (US$/ha)			798.4
Profit (US$/ha)			485.1

Source: Khon Khan University, 1986. [z]US$/ha.

Constraints

Diseases, lack of good varieties and poor management are the major production constraints for pepper. Incidence of virus diseases is high. Four viruses have been reported: cucumber mosaic virus, tobacco mosaic virus, chili veinal mottle virus and a third which resembles pepper mottle virus (Sutabutr et al. 1985; AVRDC. 1987). Besides virus diseases, leafspot (*Cercospora* sp.) and anthracnose (*Colletotrichum capsici*) are very serious on pepper (Wannagee and Jansrikul. 1977; Jutsakul and Taungpanich. 1979).

Tomato

Production

The total harvested area of tomato occupied 8,277 ha in 1985, producing a total of 93,986 t (Figure 4) (Table 7). This is made up mainly of processing tomato, using imported seed (Table 8). The trend of production has been increasing in recent years. The main production areas of tomato are in the northeast and northern regions (Figure 3). There are two types of tomato grown: those for fruit and those for F_1 hybrid seed production. Imports of tomato products have declined and export of fresh or frozen fruit has increased since 1983 (Table 9). The decline in imported products is caused by increasing production of tomato in the country. Tomato paste is the main import product. Thailand tomato paste has been improved in quality recently, so

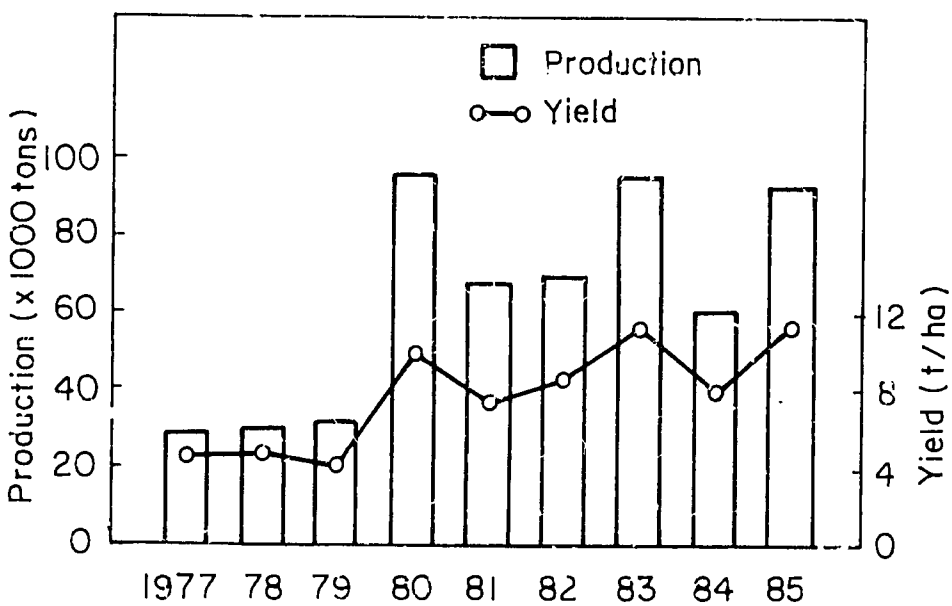

Figure 4. Total production and yield of tomato in Thailand. 1977-1985.

Table 7. Total harvested area of tomato. 1981-85.

Crop	Harvested area (ha)				
	1981	1982	1983	1984	1985
Tomato	9,240	8,110	8,465	7,906	8,277

Source: Ministry of Agriculture 1985

Table 8. Import of tomato seeds into Thailand (1983-85).

Crop	1983		1984		1985	
	Quantity[z]	Value[y]	Quantity	Value	Quantity	Value
Tomato	1.2	34.12	2.53	71.49	1.01	40.1

[z]Quantity: ton. [y]Value: US $1,000.

Table 9. Export and import of fresh and processed tomato (1983-85).

	1983		1984		1985	
	Quantity[z]	Value[y]	Quantity	Value	Quantity	Value
Export						
Fresh or frozen	1,360	307.7	2,123	477.8	3,270	618.3
Sauce, ketchup	41	47.7	68	82.4	47	47.9
Import						
Mainly paste	460	329.4	18	14.4	17	15.2

[z]Quantity: ton. [y]Value: US $1,000.

that the local paste can be used instead of the imported paste. Fresh tomato fruits have been exported to Singapore. Large amounts of fresh fruits are by-products for processing plants.

Economic Analysis of Income

Tomato is an important source of cash income for some farmers in the north and northeast. Farmers in the north can earn US $259.6/ha of profit from paddy land tomato (Table 10) (Wivutvongvana et al. 1987). Both fresh fruit production and seed production are very good sources of income for farmers. The northeast is the only region for F_1 hybrid seed production and farmers can earn a gross income of US $6,000-10,900/ha.

Varietal Improvement

Several tomato varieties have been released by government institutes. The variety Sida, which is a very popular wilt to Thai consumers, has been developed by Kasetsart University and the Department of Agriculture (Wivutvongvana et al. 1982). After long cooperation with the Asian Vegetable Research and Development Center, two outstanding heat-tolerant varieties have been released, namely SVRDC 4 developed by Khon Khan University, and L 22 developed by Chiang Mai University (Wivutvongvana et al. 1982). Both varieties have been accepted by farmers in many parts of the country. The varieties are determinate with very small fruits (approximately 60 g/fruit). Their growing period is about four months. In two rainy season experiments, the variety L 22 yielded 12.3 and 17.9 t/ha, and the variety SVRDC 4 11.5 and 20.2 t/ha, compared to 5.4 and 2.3 t/ha of the standard variety VF 134-1-2 (Lumyong and Wivutvongvana, 1984).

About 80 varieties of processing tomato have been introduced and their horticultural characteristics were recorded by IBPGR descriptors (IBPGR, 1981). Forty-four varieties were evaluated in winter 1985 (Wivutvongvana et al. 1987). They were compared with the currently grown varieties such as VF 134-1-2 and P502 and Peto 94. The yield of most introduced varieties, and postharvest and processing qualities, were similar to the currently grown varieties. The most promising varieties are Farmers 209, Lima VF, CL 1591-5-0-5-1, Hypeel 235, Aragon F1, UC 82 VF, Peto 95, and Earlypeel 1448.

Table 10. Production costs and profit of paddy land tomato in Northern Thailand.

Cost	Cash	Non-cash	Total
Variable cost			
Labor	100	267.5	367.5
Field supply	310	24.4	334.4
Opportunity cost	–	18.8	18.8
Total	410	310.7	720.7
Fixed cost			
Land	–	49.4	49.4
Depreciation cost	–	13.1	13.1
Total fixed cost	–	62.5	62.5
Total cost of prod.	410	373.2	783.2
Yield (kg/ha)	24,225		
Total income (US$/ha)	1,042.8		
Profit (US$/ha)	259.6		

Management

There are two types of cropping systems for tomato: one for highland and one for paddy land tomato. Highland tomato is grown in the highlands and uplands in the rainy season, starting from March to November. Farmers get almost twice as much fruit yield from highland tomato compared to paddy land tomato. Paddy land tomato is grown after rice in irrigated paddy fields, from November to April. In general, plants are neither mulched nor staked on the paddy land, whereas highland tomato is staked, though not mulched. Most farmers produce fruit for the fresh market and for processing at the same time. Large fruits are selected for the fresh market, the remaining fruit is taken to the processing plants

Cost of Production

Economic analyses of cost of production and return on processing tomato in winter were studied (Wivutvongvana et al. 1987). Production costs of tomato in farmers' fields were 3,257 baht/rai (US $783/ha) and at the Experiment Station 4,022 baht/rai (US $967/ha). The net income was 2,610 baht/rai (US $627/ha) in farmers' fields and 2,962 baht/rai (US$ 712/ha) at the Experiment Station.

Major Production and Marketing Constraints

One of the major constraints of tomato production is the inadequate performance of the present cultivars. They are not well adapted to high temperatures and are susceptible to bacterial wilt, tomato yellow leaf curl virus and late blight, which are serious diseases in Thailand. Poor crop management, particularly of processing tomato, is another constraint. Management is not a problem for tomato seed production, because intensive extension programs have been conducted by the private seed companies. All processing tomato varieties presently grown in Thailand are introduced from the United States and Europe. Yield and quality are poor, not only because they are unadapted but also because of poor management. Tomato paste from local companies cannot be produced up to world standard because of poor color, low viscosity and large numbers of insect fragments. Weed control, fertility management and improvement of field management and processing facilities should improve the quality of the paste. One weak point may be the existing hot-break system in the processing lines of local paste factories, which may be so poor that the viscosity of the paste is lower than with a good hot-break system. The lack of promotion on uses of tomato and lack of postharvest technology are other important constraints.

Research and Development

Breeding programs have been initiated to improve heat tolerance, and resistance to bacterial wilt and late blight (Wivutvongvana et al. 1987). High yield and good processing quality are other major breeding objectives. F_1 hybrid production, single seed descent, and modified recurrent selection methods are used in these programs.

Researchers from the universities, Department of Agriculture, Department of Agriculture Extension, Agricultural Colleges, and some private companies are involved in various aspects of tomato research. They have organized into a national working group, the Tomato National Committee. The main research targets are breeding for heat tolerance, disease resistance against bacterial wilt and late blight, the introduction and evaluation of new varieties, and the improvement of crop management.

Researchers at Chiang Mai University have been working on various aspects of tomato improvement such as identification of major production and marketing constraints, varietal introduction and evaluation, breeding and selection, crop management, training and extension (Wivutvongvana et al. 1987).

Future Prospects of Tomato and Pepper

The future prospects of both pepper and tomato are very good. Hot pepper is in demand for local markets. Although the local demand for tomato and tomato products is not so high, the export potential of tomato products is better than that of pepper. Tomato F_1 hybrid seed production is a booming business which gives higher returns to farmers than fresh fruit production. Improvement of tomato varieties and cultural practices is expected to progress faster than pepper because of economic prospects and extensive prior research.

Acknowledgments

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Symposium Discussion

N.S. Talekar: Is the labor used in pepper production family labor or hired from outside? If it is family labor the crop should be quite profitable.

M. Wivutvongvana: Mostly, the labor used in pepper production is either family or exchange labor. Hired labor is used only during transplanting and harvesting periods, but farmers usually avoid it. Yes, the crop is quite profitable because the major production input is labor.

517

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585

Subject Index

ABA (see Growth regulators, abscisic acid)
Abelmoschus esculentus 36
ACC (see 1 aminocyclopropane 1-carboxylic acid)
Aceria lycopersici 446, 449
Acid phosphatase locus 78
Aculops lycopersici 401
African bollworm (see *Heliothis armigera*)
Ageratum conyzoides 446
Agrotis ipsilon
  pepper
    Brazil 403
    India 452
  tomato, Taiwan 428
Agtron value 111
Alfalfa mosaic virus
  pepper
    Australia 250, 252
    seed 38
  tomato, Australia 250
Allium spp. 36
A. cepa 33
Alternaria alternata 38
  pepper, India 452
  seed 38
  tomato
    Australia 390
    Brazil 401
    China 416, 418
    importance in tropics 70
    India 452, 456
    Korea 500
    Liberia 504, 507
    Malaysia 512
    Mexico 532
    Nigeria 536, 541
    Philippines 554
    Taiwan 433
    tolerance 100, 103
    USA 283
A. capsici-annui 38
A. solani
  pepper
    India 452
    seed 38
  tomato
    Australia 390
    Brazil 401
    China 416, 418
    importance in tropics 70
    India 452, 456
    Korea 500
    Liberia 504, 507
    Malaysia 512
    Mexico 532, 541
    Nigeria 536
    Philippines 554
    Taiwan 433
    tolerance 100, 103
    USA 283
Amaranthus spp. 36, 538
A. hybridus 446
A. viridis 351
1 aminocyclopropane-1-carboxylic acid (ACC) 155
Amino oxyacetic acid (AOA) 270
Anther culture 44-47, 49
Anthracnose, pepper (see *Colletotrichum* spp.; *C. dematium*; *C. gloeosporioides*)
Antibiosis 113
AOA (see Amino oxyacetic acid)
Aphids
  as virus vectors 70, 253, 541, 752
  control
    biological 257
    chemical 254, 257, 449, 554
    mineral oil 257
  pepper
    India 452, 462
    Nigeria 536
    Taiwan 90
  tomato
    Australia 253
    behavior on hairy tomato 76-77
    Brazil 401
    China 416, 418
    Ethiopia 442, 449
    importance 70
    India 452
    integrated pest management 276, 278
    Nigeria 536
    Philippines 554
    vectors of tomato yellow top virus 283
Apis sp. 28

Argemone mexicana 446
Argentina, tomato improvement
processing tomato 107-112
rootknot nematode 107-112
tomato spotted wilt virus 108
Armyworm (see *Spodoptera* spp.; *S. exigua*)
Asian Vegetable Research and Development Center (AVRDC)
genebank 10
international cooperation 572
INTHOPENET 86, 93-94
pepper
genetic resources 10
germplasm
collection 12
collection, duplication 14
global base collection 3, 10
improvement program 86-98
seed multiplication 15
tropicalization 93
tomato
breeding strategies 80, 82
contribution to Taiwan 432
cultural management 349-357, 434, 438-439
genetic improvement 70-85, 555
genetic resources 10
germplasm
collection 12
distribution 17-18
recipients 17
high fruitset lines 66
lowland selections 358
processing lines 553
rainshelter 318
releases 18-19, 71, 82, 572
resistant lines/germplasm
bacterial wilt 65, 475
bacterial wilt and heat tolerance 509-510, 542
heat tolerance 66, 509-510, 542
leafcurl virus 413
multiple disease 82, 432
potato virus Y 78
rootknot nematode 99
seed multiplication 14-15
tropical tomato improvement 71-85
Aureliana sp. 2
Australia
climatic data 388, 392
pepper
cultivars 393
cultivation practices 392
diseases 386, 393
foreign trade 393
marketing 393
production
areas 250
constraints 249-253, 393
statistics 392
research and development 394-395
virus diseases 249-259
tomato
Australian tomato leafcurl virus 250, 253
breeding 386
cropping systems 388
cultivars 389
diseases 386, 391
foreign trade 389, 474
future needs 391
marketing 389
production
areas 250
constraints 249-253, 390
statistics 386-387
quarantine restrictions 390
research and development 390-391, 395
virus diseases 249-259
yield losses 390
Australian tomato leafcurl virus 250, 253
AVRDC (see Asian Vegetable Research and Development Center)

B-carotene 80
Bacillus thuringiensis (see Insecticides, *B. thuringiensis*)
Bacteria (see individual species — *Corynebacterium michiganense* pv. *michiganense*; *Erwina carotovora*; *Pseudomonas solanacearum*; *P. syringae* pv. *tomato*; *P. tomato*; *Xanthomonas campestris* pv. *vesicatoria*)
Bacterial canker (see *Corynebacterium michiganense* pv. *michiganense*)
Bacterial leafspot (see bacterial spot)
Bacterial speck (see *Pseudomonas* tomato)
Bacterial spot (see *Xanthomonas campestris* pv. *vesicatoria*)
Bacterial wilt (see *Pseudomonas solanacearum*)
Barbados, AVRDC tomato releases 18
BAS 112 W 174-181
BAS 113 W 174-181
Basal rot (see *Sclerotium rolfsii*)
BCIP (see 5-Bromo-4-chloro-3-indolyl-phosphate)
Bemisia tabaci
adult survival 243
control
chemical 245
yellow plastic mulching 248
yellow sticky traps 248

damage
direct 239
indirect 239
honeydew excretion 239, 242, 244
Israel 239-248, 260
mortality 244
Nicaragua 289, 293
Nigeria 541
reduction, in tomato-bean polyculture 293
resistance
field screening 242-244
laboratory test 242, 244
Lycopersicon hirsutum 240, 242
L. hirsutum f. *glabratum* 240, 242
L. pennellii 240, 242
screening method 239, 242, 244-245
Sudan 561-562
viruses, transmitted by *B. tabaci* 239-240, 260
Beneficial insects 280, 285
Biofilm 269
Biotechnology 47-50, 484-485
Bird pepper (see *Capsicum* spp., bird pepper; *C. annuum*, types, Piquin)
Black leafmold 87 (see also *Cercospora fuligena*)
Bombus sp. 28
Botryodiplodia palmarum 38
Botrytis cinerea
biological control
amino oxyacetic acid 271
ethylene inhibitors 268, 270-271
film-forming polymers 268-270
fungal antagonists 268-269
silver thiosulfate 271
Trichoderma spp. 268-269, 274
chemical control 269
culture medium 269
fungicide resistance 270
host predisposition 270
Korea 500
necrotic reaction 270
Brassica spp. 36
Brazil
climatic data 397, 399
pepper
breeding 56, 60-62
Capsicum chinense 55-62
cultivars 402
diseases 55
flavoring peppers 55
marketing 403
ornamental pepper 55
perennial peppers 55
production
constraints 403
statistics 402
utilization 403
tomato
AVRDC releases 18
breeding, resistance to leafminers 113-122
cropping systems 400
cultivars 397-398
diseases 401
foreign trade 401
insect pests 113-122, 401
marketing 399
nematodes 401
production
constraints 401-402
cost 401
statistics 396
research and development 402
Scrobipalpula absoluta 113-122
utilization 401
Xanthomonas campestris pv. *vesicatoria* 207
Brinjal (see *Solanum melongena*)
Brix 80
5-Bromo-4-chloro-3-indolyl-phosphate (BCIP) 260
Brunei, tomato imports 554
Buckeye rot (see *Phytophthora parasitica*)
Burkina Faso, processing tomato improvement 63

Cabbage looper (see *Trichoplusia ni*)
Calcium translocation 270
Callus culture, pepper 9
Cambodia
climatic data 405
production zones 407
soils 407
tomato
cultural management practices 413-414
leafcurl
control 413-414
disease 405
local germplasm collection 414
production constraints 405
Candida tropicalis 38
Cape Verde Islands, AVRDC tomato releases 18
Capsaicinoids 51
Capsaicin
anthracnose resistance 188
bacterial spot resistance 188
screening for 96, 462, 503
synthesis, in *Capsicum chinense* 60
Capsella bursa pastoris 254
Capsicum spp.
acceptance 4

autogamy 28
AVRDC (see Asian Vegetable Research and Development Center, pepper)
bird pepper (see also *Capsicum annuum*, types, Piquin)
Mexico 521, 527, 530, 566
pungency 566-568
resistance to *Phytophthora capsici* 521
Thailand 566-568
breeding (see Genetic improvement, *Capsicum* spp.)
cayenne pepper 189, 194, 197 (see also *Capsicum annuum*, types)
characteristics 3
chromosomal interchange 5
chromosome 5
cleistogamy 91, 96
constraints
Australia 393
Brazil 403
China 416, 419
Ethiopia 442, 445-447
identification 86
India 452, 462-463
Indonesia 472, 476-478
Japan 485
Korea 490, 495-496
Liberia 504-505
Malaysia 508, 515
Mexico 531-532
Nigeria 545
Philippines 557-558
Thailand 571
consumption
Brazil 402-403
Ethiopia 442-444
Indonesia 477
Korea 490
Malaysia 514
Mexico 522, 530
Nigeria 539, 543
cropping systems
Australia 392
Brazil 402
China 419
Ethiopia 444
India 464
Indonesia 478
Japan 480
Korea 492
Malaysia 514
Nigeria 543-544
Philippines 556
Thailand 566, 568
cross pollination, natural 28-29
cultivars
Australia 393
Brazil 402
China 419
Ethiopia 445-446
India 452, 461, 464, 466
Indonesia 476
Korea 494
Malaysia 514-515
Mexico 529-530
Nigeria 544
Philippines 557-558
Thailand 569
cultivation practices
Australia 392
Brazil 402-403
China 419
Ethiopia 447
high bed cultivation 476
India 459-460, 464, 466
Indonesia 476
intercropping 478, 514
Japan 485
Korea 490, 492-494
Liberia 505
Malaysia 515
Mexico 528
monocropping 495
Nigeria 543-545
Philippines 556
plastic roofing 478
protected culture 416
protected facilities 480
Taiwan 423
Thailand 568
dehydration methods 528
diseases (see Bacteria; Fungi; Viruses)
dispersal 5
domesticated species 3-5, 36
domestication 3-5
drought stress 90
ecological adaptation 9
economic potential 4
embryo culture 9, 28, 32, 34
flower abscission
drought stress 90
prevention 478
foreign trade
Australia 393
Ethiopia 443, 445
India 452, 460, 471
Japan 480
Korea 495
Malaysia 515
Mexico 525-527, 544
Philippines 557
Taiwan 429
Thailand 569
fruit drop
drought stress 90
prevention 478

gene transfer 7
genetic diversity 9
genetic improvement (see Genetic improvement, *Capsicum* spp.)
genetic impurity 86, 91
genetic manipulation 7
germplasm collection (see Genetic resources, *Capsicum* spp., collection)
highland pepper 4
human selection 9
interspecific barriers 7
interspecific crosses 6
interspecific gene transfer 6
interspecific hybridization 7
introduction, Africa, Asia, Europe, Old World 3
isozyme coding genes 6
isozymes 7, 29
landraces 13
Liberia, local cultivars 505
linkage, undesirable 7
marketing
  Australia 393
  Brazil 403
  Ethiopia 444-445, 447
  India 464
  Indonesia 4 '3
  Korea 493
  Malaysia 516-517
  Mexico 529-531
  Nigeria 544-545
  Philippines 557-558
  Taiwan 429
monocropping problems 495
nomenclature 7
nutrient deficiencies 516
nutritional requirements 517
origin 3
outcrossing 15
phytotoxic substances, from residues 495
pollination 28
processing
  Ethiopia 444-445
  India 464
  Korea 495
  Malaysia 515
  Mexico 527
  Nigeria 539, 544
  Philippines 557
  Thailand 569
production cost
  Ethiopia 442, 447-448
  Indonesia 457
  Malaysia 514
  Thailand 570
production statistics
  Australia 392
  Brazil 402
  China 419
  Ethiopia 442-445
  India 459-460
  Indonesia 473, 475-476
  Japan 480, 485
  Korea 490-491
  Liberia 505
  Malaysia 513-514
  Mexico 525-526
  Nigeria 543
  Philippines 556
  Taiwan 423
  Thailand 566-567
protoplast fusion 9
pungency (see Pungency, pepper)
research and development
  Australia 394
  AVRDC (see Asian Vegetable Research and Development Center)
  Ethiopia 447
  India 464-466
  Japan 486
  Korea 490, 496
  Liberia 505
  Malaysia 516-517
  Mexico 535
  Nigeria 545
  Philippines 558
seed
  abnormalities 9, 30, 33, 41
  ageing 35
  AVRDC 14
  breakdown 6
  certified seed 28, 39
  color 28-29
  dark seeds 9
  drying 15
  emergence 31
  extraction 15, 471
  genetic integrity 14
  germination
    mean germination time 31-32
    pregermination treatments 28, 35-36
    rate 14
    tests 30
    temperature 31-32
    uniformity 31-32
  mineral absorption 33
  moisture 34-35
  morphology 29
  multiplication 14-15, 28
  osmopriming 28, 35
  postharvest ripening 30
  production
    general 9, 28-42
    India 452, 446

Indonesia 476-477
Liberia 505
quality 30
regeneration 15
seed-borne diseases 38
shape 28
sources, general 91
storage 14, 28, 34-37, 40
supply
Malaysia 514
Nigeria 544
Philippines 557
Thailand 569
tetrazolium test 30
treatments 15, 463
trisodium phosphate treatment 256, 259
variability 6, 28-29, 37
viability 14, 34-35
vigor test 31
somatic hybrids 9
spice type 3
taxonomic complexity 36
taxonomy 9
utilization
Brazil 403
Ethiopia 445, 464
Indonesia 477
Mexico 522
Nigeria 543-544
Philippines 557
Taiwan 423
wild species 36, 418
C. annuum (see also *Capsicum* spp.)
anther culture 45-47
biochemical traits, screening for 471
capsaicinoids 51
capsaicin (see Capsaicin)
cayenne pepper (see *Capsicum annuum* types, cayenne)
chromosome mapping 5
chromosome races 5
Cili Padi 514
collection (see Genetic resources, *Capsicum* spp., collection)
cultivation practices
fertilization
nitrogen management 365-374
nitrogen requirement 366
nitrogen use efficiency 369
nutrient uptake 367, 369-371
irrigation
effect on yield 368
evapotranspiration 365, 371-372
frequency 365, 368, 371
furrow 365-367
management 365-374
practices 90
water use efficiency 386
mulching 386, 392 (see *also* Mulching)
shading 345-348
cytoplasmic male sterility 93
dispersal 5
diversity, genetic 5, 9
domestication 3, 5
doubled haploids 48
evapotransporation (see *Capsicum annuum*, cultivation practices, irrigation)
flower abscission
causes 150, 152, 154, 157
control 157
effect of ethylene on 150
mechanism 154
resistance to 157
flower characteristics 3-4
fruit abscission
causes 150, 152, 160
control 157, 164
mechanism 154
prevention 161, 164
resistance screening 158, 161
resistance to 150, 161
role of ACC 156
fruit characteristics 3
fruit characters, importance 92
fruit deformation 488
fruit set
conditions 164
effect of diseases on 153
effect of insects on 154
environmental influences on 152
varietal differences 150
fruit uniformity 93
fruit wall thickness 92
haploids 45-46
interspecific gene transfer 7
introduction, Africa, Asia, Europe, Old World 4
isozyme coding genes 5
male sterility 490
mutants, yellow fruited 47
nitrogen requirement 366
nomenclature 7
nutrient uptake 367, 369-371
origin 3
ornamental type 3
outcrossing 52
pigments, leaf 348
Piquin pepper (see *Capsicum annuum*, types, Piquin)
pollination
artificial 488-489
insect 28-29
processing

dehydrating methods 528
oleoresin production 445
purple leaved cultivars 3
soil moisture requirement 365-366, 371
somaclonal variants 7
spice type 3
tissue culture 44-50
types
Anaheim 527, 530
Ancho 523, 525-527, 529-530
bell 526, 529
bird 566-568 (see also *Capsicum* spp, bird pepper; Piquin)
Caloro 526-527, 529-530
Caribe 527
Cascabel 527
cayenne 476, 514, 527
cherry 527
Chilaca 526-527, 529-530
Chipotle 526-527, 529-530
Cili Padi 514
Cubanelle 527, 530
DeArbol 526-527, 529-530
Fresno 527, 530
Guajillo 526-527, 529
Guerito 527
Habanero 529-530
Hungarian 527, 530
Jalapeño 523, 525-527, 529-530
Manzano 530
Mirasol 527
Mulato 523, 529-530
Negro 527
Pasilla 523, 525-527, 529-530
Peron 526, 529
Piquin 521, 527, 530, 566
Poblano 526-527, 529-530
Pola 527
Puya 527
Seco 527
Serrano 523, 525-527, 529-530
utilization
leafy vegetable 560
medicinal 418, 522, 543
oleoresin 445
variability 5
virus resistance 51 (see *also* individual viruses)
wild types 5, 521
yield improvement
by irrigation 368, 371, 373
by N fertilization 369, 371, 374, 378-380
yield loss 463
yield, maximum 365
annuum var. *aviculare* 513
annuum var. *glabriusculum* 522
baccatum
as spice 4
AVRDC 10, 12, 14
Bolivia 4
Brazil 4, 402
characteristics 4
chromosome race 5
domesticated species 3
flowers 4
interspecific gene transfer 6
interspecific variation 4
introduction, Africa, Asia, Europe 4
pericarp 4
pungency 4
resistance to
cucumber mosaic virus 486
spidermites 403
viruses 6
C. cardenasii, AVRDC 10, 12, 14
C. chacoense
AVRDC 10, 12, 14
interspecific gene transfer 6
resistance to
tobacco mosaic virus 6
viruses 6
Xanthomonas campestris pv. *vesicatoria* 221
C. chinense
Amazonia 4, 9
Andean region 4
as ornamental pepper 55
as perennial 55, 60, 62
AVRDC 10, 12, 14
Brazil 4, 9, 55-62, 402
breeding program, use in 56-57, 60-62
capsaicin synthesis 10
Caribbean 4
center of origin 55
commercial production 58
consumers' acceptance 55, 58
domesticated species 3-4, 55-56
evaluation 55
flavoring pepper 55
flowers 4
for humid tropics 55-60
fruit 55-57
fruit quality 58
fruiting potential 56
gene transfer source 55
genetic diversity 9
hairline constriction 4
home garden production 58
interspecific gene transfer 6
large-fruited types 4
Mexico 530
morphology 4
pericarp 55, 57-58
production cost, Brazil 55, 58
pungency 4, 96

resistance to
Colletotrichum gloeosporioides 58
Erwinia carotovora 58
flower abscission 157
Phytophthora capsici 58
potato virus Y 57-58, 62
Sclerotium wilt 58
tobacco mosaic virus 486
tomato spotted wilt virus 58
Xanthomonas campestris pv. *vesicatoria*
shade reaction 57
stress reaction 57
sweet pepper substitution 55
thick-walled types 4
C. eximium 10, 12, 14
C. frutescens
AVRDC 10, 12, 14
bird pepper 566
Brazil 402
Caribbean 3
characteristics 4
Costa Rica 4
cultivation 3
domesticated species 3-4
flower 4
flower abscission, resistance to 157
fruit 4
introduction to
Asian tropics 4
Old World 3
Papua New Guinea 3
West Africa 4
large-fruited types 3
Latin America 3
Mexico 521-522
Middle America 3
morphology 4
Nigeria 543
nomenclature 7
Panama 4
pericarp 4
Tabasco pepper 3
Thailand 568, 568
weed 3
wild populations 521
wild types 3, 4
C. galapagoense, AVRDC 10, 12, 14
Capsicum Genetics Cooperative
Capsicum repository 51, 53
establishment 51
New Mexico, USA 51
research 53
Capsicum microcarpum, AVRDC 10, 12, 14
Capsicum mosaic virus 256
Capsicum newsletter 53
Capsicum nigrum, taxonomy 7
C. praetermissum
AVRDC 10, 12, 14
Brazil 402
C. pubescens
abscission, resistance to 157
Andean region 4
AVRDC 10, 12, 14
characterization 4
corolla 4
fruitset 4
interspecific gene transfer 6
lowland tropics 4
Mexico 530
Middle America 4
pericarp 4
pungency 4
seeds 4, 9
CATIE (see Centro Agronómico Tropical de Investigación y Ensenañza)
Celosia trigyna 446
Centro Agronómico Tropical de Investigación y Ensenañza (CATIE)
germplasm collection 12
global base collection 3
preservation guidelines 36
Cercospora capsici
Malaysia 516
Philippines 557
seed 38
C. fuligena
AVRDC tomato improvement program 82
Malaysia 512
Cercospora leafmold (see *Cercospora fuligena*)
Cercospora leafspot 87, 571 (see also *Cercospora capsici*)
Chapeu de frade 4, 402
Chili veinal mottle virus
AVRDC improvement program 94
importance 88
Malaysia 516
resistant germplasm 516
Taiwan 425
Thailand 571
tropics 86
Chimera 46
China
International collaboration 486
pepper
breeding 416
cultivars 420
diseases 419-420
export 515, 520
production constraints 416, 419-420
research institutes 421
tomato
breeding 416

cultivars 419
cultivation seasons 418
processing tomato 417
production
constraints 416, 418
statistics 417
research institutes 421
Choanephora blight on pepper 87
Choanephora cucurbitarum on pepper, Malaysia 516
4-chloro-2-hydroxymethyl phenoxy acetic acid (CHPA) 359-363
4-chlorophenoxyacetic acid (CPA) 133-144, 147, 175
CHPA (see 4-chloro-2-hydroxymethyl phenoxy acetic acid)
Chromosome linkage, *Capsicum* 5
Chromosome mapping, *Capsicum* 5
Chromosome races, *Capsicum* 5
Chrysonotomya punctiventris 279
Cladosporium fulvum (see *Fulvia fulva*)
C. solani 38
Cloxyfonac 175
Colletotrichum spp.
cross inoculation studies 192, 196
nomenclature 187-188, 190
pepper
chemical control 189, 191-192, 194-195
China 416, 418
disease development 197
host specificity 198
importance 87, 89, 189
India 452, 463
Indonesia 477
inoculum source 191
Korea 184-188
Malaysia 516
Nigeria 545
pathogenicity 191
Philippines 557
resistance screening 98
resistance sources 96
symptoms 190
Taiwan 89
USA 189-199
virulence 191, 198
yield loss 189, 191, 463
species 189
C. acutatum 187-189
C. atramentarium 190
C. capsici
pepper
anthracnose, cause of 189
crop debris 197
Malaysia 508, 516
nomenclature 187-188
Philippines 557
pods 193-194
seed 38, 191
Taiwan 95
Thailand 571
USA 189
weeds 197
tomato, Malaysia 512
C. coccodes
anthracnose, cause of 189
control 189
Liberia 505
resistance screening 188
USA 189
C. dematium 184-188
C. gloeosporioides
anthracnose, cause of 189
control 189
damage 184-185, 188
inoculation method 189
Korea 89, 184-185, 188, 496
nomenclature 187
on debris 197
on pods 193-194, 197
on weeds 197
predisposing factors 188
resistance screening 185-186, 189
seed 191
spore shape 187
strain G 184-185
strain R 184
strains 89, 184-185
Taiwan 95
USA 189
C. graminicola 190
C. nigrum 190
C. piperatum
inoculum source 191
pepper seed 38, 191
Colorado potato beetle (see *Leptinotarsa decemlineata*)
Commelina benghalensis 446
Commonwealth Scientific and Industrial Research Organization (CSIRO) 391, 395
Congo
AVRDC tomato releases 18
processing tomato 63
Cook Islands, AVRDC tomato releases 11, 18
Corky root (see *Pyrenochaeta lycopersici*)
Corynebacterium michiganense pv. *michiganense*
Brazil 401
Japan 480, 482
resistance in *Lycopersicon pennellii* 483
Corn earworm 418 (see also *Heliothis* spp.)

CPA (see 4-chlorophenoxyacetic acid)
Crop improvement (see Genetic improvement)
Crop losses 309
Crop productivity 309
Cross protection, virus control 478
CSIRO (see Commonwealth Scientific and Industrial Research Organization)
Cucumber mosaic virus
  pepper
    Australia 249-250, 252
    AVRDC improvement program 94
    China 416, 418
    effect on pollen 154
    host range 254
    importance 88-89
    India 452
    Korea 496
    Malaysia 516
    resistant germplasm 462, 486
    seed 38
    symptoms 252
    Taiwan 425
    tropics 86
  tomato
    Australia 250, 252
    CARNA-5 5, 258
    China 416, 418
    hairy tomato studies 76-77
    host range 254
    Japan 480, 482
    Korea 500
    Malaysia 512
    necrotic symptoms 258
    satellite RNA 258
    symptoms 76, 252, 258
    Taiwan 428
    weed hosts 254
Cucurbita spp. 36
Curly top virus
  pepper, Brazil 403
  tomato
    Mexico 532
    sources of resistance 483
Curvularia spp. 38
Cutworm (see *Agrotis ipsilon*)
Cutworm, variegated (see *Peridroma saucia*)
Cyperus spp. 446

Dacus dorsalis 508, 512, 516
Damping off (see also *Phythium sp.*; *Phytophthora* spp.; *Rhizoctonia solani*)
  peppers
    importance 87, 89
    India 452
  tomato
    control 454, 554
    fungi associated with 454
    India 452
    losses 454
    Philippines 554
Datura rhabdovirus, Australia 250
Datura stramonium 254, 446
Diabrotica spp. 292
D. speciosa 403
Diaporthe capsici 38
D. phaseolorum 38
Digiyphus intermedius 279
Dihydrozeatin riboside 138-140, 143-144
DNA hybridization 260
DNA probe 260
Drechslera spp. 38
diHZR (see dihydrozeatin riboside)
Early blight (see *Alternaria solani*)
Egypt
  pepper
    production statistics 345
    shading effect 345-347
  vegetables
    production statistics 345
Eleusine indica 446
ELISA, detection of
  geminiviruses 263
  pepper viruses 89
  potato virus Y 252-253
Embryoculture 28, 32, 34
Endovum puttleri 285
Erwina carotovora, pepper
  Brazil 55
  China 416, 420
  importance 87
  Taiwan 89
Ethepon 150, 159-160
Ethiopia
  agroclimatic data 442, 443
  pepper
    consumption 442
    cropping systems 444
    cultivars 445-446
    cultural systems 444
    disease control 447
    diseases 446
    foreign trade 443, 445
    marketing 444
    oleoresin production 445
    processing 444
    production
      constraints 442
      cost 442
    research and development 447-448
    weeds 441
  tomato
    cultivation practices 449
    processing 449

production
constraints 449
cost 449
statistics 448-449
research and development 449-450
Ethiopian mottle virus 446
Ethylene
pepper
artificial rippening 528
effect on flower production 150
in bacterial spot infection 154
in stressed buds 159
role in bud abscission 156
precursor 156, 349, 355-356
tomato, artificial ripening 531
Ethylene inhibitors
amino oxyacetic acid (AOA) 270
control of *Botrytis cinerea* 268, 270
L-methionine 270
silver thiosulfate (STS) 270
EUCARPIA (see European Association for Research on Plant Breeding)
European Association for Research on Plant Breeding (EUCARPIA) 87

FAO (see Food and Agriculture Organization)
Fiji, AVRDC tomato releases 18-19
Film-forming polymers 268-269
Flea beetles 284-285
Folicote 269
Food and Agriculture Organization (FAO) 505-506
Founder effect 5
Fruit rot
China, tomato 418
resistant germplasm, tomato 24
Fruitborer (see also *Heliothis* spp.)
Malaysia 512
resistant germplasm 24
threshold level 278
trap crop 447
Fruitfly (see also *Dacus dorsalis*)
control 393
quarantine restrictions, Australia 390
Fruitworm (see Fruitborer; *Heliothis* spp.; *Heliothis armigera*; *Heliothis zea*)
Fulvia fulva
importance on tropical tomato 70
Japan 480, 482-483, 500
Korea 500
Nigeria 541
Philippines 551, 555
resistance 483, 551
resistant germplasm 17
Taiwan 70, 428, 433
Fungal antagonists 268-269
Fungi (see individual species or disease — *Alternaria alternata*; *A. capsici-annui*; *A. solani*; *Botryodiplodia palmarum*; *Botrytis cinerea*; black leafmold; *Candida tropicalis*; *Cercospora capsici*; *C. fuligena*; Cercospora leafspot; Choanephora blight; *Choanephora cucurbitarum*; *Cladosporium fulvum*; *C. solani*; *Colletotrichum* spp.; *C. acutatum*; *C. atramentarium*; *C. capsici*; *C. coccodes*; *C. dematium*; *C. gloeosporioides*; *C. graminicola*; *C. nigrum*; *C. piperatum*; *Curvularia* spp.; damping off; *Diaporthe capsici*; *D. phaseolorum*; *Drechslera* spp.; fruit rot; *Fulvia fulva*; *Fusarium* sp.; *F. equiseti*; *F. oxysporum*; *F. oxysporum* f. sp. *lycopersici*; *F. semitectum*; *F. solani*; *Geotrichum candidum*; *Gibberella fujikuroi*; *Gloeosporium piperatum*; *Helminthosporium* spp.; late blight; *Leveillula taurica*; *Macrophomina phaseolina*; *Myrothecium roridum*; *M. verrucaria*; *Nigrospora oryzae*; *Oidiopsis taurica*; *Phaeoramularia capsicicola*; *Phoma destructiva*; *Phytophthora* spp.; *P. capsici*; *P. infestans*; *P. parasitica*; *Pichia membranefaciens*; powdery mildew; *Pyrenochaeta lycopersici*; *Pythium* sp.; *P. ultimum*; *Rhizoctonia solani*; *Rhizopus stolonifer*; *Sclerotinia sclerotiorum*; *Sclerotium rolfsii*; *Septoria apiicola*; *S. lycopersici*; *Stemphylium* spp.; *S. solani*; *Verticillium* spp.; *V. albo-atrum*; *V. dahliae*)
Fungicides
Benlate (see Fungicides, benomyl)
benomyl
control of
Cercospora fuligena 513
Fusarium wilt 428
fungi, tomato, Nigeria 539
resistance to 199
benzimidazoles, control of *Botrytis cinerea* 270
Bravo (see Fungicides, chlorothalonil)
captafol
control of
Alternaria solani 356
late blight 449
Phytophthora capsici 304-305
Septoria spp. 449
on tomato, Nigeria 539
captan
control of damping off 454-554
effect on VA mycorrhizae 305
carbendazim, control of

Botrytis cinerea 269
Colletotrichum spp. 463
Ceresan, control of
bacterial leafspot 447
Colletotrichum spp. 463
chlorothalonil, control of
anthracnose 189, 191-195
fungal pathogens 201
Phytophthora capsici 304-305
Daconil, control of *Phytophthora infestans* 428
Denmert, control of powdery mildew 447
dicarboximides, control of *Botrytis cinerea* 270
diethofencarb (see Fungicides, NPC)
Difolatan (see Fungicides, captafol)
Dithane M45 (see Fungicides, mancozeb)
Dithane M47, control of *Phytophthora infestans* 457
dithiocarbamate fungicides 191
etridiazole, control of *Pythium* spp. 303-304
isopropyl N-(3,4 dioxyphenyl) carbamate, control of *Botrytis cinerea* 269
Kocide, control of *Alternaria solani* 428
Kumulan, control of powdery mildew 447
mancozeb, control of
Alternaria solani 456, 513
Colletotrichum spp. 463
fungi, Nigeria 539
Phytophthora parasitica 457
maneb, control of
anthracnose 189, 191-192, 194-195, 197
tomato leafmold 428
Manex 4F (see Fungicides, maneb)
metalaxyl, control of
Mycorrhiza 304, 306
stem blight 447
Mycorrhiza, effect on 303, 305
NPC (see Fungicides, isopropyl N-(3,4 dioxyphenyl) carbamate)
propamocarb HCl,
control of
Aphanomyces spp. 303
Phytophthora spp. 303
Pseudoperonospora spp. 303
Pythium spp. 303
soil-borne pathogens 306
effect on mycorrhizal fungi 303, 305-306
integrated pest management 303-306
Ridomil, control of
Phytophthora infestans 428, 449
Septoria spp. 449
Terrazole, control of *Phytophthora capsici* 425
thiophanate-methyl, control of
Phythophthora capsici 304
powdery mildew 447
Thiram, control of damping off 454-455
Fungicide sticker 269
Fusarium spp.,
resistant germplasm 16, 23-24, 111
resistant tomato cultivars 18-20, 25
F. equiseti 38
F. oxysporum
pepper seed 38
seed treatment 39
tomato, Philippines 554
F. oxysporum f. sp. *lycopersici*
pepper, Liberia 505
tomato
Australia 386, 390
control 428, 456
India 542
Japan 480, 482
Korea 500, 504
Liberia 507
Nigeria 541
race 1 482, 483
race 2 391, 428, 541
race 3 386, 391
race J3 482-483, 489
resistance, genetics of 391
resistance sources 483
resistant cultivars 397, 427, 456
resistant germplasm 391
Taiwan 428
tomato-bean polyculture 296
yield loss 386, 391
F. semitectum 38
F. solani on pepper seed 38

GA3 (see Growth regulators, giberellic acid)
Gabon, AVRDC tomato releases 19
Galinsoga parviflora 446
Gametoclonal variation 44, 47
Geminivirus 253, 260, 265, 562
Genetic improvement
Capsicum spp.
Australia 386, 394
AVRDC 93-95
backcross method 52, 95
Brazil 55-62
bridging crosses 9
Capsicum chinense 55, 59
China 416, 420
early maturity 94
Ethiopia 447

heat tolerance 94, 159
high dry matter 51
high pungency 51-52
high temperature fruit set 466
high yield 94, 466, 516
horticultural traits 52
India 461-466
Japan 486-487
Korea 490, 494, 496, 502
Liberia 506
Malaysia 515-520
Mexico 529-532
New Mexico, USA 51-54
Nigeria 544-545
pedigree method 52, 95
Philippines 557, 558
processing qualities 52
recombinants 9
resistance to
Cercospora spp. 463
chili veinal mottle virus 516
Colletotrichum spp. 463, 465, 496
cucumber mosaic virus 463, 496, 558
diseases, multiple 51, 94, 256, 496, 558
Fulvia fulva 558
insects 463, 465
leafcurl virus 463, 465
Meloidogyne incognita 558
mites 405, 463
Oidiopsis taurica 463
Phytophthora capsici 403, 496
potato virus Y 256, 394, 403
Pseudomonas solanacearum 496, 558
tobacco mosaic virus 463, 465, 496, 558
viruses 516
viruses, multiple 517
Xanthomonas campestris pv. *vesicatoria* 226, 228, 403, 496
Taiwan 430
Thailand 569, 574
USA 51-54
Lycopersicon esculentum
Argentina 107-112
Australia 390
AVRDC 15, 70-71, 80, 157
backcross method 70-71
bacterial canker 401
bacterial spot 184-188, 200-228
bacterial wilt
Australia 390
Brazil 405
China 416
Ethiopia 447
India 99-106
Indonesia 473
Malaysia 512
Martinique 63-69
Philippines 552, 555
Reunion 229-234
Taiwan 428, 430, 438
Thailand 574
biotechnology 44-50
Brazil 113-122, 401, 405
China 416
combined traits 15
disease resistance 70, 99-106, 200-228, 419, 432
drought tolerance 83, 458, 552
firm fruit 63, 81
flavor 79
flood tolerance 552
fruit cracking 81, 230, 416, 553
fruit quality 79-80, 124, 458
fruit size 70, 79
fruitset 157, 555 (see also *Lycopersicon esculentum*, fruitset)
Fusarium wilt
Australia 390-391
Brazil 401
heat tolerance 16, 18-20, 63, 66, 71, 83, 85, 430, 432, 438
Heliothis sp. 459
India 25, 99-106, 458
insects 240
isogenic lines 79
Japan 483
Korea 184-188
late blight 459, 574
leaf mold 555
lycopene content 416
Martinique 63-69
mechanical harvest 430
nematodes 459
Nigeria 542, 545, 547
off-season production 435
Philippines 552
processing tomato 107-112
Pyrenochaeta lycopersici 483
resistance to
cucumber mosaic virus 416, 483
potato virus Y 249, 256
tobacco mosaic virus 47, 70, 430, 483
tomato spotted wilt virus 401
Reunion 229-234
rootknot nematode
Argentina 107-112
Brazil 401
Indonesia 99-106
Taiwan 430
salt tolerance 173
Scrobipalpula absoluta 113-122

Septoria leafspot 416, 555
shelf life, improved 124
soluble solids 416
soluble solids, high 47, 63
somaclonal variation 47
storage 123-135
storage quality 475
strategies, AVRDC 80
Thailand 572, 574
tissue culture 44-50
transportation 24
tropical adaptation 71
tropics 70-71, 79, 81
tropics, lowland humid 63, 70, 81
uniform maturity 432
USA 200-228
Verticillium wilt 401
yield 16, 23-24, 435
Genetic resources
Capsicum spp.
characterization 5, 10, 15, 38
collection
AVRDC 10, 12-14, 18
CATIE 37
France 37
German Democratic Republic 37
global base 3, 10, 12-14
Italy 28, 36
Mediterranean 37
Mexico 37, 521, 533
Netherlands 37
Thailand 568
United Kingdom 37
USA 37, 51
USSR 37
conservation 14, 28, 533
descriptor list 5, 15
distribution 10, 17
documentation 10, 17
duplication 14
evaluation
agronomic characters 15
AVRDC 10, 15, 20
bacterial wilt resistance 15
climate, unfavorable 36
Italy 28
Mexico 532
nematode resistance 15
pest and disease resistance 5, 36
tobacco mosaic virus resistance 15
virus resistance 6
exploitation 2
genetic impurity 86, 91
maintenance 28-39, 465
management 37
multiplication 10, 15, 28-39
variability 37
wild species 36
Lycopersicon spp.
characterization
AVRDC 10, 15
India 22, 23
collection
AVRDC 7, 10-12, 14-16, 18, 20
base collection 10-11
India 22-27, 465
Mexico 533
conservation
AVRDC 10-12, 14-15
domesticated species 12
landraces 533-534
Mexico 533
wild species 11-12, 14, 23, 533
descriptors 10, 15-16
distribution, AVRDC 10, 17-18
documentation
AVRDC 10, 17
India 22-23
evaluation
agronomic characters 16
AVRDC 10, 15-16
cold tolerance 16
disease resistance 16, 533
environmental stress 533
flood tolerance 16-17
fresh market qualities 16
heat tolerance 15-16
high yield 16
India 22, 465
Mexico 533
information management system 10
multiplication, AVRDC 10, 14-15
passport information 12
resistance to
fruit worm 17
Fulvia fulva 16
Fusarium wilt 16
gray leaf spot 17
late blight 16
powdery mildew 17
Pseudomonas solanacearum 15-16
rootknot nematodes 15-17
tobacco mosaic virus 15-17
utilization, India 24-25
Gene transfer, interspecific 3, 6
Geotrichum candidum on tomato, Nigeria 541
Ghost spot (see *Botrytis cinerea*)
Gibberella fujikuroi 38
Gloeosporium piperatum 191 (see also *Colletotrichum gloeosporioides*)
Gray leaf spot (see *Stemphylium solani*)
Gray mold (see *Botrytis cinerea*)
Green peach aphid (see *Myzus persicae*)
Greenhouse whitefly (see *Trialeurodes*

vaporariorum)
Growth regulators
abscission, role in 150-165
abscission of reproductive structures 150-165
abscisic acid
bud abscission, role in 156
fruit set, effect on 139, 141-142
pollen germination, effect on 146
translocation 146, 180
auxin in embryoculture medium 34
auxins, synthetic
CHPA 359-363
Cloxyfonac 175
Tomatolane 175
Tomatotone 175, 181, 498
auxin-type bioregulators 34, 150, 174-181
blossom end rot, effect on 361-362
4-chloro-2 hydroxymethylphenoxyacetic acid 349, 355, 358-363
4-chlorophenoxyacetic acid 133, 144, 147, 175, 181
cytokinin 34, 138
dihydrozeatin riboside 138, 140, 143-144
embryo culture medium 34
extraction 139
flower retention, role in 156
gibberellic acid 140, 147, 139, 143-144
imbalance 6
indole-3-acetic acid 139, 141, 146
inhibitors 139-142, 155
NAA 155-156
parthenocarpic fruit induction 147, 181
peppers
abscission, reproductive structures, prevention 150-165
flower retention 156
Indonesia 478
off-season production 174-181
pollen germination, effect on 146
purification 140
quantification 139
tissue culture medium 45
tomato
application 140, 175, 180, 355-357, 359
blossom end rot, effect on 361-362
fruit set, control of 138-139, 178-179
fruit set, effect on
4-chloro-2 hydroxymethylphenoxy-acetic acid 349, 355, 358-363
4-chlorophenoxyacetic acid 133, 144, 147, 175, 181
cytokinin 138
dihydrozeatinriboside 138, 143-144
giberellic acid 139, 141-143
indole-3-acetic acid 139, 141
N-6 benzyladenine 48, 138
zeatin riboside 138
in Japan 174-177, 180, 359
in Korea 498
parthenocarpic fruit induction 147, 175, 181
quality, effect on 178, 181
tolerance 175, 177, 181
translocation 180
in Taiwan 174-175, 178-180
yield, effect on 175-177, 180, 349, 355, 358-359
zeatin riboside 138, 140
Guam, AVRDC tomato release 19
Guizotia scabra 446

Heliothis spp. (see *also* Fruitborer)
control 278, 457
damage 291, 297, 299
India 452
Indonesia 475
integrated pest management 277
Malaysia 508, 516, 520
Nicaragua 289-302
Nigeria 535
Philippines 554
population dynamics 295
yield loss 457
H. armigera
pepper
Ethiopia 447
role in fruit abscission 164
Taiwan 90
yield loss 447
tomato
antibiosis 78
Cambodia 409
Ethiopia 449
importance 70, 409
Nigeria 541
pheromone traps 285-286
resistance screening, AVRDC 78
resistant germplasm 17, 79
trap crops 447
H. assulta 496
H. virescens 290
H. zea
control 428
life cycle 290
Mexico 532
Nicaragua 290
Taiwan 428
USA 284

Helminthosporium spp. 38
Herbicides
crop injury 352
tomato
alachlor 352-353
diphenamid 539
EL-5219 352
Metribuzin 339, 352-353, 357, 388
oryzalin 352
oxyfluorfen 352-353
Paraquat 388
Pebulate 388
pendimethalin 352
trifluralin 352
Heterosis 25
High performance liquid chromatography 53, 139, 503
Honeydew
correlation, tomato yellow leafcurl virus 242, 244
excretion, whiteflies 242
Hong Kong
pepper import 393
tomato import 554
Hormones (see Growth regulators)
Hot pepper (see also *Capsicum frutescens*; *C. annuum*)
as food 444
Ethiopia 442-448
flavor 92
fruit characters, importance 92
genetic improvement, AVRDC 93-94
pungency level 92-93
seed sources 91
shape, importance 92
size, importance 92
HPLC (see High performance liquid chromatography)
Hungary, tomato paste export 506
Hybrid sorting 44
Hydroponic culture
production cost 364
temperature 363
tomato, effect on
fruit quality 361-362
fruitset 360-361
yield 358

IAA (see Growth regulators, indole-3-acetic acid)
IBPGR (see International Board for Plant Genetic Resources)
IDRC (see International Development Research Centre of Canada)
IFS (see International Foundation for Science)
IIF (see Indirect immunofluorescence)
India
All India Coordinated Vegetable Improvement Project 468-470
climatic data 366, 452
pepper
capsaicin screening 462
cultivars 452, 461, 464, 466
cultural practices 459-460, 466
disease-resistant lines 463
diseases 452, 463
export 460, 514, 520, 566
irrigation management 365-374
marketing 463
nitrogen management 365-374
pests 462-463
processing 463
production statistics 459-460
research and development 463, 465-466
seed production 452, 466
utilization 463
tomato
breeding 23, 25, 99
cultivars 452, 455-456
cultivation practices 453
diseases 452, 454, 456-457
genetic resources 22-27
germplasm
evaluation 23-24
utilization 24
growing areas 25
growing periods 452
marketing 454
processing 454
production statistics 452
resistance breeding
bacterial wilt 99-106
rootknot nematodes 99-106
seed production 452
selections 25
yield, average 22
Indirect immunofluorescence 210
Indonesia
dietary shortage
iron 472
vitamin A 472
pepper
cultivars 476
cultivation practices 476-477
intercropping 478
production
constraints 472, 477
cost 477
statistics 476
research and development 478
seed production 476
virus control 478
tomato
cultivation practices 474

foreign trade 474
marketing 473
production constraints 472, 475
production cost 474
seed supply 473
varieties 473
INRA (see Institut national de la recherche agronomique)
Insecticide residues (see Insecticides, residues)
Insecticides
abamectin, control of leafminers 279
aldrin 447
aphicides 254
Bacillus thuringiensis, control of
armyworms 278
cutworms 285
insects 283
loopers 278
carbaryl
control of
cutworm 285
fruitworm 539
insects 283
whiteflies 245
effect on spider mites 284
integrated pest management 283-285
chloropyrifos on pepper insect complex 463
cypermethrin, control of
African bollworm 447
Heliothis spp. 463
cyromazine, control of leafminers 279
DDT, control of whiteflies 245
deltamethrin, control of
African bollworm 447
Heliothis spp. 457
diazinon, control of aphids 554
dimethoate, control of whiteflies 457, 563
endosulfan
combination with *Bacillus thuringiensis* 279
control of
African bollworm 447
aphids 278
armyworms 278
stinkbugs 278
effect on leafminer parasites 279
endrin, *Heliothis* spp. resistance 290
esfenvalerate, control of leafminers 279
fenvalerate, control of
armyworms 278
fruitflies 513
Heliothis spp. 457, 513
loopers 278
stinkbugs 278
tomato fruitworms 278
tomato pinworms 278
formothion, control of
leafcurl virus 563
whiteflies 563
Furadan, control of leafcurl virus 463
Lannate, control of (see *also* insecticides, methomyl)
Diabrotica spp. 292
Heliothis zea 428
methamidophos
control of
aphids 254, 278
armyworms 278
insects 283
leafminers 278-279
lepidopterous insects 285
stinkbugs 278
integrated pest management 285
toxicity to beneficial parasites 285
methiocarb, reduction of tomato spotted wilt virus 513
methomyl (see *also* Insecticides, Lannate)
control of
aphids 278
armyworms 278
insects 283
leafminers 279
lepidopterous insects 285
loopers 278
effect on leafminers 284
integrated pest management 285
variegated cutworm 285
methyl parathion, *Heliothis* spp. resistance 290
mineral oil, control of
leafcurl virus 463, 563
whiteflies 457
Monitor, control of *Liriomyza sativae* 290
parathion
control of whiteflies 245
effect on *Myzus persicae* 284
permethrin
control of
armyworms 278
fruitworms 278
loopers 278
stinkbugs 278
temperature, effect on 278
phorate, control of whiteflies 457
phosphamidon, control of whiteflies 457, 563
pirimicarb, control of aphids 254
profenofos, reduction of tomato spotted wilt virus 513

prothiofos, reduction of tomato spotted wilt virus 513
pyrethroids
control of
aphids 257
fruitworms 539
leafcurl virus 563
leafminers 279
whiteflies 248, 563
temperature, effect on 286-287
quinalphos, control of *Heliothis* spp. 457
residues 269, 478
resistance to 290
Senprotathrin, control of whiteflies 265
Sevin (see Insecticides, carbaryl)
Smash (see Insecticides, Senprotathrin)
Thiodan, control of aphids 554
tomato, recommended for 278
Vetox (see Insecticides, carbaryl)
Insects (see individual species or pest — *Aceria lycopersici*; *Agrotis ipsilon*; aphids; *Apis* sp.; *Bemisia tabaci*; *Bombus* sp.; corn earworm; *Dacus dorsalis*; *Diabrotica* spp.; *D. speciosa*; flea beetles; fruitborer; fruitfly; *Heliothis* spp.; *H. armigera*; *H. assulta*; *H. virescens*; *H. zea*; jassids; *Keiferia lycopersicella*; leafminers; *Leptinotarsa decemlineata*; *Liriomyza* spp.; *L. sativae*; *Lygus lineolaris*; *Macrosiphum euphorbiae*; *Manduca* spp.; *M. sexta*; *Myzus persicae*; *Peridroma saucia*; *Phthorimaea operculella*; *Scrobipalpula absoluta*; *Spodoptera* spp.; *S. exigua*; *S. latifascia*; *S. litura*; *S. sunia*; stinkbugs; termites; *Tetranychus urticae*; thrips; *Trialeurodes vaporariorum*; *Trichoplusia ni*; *Tripetidae*; whiteflies)
beneficial insects 280, 285
control
biological 275
chemical 278
damage 291
growth regulators 301-302
parasites 275, 277-279, 281, 285, 531
(see also Parasites [of insects])
predators 531
resistance screening 240-241
thresholds, tomato 278, 286
traps
light trap 285
pheromone traps 285-286
trap crops 297
Institut de recherches agronomiques tropicales et des cultures vivrières/Centre de coopération internationale en recherche agronomique pour le développment (IRAT/CIRAD)
tomato
bacterial wilt resistance program 230
bacterial wilt-resistant lines 65
breeding program 63
West Indies 63, 229-234
Institut national de la recherche agronomique (INRA)
pepper
anthracnose-resistant germplasm 96
germplasm collection 12, 37
pepper veinal mottle virus, resistant germplasm 96
tomato, bacterial wilt-resistant lines 65
Integrated pest management
control of
aphids 276, 278
armyworms 278, 531
fruitworm 531
greenhouse whitefly 265
leafminers 275, 531
lepidopterous larvae 275-282, 285-286
loopers 278
stinkbugs 276, 278
thrips 278
tomato pinworms 276, 278, 531
insect
action thresholds 277, 286
parasitism 285, 531
predators 531
reduction 289, 294-296
scouting for 277, 285-286
surveillance 286
toxicity 277
insecticide
application 286
recommendations 278, 285
insects, beneficial 280, 285
intercropping 290
pesticide residues 478
pheromone traps 285-286
polyculture 289-290, 292, 294-296
practical application 268-306
protective crops 517
recommendations 268-288
Indonesia 478
Malaysia 515
Mexico 531-532, 535
Nicaragua 289-299
USA 275-288
reflective mulches 517
weed management 277, 284
Intercrossing, *Capsicum* spp. 2
International Board for Plant Genetic Resources (IBPGR), pepper
collection 3, 12, 533, 568
crop situation summary 87
descriptor lists 5, 10

designated genebanks 14
taxonomy 7
International Development Research Centre of Canada (IDRC) 17
International Foundation for Science (IFS) 517
International Hot Pepper Trial Network (INTHOPENET) 86, 93-94, 405
International Society of Horticultural Science (ISHS) 87
Interspecific hybridization, *Capsicum* sp. 2
INTHOPENET (see International Hot Pepper Trial Network)
Intraspecific hybridization, *Capsicum* sp. 2
IRAT/CIRAD (see Institut de recherches agronomiques tropicales et des cultures vivrières/Centre de coopération internationale en recherche agronomique pour le développement)
ISHS (see International Society of Horticultural Science)
Isozyme analysis, tomato 12
Isozyme coding genes 5-6
Israel, tomato
gray mold disease 268-274
production constraints 239
tomato yellow leafcurl virus control 245, 248
whiteflies 239-247
viruses 239-247
ISTA seed germination method 30-31
Italy, pepper
germplasm collection 37
seed storage 34-35, 37

Japan
international collaboration 485-486
National Research Institute of Vegetables, Ornamental Plants and Tea 484
pepper
constraints 485
cropping systems 480
cultivation practices 485
diseases 485-486
production statistics 485
research and development 486
tomato
bioregulators, use of 174-181, 359
consumer requirements 489
consumption 482-483
cropping systems 481
diseases 480, 482
foreign trade 480
fruitset improvement 173, 349
Fusarium wilt races 482-483, 489
growing season 174
hydroponic culture 481, 485
processing tomato production 483
production statistics 480-481
protected culture 481
research and development 483-484
yield increase 174
yields 349
Tropical Agricultural Research Center (TARC) 486
Jassids 452

Keiferia lycopersicella
integrated pest management 266
Mexico 532, 535
threshold, tomato 277, 281
Kelman's medium 64
Korea
pepper
anthracnose 184-188
Colletotrichum dematium 184
C. gloeosporioides
strain G 184
strain R 184
consumption 490
foreign trade 495
'kimchi' 490
pest and disease control 492
pests and diseases 496
Phytophthora capsici 184
production
constraints 184, 490, 495-496
statistics 490-492
research and development 496, 500
shading effect 345
sick soil problem 493
varieties 494
tomato
commercial seed companies 502
consumption 490
cultivation practices 497-498
foreign trade 499
marketing 499
pest and disease control 498
pests and diseases 500
processing 499
production
constraints 499
statistics 490, 497-498
protected culture 497-498
research and development 500, 502
varieties 499

L-methionine 270
Lablab purpureus 562
Land equivalent ratio (LER) 289, 293-294
Late blight (see *Phytophthora infestans*)
Leaf blight (see *Choanephora cucurbitarum*)

Leafcurl virus (see also Tomato yellow leafcurl virus)
pepper
control 463
India 452
Nigeria 536, 545
resistant cultivars 461-462
tomato
control
chemical 457, 562-563
cultural management 562
disease escape 562
high-yielding cultivars 562
interplanting 562
detection 260-266
DNA hybridization 260
Ethiopia 446
India 452
Indonesia 75
losses 75, 457, 562
Nigeria 536
Philippines 75
relationship with tomato yellow leafcurl virus 78
resistance screening 78
resistant germplasm 23
Sudan 561
symptoms 562
Taiwan 75, 78
Thailand 75, 566
virus particle, associated with 562
Leafminers (see also *Liriomyza sativae*; *Scrobipalpula absoluta*)
breeding for resistance 113-122
effect of methomyl 284
pepper, Brazil 403
tomato, Brazil 396
Leafmold (see *Fulvia fulva*)
Leptinotarsa decemlineata
integrated pest management 283
USA 283-284
Leveillula taurica (see also Powdery mildew)
pepper
cause of defoliation 154
control 447
Ethiopia 444, 447
importance 87
Taiwan 89
tomato
importance 70
Mexico 532
Liberia
agroclimatic data 504
pepper
farming systems 504
local hot cultivars 505
pests and diseases 504
production constraints 505
production statistics 505
research and development 505-506
tomato
production
constraints 507
statistics 506
research and development 507
Liriomyza spp.
control
biological 275
chemical 278
damage 276
defoliation, caused by 275
integrated pest management 275-277
Malaysia 520
parasites of 275, 277-279, 281
threshold, tomato 278
L. sativae
control 290
damage 290, 293
insecticide resistance 290
integrated pest management 289-290
Mexico 532
Nicaragua 289
population dynamics 295-296
tomato-bean polyculture 289, 296-297
USA 284
Lupinus albus 171
Luteovirus 252
Lycopersicon spp.
fruitset, high temperature 72, 174
genetic diversity 12
glandular trichomes 113
interspecific gene transfer 7
interspecific hybridization 44
isozyme analysis
landraces 529
nomenclature 21
off types 15
parthenocarpy 17
resistance to
insects 113-114
nematodes 7
Scrobipalpula absoluta 114
virus transmission 239-248
seed extraction 15
soluble proteins 12
wild types 11-12, 14, 23, 113, 245, 533
L. cheesmanii
AVRDC 10-12
India 23
salt tolerance 167, 173
L. esculentum
alcobaca variety 125, 135
anther cone splitting 73
artificial ripening 528
consumption
Japan 482

Korea 490
Liberia 506
Malaysia 511
Nigeria 539
Philippines 554
cropping systems
Australia 386
Brazil 400
Cambodia 407-408
China 416-417
Ethiopia 449
Indonesia 474
Japan 174, 481
Korea 497, 498
Malaysia 511
Nigeria 538
Philippines 551
Taiwan 174, 423, 426-427
Thailand 573
cultivars
Australia 389
Brazil 397, 398
China 419
India 452, 455
Indonesia 473
Korea 499
Malaysia 510
Mexico 528, 531
Nigeria 539-540
Philippines 551-555
Sudan 562
Taiwan 427
Thailand 572
cultivation practices
bed preparation 349
continuous cropping problem 500
crop losses, associated with 309-310
crop rotation 456
fertilization (see *L. esculeutum*, fertilization)
forcing culture 481, 496
framing 439
high bed 435
high pot 439
hormone application 139-149, 174-175, 180, 358, 362 (see *also* Growth regulators)
hydroponic culture 481, 485 (see *also* Hydroponic culture)
India 452-453
intercropping 511
interplanting 562
irrigation (see *L. esculentum*, irrigation)
Japan 481
Korea 498
Malaysia 511
Mexico 527
mixed cropping 538
mulching (see *also* Mulching)
black plastic 349, 354, 357
rice straw 354
silver covered plastic 357
Nigeria 538-539
Philippines 551
polyculture 289-302
protective tunnels 317-318
pruning (see *also* Pruning) 15, 527
rainshelter 317-318, 339
seedling raising 350
soilless culture (see Hydroponic culture)
spacing 349-350
staking 15
Sudan 562-563
Taiwan 438
transplanting 349
USA 309
water fertility management 323-338
water management (see Irrigation)
fasciated tomato 535
fertilization
application 331
efficiency 324
irrigation 323-338
nitrogen
deficiency 376, 383
demand 332, 375-376
effect on maximum yield 377-380
excess 375, 382-383
loss 376
management 375, 377, 380-381
firmness 436
firmness genes 134
flavor 128
foreign trade
Brazil 401
Indonesia 474
Japan 480, 482
Korea 499
Malaysia 508, 511-512
Mexico 524, 528-529
Nigeria 539-540
Philippines 554
Taiwan 429-430, 435
Thailand 572
fruitset (see *also* Growth regulators, fruitset, tomato; Genetic improvement, *Lycopersicon esculentum*, fruitset)
affected by hormones 138-149
affected by temperature 138
cool temperature 174
hairy type, effect on cucumber mosaic virus 76-77
heat tolerance, genetic basis 71, 73

heterosis 25
hollow cavity 181
irrigation
basic concepts 314, 329
California 315
drip
distribution uniformity 330
efficiency 324, 329-330
elimination of leaching 324
fertilizer injection 331
frequency 312, 314, 323, 339, 354
high frequency 323, 325, 328, 334-335
high frequency subsurface 323-328, 334-335
low frequency surface 323, 325, 328, 335
low pressure drip 349, 355-356
plugging problems 337
subsurface 309, 312, 318, 320, 323, 334
surface 312, 323
volume 314
effect on yield 312, 315, 323, 333, 339
evapotranspiration 310-311, 314, 316, 320, 325-328, 335
furrow 324, 349, 355-356, 551
problems 309
scheduling 314-316, 330, 354
sprinkler 325, 328
systems 312, 324, 340
trickle 325, 388, 391
water balance 311
water fertility management 323, 335
water management, tropics 317-320, 339
water requirement 310-311, 313, 337
water stress 320, 326
water use efficiency 310, 312, 314, 323, 330, 333-334, 341, 354
isogenic lines 70
lowland lines 509-510
marketing
Australia 389
Brazil 399
India 454, 457
Indonesia 473-475
Korea 499
Malaysia 511
Mexico 529
Nigeria 539
Philippines 553
maturity stages 124
mutants, ripening 123, 135
off-season production 432
parthenocarpy 17, 41, 131, 141, 147, 481
postharvest diseases 541
processing tomato (see Processing tomato)
production constraints
Australia 249, 390
Brazil 401
Cambodia 407, 409
China 416, 418
Ethiopia 449
Guadeloupe 239
India 452
Indonesia 472, 475
Japan 480, 482
Korea 499-500
Liberia 504, 507
Malaysia 508, 512
Mexico 532
Nigeria 540-541
Philippines 554
Sudan 561, 565
Taiwan 428, 435
Thailand 573
production cost
Brazil 401
Ethiopia 442
Indonesia 474
Japan 482
Taiwan 432, 435, 438
Thailand 573, 575
production statistics
Australia 386-387
Brazil 396
China 416-417
Ethiopia 448
India 452
Indonesia 472-473
Japan 480-481
Korea 490, 497-498
Malaysia 509
Mexico 524-525
Nigeria 537
Philippines 549-550
Sudan 561
Taiwan 425, 428, 435
Thailand 571
profitability 381
regeneration, *in vitro* 44
research and development
Australia 390-391
Brazil 402
Ethiopia 449
India 457-458
Indonesia 475
Japan 483
Korea 500
Mexico 533
Nigeria 542

Philippines 555
Taiwan 430
Thailand 572, 574
ripening aberrancy 125
ripening behavior 123
ripening inhibition 124-125, 133
ripening mutants 123, 125, 135
Roma type 229
salt tolerance
mechanism 167
screening for 166, 172-173
seed extraction 15
seed maintenance 15
seed production
India 452
Indonesia 474
Korea 502
Malaysia 511
Philippines 551, 555
Taiwan 428
Thailand 571
seed storage 14
seed supply
Brazil 401
India 452
Indonesia 473
Nigeria 539
Philippines 551
Thailand 572
shelf life
definition 126
improvement 123-127
sodium
recirculation 167-168, 170
translocation 167
uptake 167-170
storage
effect on quality 128, 132
environment 131-134
extension 126-127, 130
style elongation 157
substitutes 522
tissue culture 44-45
transgenic plants 77
transplanting shock 349
utilization
Brazil 401
China 416
Malaysia 508
Philippines 533, 554
Taiwan 425
Thailand 571-572
weed interference 349
weeds (see Weeds, tomato)
yield
factors affecting 349, 352-353
improvement
AVRDC 16, 70, 435
fertilizer 349, 355
genetic improvement 16, 23-24, 435
growth regulators 349, 355, 358-360, 362-363
hydroponic culture 358
mulching 349, 475
pruning 388-359, 361 (see also Pruning, tomato, effect on yield)
maximum 377-380
yields 293, 297, 309, 349
L. esculentum var. *cerasiforme*
AVRDC 12
India 23
Mexico 522, 529
L. glandulosum
India 23
resistance to *Pyrenochaeta lycopersici* 483
resistance to tomato mosaic virus 76
L. hirsutum
AVRDC 10, 12
India 23
resistance to
Pyrenochaeta lycopersici 483
potato virus Y 78, 249, 254-255, 391
tomato fruitworm 287
tomato mosaic virus 76
whiteflies 240-243
L. hirsutum f. *glabratum*, resistance to
Heliothis armigera 79
Manduca sexta 79
Scrobipalpula absoluta 113, 117-121
whiteflies 241-243
L. hirsutum f. *typicum*, resistance to
Scrobipalpula absoluta 113, 117-121
L. pennellii
AVRDC 10, 12
leaf tackiness 242-244
resistance to
Corynebacterium michiganense 483
Fusarium oxysporum 391, 483
Scrobipalpula absoluta 113-114, 117-121
tomato mosaic virus 76
whiteflies 240, 242-244
salt tolerance 167-171
sodium accumulation 169-171
sodium translocation 167
sodium uptake 167-170
L. peruvianum
AVRDC 10, 12
India 23
interspecific hybridization 44
resistance to
curly top virus 483
Fusarium wilt 483

leaf mold 483
nematodes 107, 483
Scrobipalpula absoluta 113
tomato mosaic virus 76
tomato spotted wilt virus 483
Verticillium wilt 483
L. peruvianum race *glandulosum*, AVRDC 10, 12
L. peruvianum var. *humifusum*, AVRDC 12
L. pimpinellifolium
AVRDC 10, 12
Mexico 522, 529
resistance to *Fusarium oxysporum* 391, 483
L. pissisi, collection, India 23
Lygus lineolaris 154
Lysimeter 325-327, 330, 335

Macrophomina phaseolina 38
Macrosiphum euphorbiae
pepper, Brazil 403
vector of tomato yellow top virus 252
Malaysia 520
Malaysia
agroclimatic data 508-509
international collaboration 508
MARDI (see Malaysian Agriculture Research and Development Institute)
pepper
cropping systems 514
cultivars 515
cultural practices 515
diseases 516
foreign trade 393, 471, 515, 520
production constraints 515-516
production cost 514
production statistics 513-514
seed supply 514
tomato
AVRDC releases 19
consumption 511
cultivars 510
cultivation practice 511
disease control 513
foreign trade 511-512
hydroponic culture 358-364
marketing 511
production
constraints 512
statistics 509
research and development 512
seed production 511
yield 349
vegetable consumption 511
Malaysian Agriculture Research and Development Institute (MARDI)
international cooperation 486
pepper
bacterial wilt-resistant lines 96
germplasm collection 12
improvement 519-520
tomato improvement 519-520
Manduca spp. 289
M. sexta, resistant germplasm 79
MARDI (see Malaysian Agriculture Research and Development Institute)
Martinique
oxisols 64
tomato
bacterial wilt, evaluation for resistance 68
breeding 63
Mauritius
AVRDC tomato release 19
tomato selections 231
Meloidogyne spp.
pepper
Korea 496
Nigeria 536
tomato
Brazil 401
control 325, 338-340
effect of irrigation 339-341, 343
Ethiopia 442, 449
India 452, 457
Nigeria 541
Philippines 554
resistant germplasm 15-17, 23, 99, 435, 455-457
Taiwan 433
yield reduction 435
M. arenaria, India 457
M. incognita
pepper
Liberia 505
resistance
breeding 51-52
screening 52
tomato
control 482
India 99
Japan 480, 482
Liberia 507
Mi gene 107
multiple resistant lines, AVRDC 82
resistance
breeding 78 99-105
genes 78
genetics of 71, 101, 107
marker genes 78
screening 78
screening methods 78, 100, 108
resistant cultivars 25, 99, 108-110, 343, 427-428

resistant germplasm, AVRDC 78, 81, 99-100
Sudan 563
Taiwan 428
M. javanica
control
chemical 563
rotation 563
India 457
resistant cultivars 563
Sudan 561-563
methyl bromide 340-341, 343
Mexico
growers association 533
international collaboration 533
pepper
center of diversity 3
consumption 514, 522, 530
cultivars 529
cultivation practices 527
foreign trade 524, 527, 530
germplasm
collection 533
evaluation 533
wild germplasm 533
marketing 520, 530-531
production
areas 522-523
constraints 531-532
statistics 525-526
research and development 535
'salsa' 522
seed production 534
types 523, 525-527, 529-530
wild types 521-522
research institutions 531
tomato
consumption 522
cultivars 528
cultivation practices 527
foreign trade 524
marketing 520, 530
processing tomato 528
production areas 522, 527
production constraints 531-532
'salsa' 522
wild types 522
MINISIS 11
Mites
pepper
Brazil 403
control 425
India 452, 462
Korea 496
Polyphagotarsonemus latus 403, 405
Taiwan 425
tomato
Aculops lycopersici, Brazil 401
spider mites 283
Tetranychus truncatus, Philippines 403, 405
tomato erinose mite 442
Momordica spp. 36
Mulching (see also *Capsicum* annuum, cultivation practices)
control of tomato leafcurl virus 562
effect on yield 354, 357, 475
plastic 349, 354, 357, 386, 391, 417, 439, 494
rice straw 354, 551
Multivariate analysis 5
Mutaclones 47
Mutants
Capsicum spp.
carotene 123
fruit ripening 123-135
nonlethal 35
nonpungent 2
somatic 46
tissue culture 45
yellow fruited 47
tomato, closed anther 25
Mutation breeding 25, 46
Mycorrhiza, effect of fungicides on 303, 305
Myrothecium roridum 38
M. verrucaria 38
Myzus persicae
Australia 253
Brazil 403
Nigeria 541
USA 283-284
vector of tomato yellow top virus 252

National Bureau of Plant Genetic Resources (NBPGR) 22, 25
National Plant Genetic Resources Laboratory (NPGRL)
AVRDC pepper germplasm collection, duplication 14
pepper germplasm collection 12
National Research Institute of Vegetables, Ornamental Plants and Tea (NIVOT)
biotechnology 484
international collaboration 484
pepper improvement 486-488
tomato improvement 483, 487-488
NBPGR (see National Bureau of Plant Genetic Resources)
NBT (see Nitroblue tetrazolium)
Near infrared reflectance (NIR) 95-96
Nematodes
Meloidogyne spp.
pepper
Korea 496

Nigeria 536
tomato
Brazil 401
control 325, 338-340
effect of irrigation 339-341, 343
Ethiopia 442, 449
India 452, 457
Nigeria 541
Philippines 554
resistant germplasm 15-17, 23, 99, 435, 455-457
Taiwan 433
yield reduction 435
M. arenaria 457
M. incognita
pepper
importance in tropics 87
Liberia 505
resistance
breeding 51-52
screening 52
tomato
control 482
India 99
Japan 480, 482
Liberia 507
Mi gene 107
multiple resistant lines, AVRDC 82
resistance
breeding 78, 99-105
genes 78
genetics of 71, 101, 107
marker genes 78
screening 78
screening methods 78, 100, 108
resistant cultivars 25, 99, 108-110, 343, 427-428
resistant germplasm, AVRDC 78, 81, 99-100
Sudan 563
Taiwan 428
M javanica
India 457
resistant cultivars 563
Sudan 561-563
rootknot nematodes (see *Meloidogyne* spp., *M. arenaria*, *M. incognita*, *M. javanica*)
Xiphinema ifacolum
pepper, Liberia 505
tomato, Liberia 507
New Zealand
pepper, import 393
tomato, import 389
Nicandra physalodes 254, 446
Nicaragua, tomato
cultural practices 291
integrated pest management 289-302
pest control 290
pests 289-291, 293
polyculture 292
Nicotiana benthamiana 78
Nigeria
climatic data 536, 538, 543
pepper
local selections 544
marketing 544-545
processing 539, 544-545
production
constraints 536, 544
statistics 536, 543
research and development 545
seed supply 544
tomato
cultivars 540
foreign trade 539-540
marketing 540
pests and diseases 541
postharvest losses 541
processing 540
processing companies 538-539
production
constraints 536, 540
statistics 536-537
research and development 542
seed supply 540
Nigrospora oryzae 38
Ninhydrin 242
NIR (see Near infrared reflectance)
Nitrate quick test, tomato 375-382
Nitroblue tetrazolium 262
NIVOT (see National Research Institute of Vegetables, Ornamental Plants and Tea)
NPGRL (see National Plant Genetic Resources Laboratory)
Nucleic acid hybridization 260-261, 263, 265

Oidiopsis taurica 463
Oleoresin
assay 54
export, Ethiopia 445
production, Ethiopia 445
Opius dissitus 279
Orobanche spp., tomato, Ethiopia 442
Osmopriming 28, 35
Osmoregulating substances 32
Oxisols 64

Pakistan, tomato import 554
Panama, AVRDC tomato releases 19
Papua New Guinea, tomato imports 389
Parasites [of insects]
Chrysonotomya punctiventris 279
Diglyphus intermedius 279
endoparasites 277

Endovum puttleri 285
exoparasites 277
hymenopterous parasites 275
leafminers 275, 277, 281
Opius dissitus 279
Parthenocarpy, tomato 17, 41, 138, 147
PCARRD (see Philippine Council for Agriculture, Forestry and Natural Resources Research and Development)
Pepper (see *Capsicum* spp.; *C. annuum*)
Pepper fruitrot (see *Colletotrichum capsici*)
Pepper mild mottle virus 88
Pepper mottle virus
importance 88
resistance
breeding 51, 52
screening 52
Pepper veinal mottle virus
importance 88
Nigeria 536, 545
resistance sources 96
Pepper wilt (see *Phytophthora capsici*)
Peridroma saucia
head capsule 286
integrated pest management 283-286
size determination 286
Phaeoramularia capsicicola 38
Phaseolus vulgaris 33, 153
Pheromone traps 285
Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) 555
Philippines
climatic data 549-550
pepper
consumption 557
cultivars 557-558
foreign trade 557
processing 557
production
constraints 557-558
statistics 556
research and development 558
seed supply 557
tomato
AVRDC releases 19
commercial seed companies 551-552, 555
cropping systems 551
cultivars 551-555
cultural practices 551
fasciated tomato 535
foreign trade 554
marketing 553
native cultivars 551
processing
industry 549
tomato 552-553
production
constraints 554
statistics 549-550
research and development 555
utilization 554
yield 349
Phoma destructiva 38
Phosphoglucomutase-2 29
Phthorimaea operculella 449
Physalis ixocarpa, tomato substitute 522
Physiological disorders
pepper
blossom end rot 89-90
chlorosis 495
fruit abortion 90 151-165
nutrient deficiency 516
sunscald 86, 89, 91, 164, 405, 420
sunscorch 545
virus-like syndrome 6
wilting 495
yolo spot, Australia 393
protected culture 485
tomato
blossom end rot
effect of hormones 361-362
India 457
Philippines 554
resistant lines 397
varietal susceptibility 362
blotchy ripening 554
cat face 457
cracking 499, 554, 565
gray wall 527
puffiness 554
sunscald 200, 457, 499, 541
Phytophthora blight (see *Phytophthora capsici*)
Phytophthora spp.
control 447
damping off, tomato 554
pepper stem blight, Ethiopia 446
P. capsici
Brazil 396, 403
control 303-305, 425, 528
importance 86-87, 89
Japan 485
Korea 496
mass screening method 95
Mexico 528, 532
on seed 38
resistance
breeding 51-52, 403
screening 52
sources of 96, 184, 520-521, 533
resistant cultivars 403
Taiwan 87, 425
yield losses 528
P. infestans

pepper, Liberia 505
tomato
Brazil 396, 401
China 416
control 277, 428, 449, 457
Ethiopia 442, 449
importance 70
India 452, 457
Korea 500
Liberia 507
Mexico 532
Nicaragua 293-294
Nigeria 541
resistant germplasm 16
Reunion 231-233
Taiwan 428, 433
Thailand 573
tomato-bean polyculture 292
yield losses 457
P. parasitica
India 452, 457
losses 457
Reunion 231
Pichia membranefaciens 38
Pinworm (see *Keiferia lycopersicella*)
Piquin pepper (see *Capsicum annuum*, types)
Pisum sativum 33
Portugal, pepper 157
Portulaca oleracea 351
Potato leafroll virus, strain 252
Potato tuber moth (see *Phthorimaea operculella*)
Potato tuber worm (see *Phthorimaea operculella*)
Potato virus X 416, 419
Potato virus Y
pepper
Australia 249-250, 393
AVRDC improvement program 94
China 416, 419
control 249, 254, 256, 393
Ethiopia 446
importance 88-39
India 452
Liberia 505
resistance breeding 394, 403
resistant germplasm 96, 255-256, 402-403, 462
strains 89, 249, 251, 255, 258, 402
symptoms 251
Taiwan 425
tropics 86
yield loss 250, 251
tomato
Australia 249-250, 254, 256, 386, 391
Brazil 401
control 254
genetics of resistance 405
Malaysia 512
natural hosts 254
necrotic symptoms 77
pathotypes 77
resistance breeding 249
resistance screening 77, 405
resistant germplasm 17, 78, 249, 254, 386, 391, 397, 401, 405
strains 249, 251
symptoms 77, 250
Taiwan 75, 77
yield loss 77, 250, 386
Powdery mildew (see also *Leveillula taurica*)
tomato, resistant germplasm 17
tomato, Sudan 562
Processing tomato
Argentina 105-112
AVRDC 281-288
Brazil 369-402
breeding 111
Burkina Faso 63
characteristics 111
China 417-418
Congo 63
Ethiopia 449
evaluation 67
importance 308-310
India 24, 26, 454-458
Japan 480, 482-484
Korea 497-500
Liberia 506-507
Malaysia 511-512
Martinique 63-69
Mexico 521, 524, 528-529
Nigeria 539-540, 542
Philippines 549, 551-555
production cost 298
Taiwan 423-430, 433-438
Thailand 566, 571-574
USA 281-288, 323-338
water balance 311
yields 309
Protoplast
culture 44
fusion 9
Pruning, tomato
cultivation practices 15, 527
effect on fruit quality 80, 348
effect on yield 358-363
in hydroponic culture 358-359
Pseudomonas solanacearum
culture medium 64
pepper
AVRDC improvement program 94

Ethiopia 446
importance 87, 89
Indonesia 472
Korea 496, 500
Malaysia 516
Philippines 557
resistance screening 94
resistance sources 96
seed 38
tomato
aggressiveness 236
Australia 390
AVRDC improvement program 70, 74-75
biovar III 100, 552
Brazil 401
China 416-417
control
crop rotation 236, 456
grafting on resistant rootstock 482, 509
soil amendments 237
suppressive soils 236-238
Guadeloupe 235-238
India 452, 456
Indonesia 475
Japan 480, 482
Liberia 507
Malaysia 508, 512
Nigeria 541
pathotypes 235
Philippines 551-552, 554
race 1 237
resistance
breeding 63, 82, 99-100, 104, 386
combined, nematode 99, 102-104
mechanism 74, 102
multiple resistant lines 82
polygenic 236
screening method 74, 100, 231
resistant cultivars 18-20, 68, 74, 390, 427, 432, 435, 510, 552, 554
resistant germplasm 15-16, 65, 74-75, 81, 99-100, 236
Reunion 229-234
Thailand 573
variability 66, 236
P. syringae pv. *tomato*, Brazil 401
P. tomato
pepper, Australia 386
tomato
Australia 386, 390
Mexico 532
USA 283-284
Pungency, pepper
bird pepper 566
breeding for 52, 496
genetic control 52
high pungency lines 96, 480, 494, 505, 517, 525, 527, 566
measurement 52-53, 95
preference for 86, 92-93
Pyrenochaeta lycopersici, resistant germplasm 483
Pythium sp.
pepper, control 303
tomato
control 292, 303, 428
Taiwan 428
P. ultimum, control 303

Raphanus spp. 36
RDA (see Rural Development Authority)
Regeneration, *in vitro* 44-47
Resistance screening 240-241
Resistance to virus vectors 240
Reunion
agroclimatic data 229
pepper cultivation 229
tomato
adaptability trials 230
AVRDC
lines 233
releases 19
bacterial wilt 229-234
late blight 232
lowland tomato 233
marketing problems 229
processing tomato 63
variety trials 230
Rhabdovirus 252
Rhizoctonia solani
on pepper seed 38
tomato
Brazil 401
Philippines 554
Rhizopus stolonifer on tomato, Nigeria 541
Rootknot nematodes (see *Meloidogyne* spp.; *M. arenaria*; *M. incognita*; *M. javanica*)
Root rot (see *Phytophthora capsici*)
Rural Development Authority (RDA) 12

'Salsa' 522
Salt tolerance, *Lycopersicon* 166-173
Sclerotinia sclerotiorum on pepper seed 38
Sclerotium rolfsii
pepper
importance 87
Malaysia 516
Taiwan 89-90
tomato
importance 70

losses 541
Malaysia 512, 516
Nigeria 541
Scrobipalpula absoluta
adult emergence 119
Brazil 113-122
damage 113, 117, 119-120
feeding habit 113
importance, Brazil 401
oviposition 116-118
resistance
assessment 117-118
breeding 113, 118
screening 115, 118-120
resistant germplasm 113-114
yield loss 113
Seed-borne bacteria, pepper 38
Seed-borne fungi, *Capsicum* spp. 38
Seed-borne viruses 15, 38
Senegal, AVRDC tomato releases 19
Septoria apiicola, pepper, Liberia 505
Septoria leafspot (see *Septoria lycopersici*; *Septoria apiicola*)
Septoria lycopersici
Brazil 401
China 416, 418
control 449
Ethiopia 442, 449
importance 70
India 452
Liberia 504
Nigeria 536, 541
resistance sources 542
Seychelles, AVRDC tomato releases 19
Shading, pepper
effect on
ethylene production 156
flowering 154
growth 54
yield 164
role in flower bud abscission 154
Silverthiosulfate 270
Singapore
pepper
export 474
import 393
tomato
AVRDC releases 19
import 389, 511, 554, 572
Sodium nitrophenolic compounds 478
Sodium-4-chloro-2-hydroxy-methyl-phenoxyacetate (see Tomatolane)
Soil
Bris 516
conducive 64, 235
ferralitic 235
fumigation 325, 337, 339, 340, 343
disease control
liming 237
mineral amendments 237
organic amendments 237
nematodes 318
influence on bacterial wilt of tomato 235, 237
matric potential 316, 319, 326, 365, 367, 372
oxisols 64
phosphorous adsorption 324
problems 493
smectic clay 237-238
sterilants 539
tin tailing 516
water content profile 327-329
Solanum spp. 83
S. americanum 254
S. lycopersicoides, cold tolerance 485
S. melongena 33, 36, 253, 509
S. tuberosum 252
Somaclonal variation 44, 46-47
Sorghum spp. 446
Southern blight (see *Sclerotium rolfsii*)
Spider mites, (see *Tetranychus urticae*)
Spodoptera spp.
damage 291, 297, 299
integrated pest management 289
Nicaragua 289-290
population dynamics 295
tomato-bean polyculture 289-290, 294-296
S. exigua
Mexico 532
weeds 281
S. latifascia 290
S. litura
pepper
Indonesia 477
Korea 496
tomato, Cambodia 409
S. sunia 289
Squash blot 260
Sri Lanka
AVRDC tomato releases 19
pepper import 480
Stellaria media 254
Stem blight (see *Phytophthora* spp.)
Stemphylium spp. 551-552
S. lycopersici, tomato, Korea 500
S. solani
importance, tomato 70
resistant cultivars 397
Stinkbugs 284
Sudan
agroclimatic data 561
tomato
cultivars 562
disease problems 561-565

irrigation 561
rootknot nematodes 562-563
tomato leaf curl virus, control 562-563
vegetable
export 561
production 561
Sunflower ringspot virus 250
Sweet pepper (see *Capsicum* spp.; *Capsicum annuum*)
Sweet potato whitefly (see *Bemisia tabaci*)

Taiwan, China
agroclimatic data 426
pepper
cultivars 424, 427
export 515
production
constraints 425
statistics 422-423
seed export 511
utilization 423
tomato
AVRDC releases 19
bioregulators, use of 174-181
cropping systems 427
fruitset improvement 174
growing seasons 174
marketing 429
off-season production 432
processing tomato 429-430, 432
processing tomato industry 344-347
production
constraints 428, 433
cost 432
statistics 422, 425-426, 432
seed
companies 428
export 511
hybrids 422, 428
production 422
utilization 428
yield increase 174
Tanzania, AVRDC releases 19
Telone 340
Termites
control 447
Ethiopia 446-447
India 452
Tetranychus urticae
pepper, Brazil 403
tomato, USA 284
Tetrazolium chloride medium 64
Tetrazolium test 30
TGC (see Tomato Genetics Cooperative)
Thailand
pepper
'bird' pepper 566-568
chili pepper 566-568
cropping systems 566
cultural practices 568
farm income 569-570
foreign trade 515-516, 566, 569
germplasm collection 568
production
constraints 570
cost 570
statistics 566
seed
export 514
supply 569
types 566
varieties 569
viruses, statistics 571
tomato
AVRDC
cooperation 572
releases 19
cultivars 572
farm income 572
foreign trade 572
processing
products 571-572
tomato 573
production
cost 573, 575
statistics 566, 571
research and development 574
seed export 511
yield 349
Thrips
pepper
India 452, 462, 463
Taiwan 90
tolerant cultivars 461
tomato
Brazil 401
chemical control 278
integrated pest management 276
threshold 278
Tissue culture, in crop improvement 44-50
TMV (see Tobacco mosaic virus)
Tobacco budworm (see *Heliothis assulta*)
Tobacco cutworm (see *Spodoptera litura*)
Tobacco etch virus
pepper
importance 88
Mexico 532
resistance breeding 51
resistance sources 521, 533
tomato, Mexico 532
Tobacco hornworm (see *Manduca sexta*)
Tobacco leafcurl virus, pepper 88
Tobacco mosaic virus
pepper

China 416, 418
control 486
Ethiopia 444
importance 88-89
India 452
Korea 496
Malaysia 516
production constraint 86
resistance sources 96
resistant germplasm 462, 486
Taiwan 425
Thailand 571
tomato
China 416
India 452
Japan 480, 482
Korea 500
multiple resistant lines, AVRDC 82
resistance sources 6, 483
resistant germplasm 15-17, 23
resistant somaclones 47
Tobacco rattle virus, Brazil 403
Tobacco ringspot virus 88
Tobacco streak virus, Australia 250, 252
Tobacco whitefly (see *Bemisia tabaci*)
Tomato (see *Lycopersicon esculentum*)
Tomato erinose mite (see *Aceria lycopersici*)
Tomato fruitspot (see *Xanthomonas campestris* pv. *vesicatoria*)
Tomato Genetics Cooperative (TGC) 12
Tomato leafcurl disease (see *also* Tomato yellow leafcurl virus; Leafcurl virus, pepper)
control 413-414
factors, affecting incidence 409-410
resistance screening 410-411
tolerance 412-413
yield reduction 412
Tomato leafminer (see *Scrobipalpula absoluta*)
Tomato leafspot (see *Xanthomonas campestris* pv. *vesicatoria*)
Tomato mosaic virus
pepper
Australia 252, 256
control 256-257, 259
Liberia 505
Taiwan 89
tomato
Australia 252, 256
control 256
Malaysia 512
Philippines 554
resistance
breeding, AVRDC 70, 432
genes for 76
genetics of 71
screening method 76
resistant germplasm 70, 76, 81-82, 483
soil, survival 76
strains 70, 76
Taiwan 75, 435
tropical tomato 70
weed hosts 256
Tomato pinworm (see *Keiferia lycopersicella*)
Tomato spotted wilt virus (see *also* Leafcurl virus, tomato)
pepper
Australia 250, 252
Malaysia 516
symptoms 252
tomato
Brazil 396, 401
Malaysia 512
Mexico 532
resistance screening 405
symptoms 252
Tomato yellow leafcurl virus (see *also* Leafcurl virus, tomato)
coat protein gene 261
control 245, 248, 260
detection 260-266
DNA probe 260-261, 263
epidemiology 264
geminivirus 562
honeydew, correlation with 239
hosts 260
hybridization studies 265
Israel 239-248, 260-266, 562
Near East 78
relationship, other leafcurl viruses 248, 265
seed 265
squash blot 260
Thailand 573
transmission 240-242
whitefly resistance 239-247
whitefly vector 239
Tomato yellow top virus
Australia 250, 252
host range 252
incidence 250, 252
strain of potato leafroll virus 252
symptoms 252
transmission 252
Tomato yellow vein virus
Australia 250, 252
host range 253
transmission 253
Tomatolane 175
Tomatotone 175, 181, 498
Total soluble solids, measurement 80
Transgenic plants 44, 77

Trap crops 297
Traps, insects
light trap 285
pheromone traps 285-286
Trialeurodes vaporariorum (see *also* Whiteflies)
damage 242-243
honeydew excretion 239
oviposition 243
resistance screening methods 241
tomato, USA 284
viruses, transmitted by 240, 248
Trichomes, glandular 113
Trichoplusia ni, integrated pest management 283
Trifolium alexandrinum 171
Trinidad and Tobago, AVRDC tomato releases 20
Tripetidae 28
Trisodium phosphate
control of bacterial leafspot 447
seed treatment 15, 256-257, 259
Triticum aestivum 21
Tropical peppers, importance 87
TSS (see Total soluble solids)
TSWV (see tomato-spotted wilt virus)
2-3-5-TTC 28
Tunisia, tomato 310
Two spotted spider mite (see *Tetranychus urticae*)
United States Department of Agriculture (USDA)
pepper
germplasm collection 12
Phytophtora rot-resistant germplasm 96
tomato
collection 12
Septoria lycopersici-resistant germplasm 542
USA
pepper
anthracnose 189-199
export 474
imports 48, 525-526
tomato
AVRDC releases 20
foliage diseases 283
greenhouse production, Hawaii 317
integrated pest management 268, 275, 288
processing
areas 324
California 323
consumption 283
foreign trade 506
irrigation 324
production cost 283, 288, 438
yields 309, 324
USDA (see United States Department of Agriculture)

Vapam 325, 337
Vapor Gard 269
Variegated cutworm (see *Peridroma saucia*)
Vector resistance 239-247
Vegetable leafminer (see *Liriomyza* spp.)
Verticillium spp., tomato, resistant cultivars 26, 111, 456
V. albo-atrum
nomenclature 54
pepper
China 416, 419
seeds 38
tomato, Brazil 401
V. dahliae
control 482
pepper
nomenclature 54
resistance breeding 51-52
screening 52
tomato
Japan 482
resistance 483
Virus complex
pepper
Indonesia 477
Liberia 504
Malaysia 508, 516
Taiwan 87, 89
tomato, Liberia 504
Virus vectors, resistance to 240
Viruses (see individual virus — alfalfa mosaic virus; Australian tomato leafcurl virus; Capsicum mosaic virus; chili veinal mottle virus; cucumber mosaic virus; curly top virus; Datura rhabdovirus; Ethiopian mottle virus; geminivirus; leafcurl virus; luteovirus; pepper mild mottle virus; pepper veinal mottle virus; potato leafroll virus; potato virus X; potato virus Y; rhabdovirus; sunflower ringspot virus; tobacco etch virus; tobacco leafcurl virus; tobacco mosaic virus; tobacco rattle virus; tobacco ringspot virus; tobacco streak virus; tomato leafcurl disease; tomato mosaic virus; tomato spotted wilt virus; tomato yellow leafcurl virus; tomato yellow top virus; tomato yellow vein virus)
pepper
China 416
Ethiopia 446
Indonesia 477

Japan 485-486
Mexico 531
Nigeria 545
Philippines 557
seed-borne viruses 38
Thailand 571
importance 88
resistance
breeding 51-52
screening 52
resistance to virus vectors 240
seed-borne viruses 15, 38
tomato
Australia 249-259
Cambodia 406, 409-413
China 416
India 457
Indonesia 475
Israel 239-248
Japan 482
Korea 500
Malaysia 508, 517
Mexico 531
Nigeria 541
Philippines 554
Sudan 561-562, 565
Taiwan 75-78
Thailand 573
tomato-bean polyculture 292, 294
yield reduction 531
virus complex
pepper
Indonesia 477
Liberia 504
Malaysia 508, 516
Taiwan 87, 89
tomato, Liberia 504
weed hosts 254
Vitamin A, shortage, Indonesia 472
Vitamin C, measurement 80

Wax, epicuticular 268
Weeds
as pest reservior 281
as virus reservior 254
integrated pest management 284
pepper
Ageratum conyzoides 446
Amaranthus hybridus 446
Argemone mexicana 446
Capsella bursa pastoris 254
Celosia trigyna 446
Commelina benghalensis 446
Cyperus spp. 446
Datura stramonium 254, 446
effect on yield 545
Eleusine indica 446
Galinsoga parviflora 446
Guizotia scabra 446
Nicandra physalodes 254, 446
Solanum americanum 254
Sorghum spp. 446
Stellaria media 254
tomato
Amaranthus viridis 351
Chenopodium ficifolium 351
control 319, 325, 352, 388, 539
Cynanchum acutum, natural host of tomato yellow leafcurl virus 260
Cyperus rotundus 291, 357
Eleusine indica 351
Portulaca oleracea 351
purple nutsedge (see *Cyperus rotundus*)
yield, effect on 351, 353, 539
West Indies
pepper, shading 345
tomato
bacterial wilt resistance breeding 239-243
bacterial wilt, environmental influences 235-238
breeding 63, 229-234
Guadeloupe 235-238
processing 63
Western Samoa, AVRDC tomato releases 20
White ants (see Termites)
Whiteflies (see also *Bemisia tabaci; Trialeurodes vaporariorum*)
as virus vectors 70, 90, 239-240, 541
Nigeria 536
resistance screening methods 242-244
tomato, importance 70
Wilt Pruf 269
Witheringia sp. 2

Xanthomonas campestris pv. *vesicatoria*
culture medium 209
pepper
additive gene action 224-225
aggressiveness 216
Australia 386, 393
AVRDC improvement 94
bacterial cell population 222-223, 226
Brazil 396, 402-403
China 416, 420
control 447
damage, in polyculture 292-293
defoliation, role in 154
disease
epidemic 217
progress, evaluation 214-218
severity 217, 221

Ethiopia 447
ethylene production 272
importance 86-87, 89
India 452, 463
inoculation method 214, 221
Korea 496
lesion diameter 215, 224-226
lesion number 215, 224
Mexico 532
mutants 213
races 214, 220-222, 394
resistance
breeding 226, 228, 394, 403
hypersensitivity 220, 222
inheritance 220-222
measurement 213-218, 220
quantitative 213-214, 222-223
screening 213-215, 217, 221
sources of 58, 213
resistant lines 214, 220, 394, 403
seed 38
seed dressing 447
strains 216
Taiwan 89
yield loss 393
Tomato
Australia 386, 390
Brazil 401
confusion with bacterial speck 206
control 200, 428
disease
development 208
pressure 202-203
severity 204, 208
disease development 208
Ethiopia 446
foliar infection 200-201, 203-204
fruit infection 200-201, 203-204
importance 200
Korea 500
lesion
development 208
diameter 211
number 200, 213
size 200, 213
Malaysia 512
Mexico 532
Nigeria 541
races 207, 213
resistance
foliar infection 200
genetic control 200
inheritance 200, 207, 213
inheritance of field resistance 200, 202-203, 208
selection for 200, 207
resistance screening
conditions 206, 208, 210
field 201-204
growth chamber 210
hypersensitive response 208-209
inoculum preparation 209-210
methods 210
preconditioning 202, 204-205
quantification of bacteria 208-210
seedling 201-202, 209-210
resistant cultivars 200, 202-203, 208
strains 212
Taiwan 428, 433
tomato-bean polyculture 292, 294-295
variability 212
yield loss 200
Xiphinema ifacolum
pepper, Liberia 505
tomato, Liberia 507

Yield (see *Capsicum annuum*, yield; *Lycopersicum esculentum*, yield)

Zaire, AVRDC tomato releases 20
ZR (see Growth regulators, zeatin riboside)