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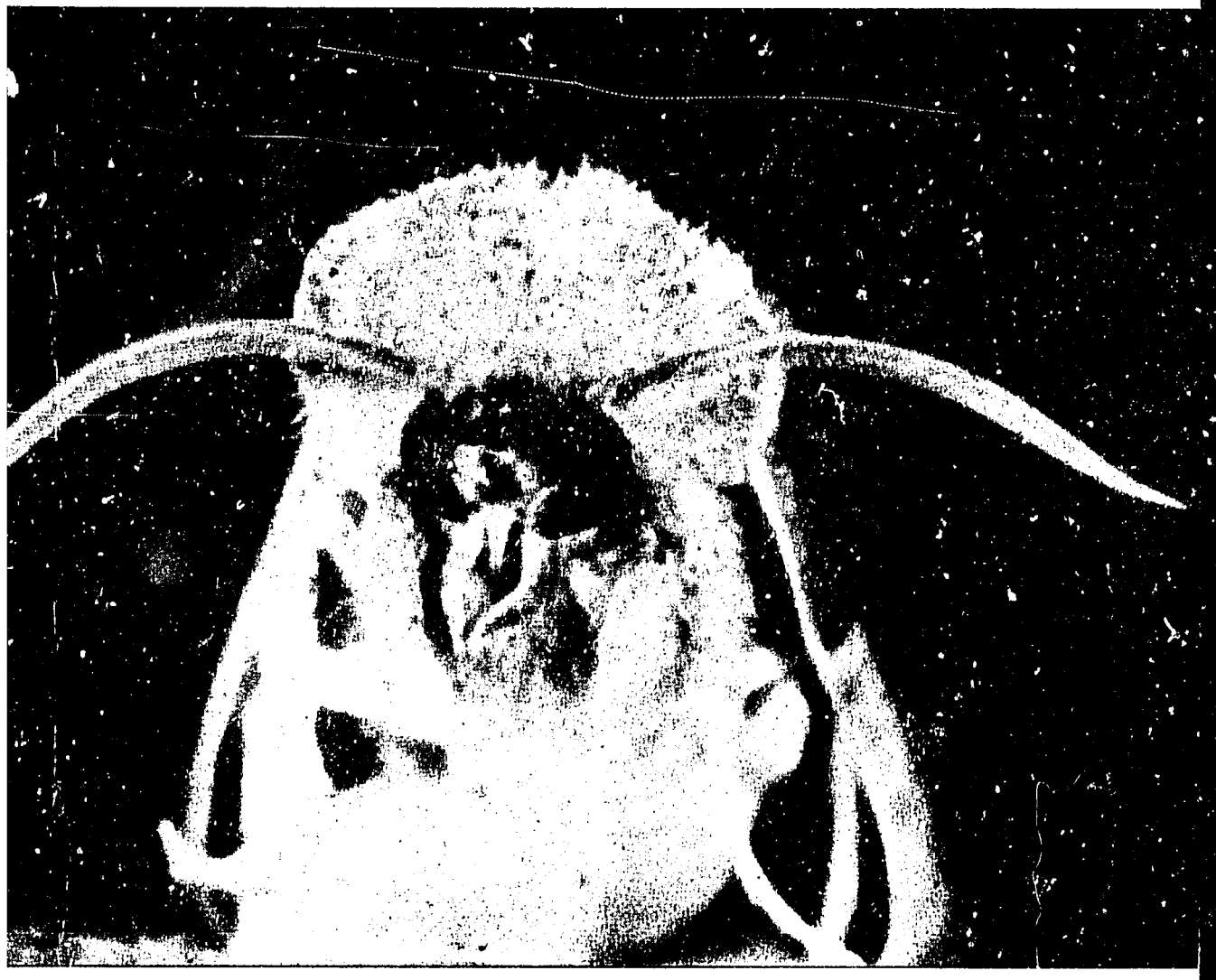
# Integrated Pest Management



INTERNATIONAL POTATO CENTER (CIP)

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Left to right: S. Voerman, L. Valencia, F. Cisneros, P. Jatala, F. Bennett, I. Zenner de Polanía, F. Maxwell, K.V. Raman, O. Page, W. Tingey, E. Radcliffe, B. Parker, P. Accatino, D. Hall, P. Gregory. Missing from photograph: T. Odhiambo.

# R E P O R T

OF

THE

# XXII PLANNING CONFERENCE

ON

# INTEGRATED PEST MANAGEMENT

June 4-8, 1984

Lima-Peru

# F O R E W O R D

This is the twenty-seventh Planning Conference sponsored by the International Potato Center to develop guidelines for the Center's research program. In the twenty-six previous Planning Conferences 263 participants from 40 countries have contributed by presenting papers, discussing research strategy and formulating recommendations for future CIP research.

The purpose of the Conference is to identify those priority components of Integrated Pest Management for which CIP has a comparative advantage to research. Through complementary information generated elsewhere and through CIP's own research, technology is being developed to solve major insect problems that limit potato production in developing countries.

O. T. Page

June, 1984

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# RECOMMENDATIONS

## I. Acknowledgments

On behalf of those participating in the 27th CIP Planning Conference: Integrated Pest Management, the panel wishes to thank CIP Administration for providing the support and opportunity for this conference. We recognize the considerable effort in planning and organization for an endeavor of this magnitude and wish to express our appreciation to all of those involved.

We also wish to commend Dr. K.V. Raman, CIP entomologist and his co-workers for the excellent progress they have made researching the major pests of potatoes.

## II. Introduction

A. I.P.M. Concept: Integrated potato pest management involves a total systems approach to the suppression of pest populations to a level where high quality yields can be obtained which provide the farmer with a maximum economic return. The strategies used require input from varied disciplines and normally make use of locally available technology. The individual components of the system must be compatible and the pest population controls implemented should take into consideration the total environmental impact. It should be recognized that it is impractical and impossible to reduce pest population levels to zero and therefore, attitudes need to be modified to accept a certain level of damage to our crops. In addition, host pest populations need to be preserved at relatively low levels to support the natural enemy complex. Economic threshold levels, which signal control actions, are determined on the basis of a defined pest population level which maximizes the difference between the cost of control and gross income. No control measures are normally implemented until this level is reached. Then a multiple tactics approach is used realizing that agricultural chemical control is one of the last defence mechanisms applied.

B. Minimum Core Disciplines for CIP IPM: Taking into account the IPM concept, a basic team of scientists working closely together is needed in order to put together the technology for an IPM program. Given CIP's current limitation on personnel and resources the following minimum team of scientists is recommended:

1. Entomologists
2. Plant Breeders (at least one)
3. Plant Pathologists (one virologist)
4. Agronomist (production)
5. Socio-Economist
6. Nematologist

C. Administrative Support:

1) Funding: It is recognized that funding through traditional disciplinary routes may be necessary to a degree, but if interdisciplinary research is to be encouraged and stimulated resources must be reserved for team funding of IPM objectives that go beyond disciplinary boundaries. CIP Administration is encouraged to continue mechanisms for doing this within the context of present resources.

2) Facilities: Current basic facilities seem to be adequate. The principle envisioned need will be for an isolated test area of several hectares dedicated to experiments evaluating individual or various combinations of IPM suppression tactics or strategies that could also be used as demonstrations.

Envisioned also is the need for rustic, farmer type storage facilities for testing and demonstration of storage IPM tactics currently known or under development.

3) Reward and Recognition: CIP Administration is encouraged to stimulate interdisciplinary research necessary for IPM through rewarding and properly recognizing those scientists who meaningfully become involve and contribute significantly to the furtherance of IPM research and demonstrations.

## III. Recommendations

A. Context in which Recommendations are Given: The purpose or charge to the conference was to identify those priority components of IPM for which CIP has a comparative advantage. This charge was undertaken keeping in mind the resource and facility constraints that would allow only minimal growth in the years ahead. The committee did consider that the future scope of research at CIP might change with the addition of another major crop, sweet potatoes. If this occurs a major opportunity may occur to obtain additional resources for IPM

research that might be relevant to both crops. To be avoided would be further dilution of an already deficient group in the plant protection area.

B. IPM Component Research:

1) Host Resistance to Arthropod Pests: The panel believes that pest resistance should serve as the foundation upon which a philosophy of integrated insect pest management should be based. Consistent with CIP's focus on the potato, its unique location at the center of origin for this crop plant, and the availability of genetic resources, the panel recommends that research focused on identification and development of host resistance against major arthropod pests be accorded a high priority. Efforts to identify resistance in wild and cultivated solanum germplasm should be continued and efforts to incorporate resistance into breeding populations adapted to major potato production regions should be expanded. Special emphasis in this regard should be accorded to pests of international importance such as potato tubermoth and aphids. Germplasm also should be evaluated in as many diverse environments as possible, not only to determine the availability of resistance to major pests, but also levels of resistance against minor pests and those of localized significance. Germplasm bearing glandular trichomes should be accorded high priority for adaptation.

2) Pheromones: The mass trapping, mating disruption and monitoring of potato tuber moths using synthetic pheromones is recognized as a potentially valuable tool for the suppression of this pest. Research on the efficacy of this method should be continued. Efforts to identify and synthesize the aggregation pheromone of the Andean potato weevil and the other species of PTM should be made. Once this is accomplished CIP should transfer this information to the regions where this pest is important and help in the development of its use.

3) Biological Control: A data bank of the natural enemies of the major pests of potato should be made in cooperation with National Programs. This inventory should be limited to the immediate area of the origin of the potato. Of importance is that natural enemy identifications be made from pest populations at both epidemic and endemic levels. Research on the potential use of control agents, such as Bacillus thuringiensis, Paecilomyces, Metharizium should continue.

4) Chemical Control: It is recognized that CIP should not be involved in making recommendations on insecticide use or in the extensive testing of insecticide efficacy. However, the use, storage, and disposal of agricultural chemicals at all CIP facilities, fields, and storage areas should serve as a model to facilitate the training of others. The use of pesticides is a valuable and important tool in potato IPM and every effort should be made to enhance its utility. CIP personnel using pesticides should adhere to the basic philosophies of sound utilization which include the selective use of materials to minimize resistance development of pests and conserve the natural enemy complex. The main emphasis of insecticide component research should contribute to potato storage IPM and on a longer term basis to field crop protection.

5) Other Promising Methods: We encourage the continued exploration of alternative, novel methods of pest control. Of particular interest are the use of sticky traps for leafminer control and pulverized Lantana, Muña and Eucalyptus for suppression of PTM in field and potato stores. The identification of active ingredients is encouraged. Cultural practices should continue to be investigated and promoted where appropriate.

C. Validation and Demonstration of IPM Strategies:

1) I.P.M. of Aphids, PTM and Mealybugs in Potato Stores: We recommend a continued emphasis be placed on integrating the following components in the management of pests of potatoes in storage:

a. Sanitation procedures.
b. Use of pheromones of PTM.
c. Pulverized Lantana, Muña, and Eucalyptus dusting of tubers.
d. Utilization of various barriers.
e. Use of pathogens such as *Bacillus thuringiensis*.
f. Insecticides.

We believe that CIP has a comparative advantage to conducting this research considering much of the component research is available and a mechanism for the transfer of this Technology is in place.

2) IPM of Field Populations of PTM: The economic feasibility of managing PTM populations by integrating the use of pheromones and chemical control with insecticides should be evaluated under field conditions.

3) Evaluation of Adapted Insect Resistant Germplasm: Adapted resistant germplasm demonstrated to be of value in suppression of potato tuber moth, aphids, and other pests of worldwide importance should be increased and tested under conditions representative of actual production areas. Particular attention should be paid to demonstration/evaluation trials of this germplasm for performance against the complex of pest species, and the cumulative benefit of resistance in reducing losses in yield and quality. These demonstration trials should be structured so as to incorporate as many other promising control tactics as possible for example, the integration of resistant germplasm and insecticides, may well provide visible and dramatic evidence that both tactics together result in greater levels of control and greater economic advantage, than the use of either tactic alone.

   Resistant germplasm proven useful in these trials should be integrated into breeding programs for improved adaptation, further testing, and distribution to National Programs for evaluation, refinement, and consideration for use in insect pest management programs.

4) Integration of Other Control Tactics: CIP scientists should continue to integrate other control components into pest management strategies for demonstration/evaluation, as the potential usefulness of new tactics becomes apparent. These demonstrations should address insect management problems in both field production and storage. Trials focused on integration of several or more management tactics provide a valuable opportunity to evaluate possible interactions (complementary, neutral, or antagonistic) as well as the total or cumulative suppression effect on pest populations.

D. Role of CIP in Delivery and Implementation of Integrated Pest Management in National Programs:

1. CIP should encourage national research authorities to incorporate IPM personnel into potato programs.

2. CIP should continue to foster cooperation with National Scientists in the research and testing of promising IPM tactics as they are shown to have potential in local or National IPM Programs.

3. CIP should develop and provide training and educational material relevant to IPM tactics and to the safe use and disposal of Toxic Agricultural chemicals. CIP should be aware of and coordinate training and educational material concerning pesticide safety, storage and disposal with other agencies involved in this type of activity, i.e. USAID, USDA ITD, FAO, WHO and CICP.

4. Post-doctoral scientists should continue to be utilized in addressing research problems which cannot be handled by CIP permanent staff already fully committed to other responsibilities. The continued use of graduate students can provide excellent training as well as contribute to the solution of research problems which could not otherwise be addressed by CIP staff.

## IV. Suggestions for Future Planning Conferences

Several procedural changes, if adopted, may aid in providing for a more efficient exchange of information between participants and help the panel in formulating its recommendations. These are as follows:

1) Provide all participants with a written document several weeks prior to the planning conference. This document should include detailed information about each CIP scientist's program, especially a description and justification of research objectives progress to-date, and resource availability and needs relative to current and future research. Information describing CIP's mission, mandate, and organizational structure would also be useful.

2) Identify members of the panel prior to the conference so that these individuals have the opportunity to seek out any additional information that may be desirable about individual scientists and respective programs.

3) Encourage use of visual materials by participants in their oral presentations.

# Development of IPM Programmes for Different Environmental Conditions in Developing Countries

Thomas R. Odhiambo

It is instructive to note that of the 17 recommendations advanced by the Future Actions Committee of the International Conference on Chemistry and World Food Supplies held in Manila, Philippines, in December 1982, 6 of them dealt with the management of pests (insects, diseases, weeds, etc.)[1]. Moreover, these recommendations were considered under the rubrics of "longer-range research at the forward edge" (1), and "near-term R & D [i.e. research and development] related to soils, crops, pests and animal production systems" (5 recommendations). The recommendations dealt with assigning high priority to R & D programmes in genetic engineering in relation to improved stress resistance in plants; establishment of safety standards of pest-control agents in different environments, and the development of international agreements covering the registration, licensing, and patent procedures for pesticides and methods; undertaking multiple and interdisciplinary field studies in tropical countries to identify the factors limiting the current and optimum yield potentials; and the giving of some urgency to the development of new chemical and biological methods for the control of pests, especially under integrated pest management (IPM) strategies.

It is not usual, in a forum dealing with agricultural production, for pest management to play more than an incidental, after-thought role. But this departure was probably due to the circumstance that the Manila Conference was largely concerned with agricultural production problems of the tropical developing world, where it is recognized that losses due to pests could be as high as 35-50%, and where therefore, pest control has a necessary part to play in increased overall production, particularly as agriculture becomes more intensified[1].

At the subsistence level of farming, reliance has traditionally been given to natural selection to single out crop strains that resist pest attack[1,2]. Such traditional cultivars have shown great stability in performance, as they are in overall balance with their total physical and biological environment[2]. Thus, although in the tropics there is a great abundance of pests (or potential pests) of the cultivated plants, the latter and their pests have coevolved over thousands of years by the

elaboration of natural defensive chemicals by plants, and the genotypic response of pests to such secondary metabolic products - such that a measure of a balanced co-existence has been established[2,3].

## Crop Genetic Diversity and Centres of Origin

Destabilization of this co-existence has been brought about by the commercialization of agriculture beyond the needs of subsistence: through the intensification of cropping, the simplification and uniformalising of the genetic base of the cultivated crops, and the synchronization of the cropping pattern. Such procedures have given pests a competitive edge over the cultivated plants, especially among annual crops.

In this respect, it is instructive to observe that the principal production areas for the major agricultural crops are not in their centres of origin but rather outside these regions, which are usually temperate countries (Table 1). The factor responsible is largely that relating to technology: the fact that the causal agents for yield losses due to pests can be more easily controlled under temperate conditions; as well as the circumstance that whereas the temperate ecologies can sustain a cropping system with a more homogeneous genetic base, the tropical environment is such that greater genetic heterogeneity is demanded by the greater environmental stress existing therein [2,4].

Table 1. Yields of selected crops within and outside their centres of origin (modified from Kawano and Jennings[2] .

| Crop | Centre of Origin | Yield (t/ha) | |
|---|---|---|---|
| | | Within Centre of Origin | Outside Centre of Origin |
| Barley | West Asia | 1.33 | 2.05 |
| Cowpea | Africa | 0.20 | 0.70 |
| Maize | Central America | 1.22 | 3.02 |
| Potato | Andean Region | 8.20 | 14.41 |
| Rice | South Asia | 1.85 | 3.31 |
| Sorghum | North-East Africa | 0.70 | 1.33 |
| Soybean | China | 0.87 | 1.67 |

Recent pest management research, particularly in respect of plant pathogens, has shown that in order to minimise genetic vulnerability and avoid epidemic catastrophe, cropping systems encouraging heterogeneity

should be put into practice. Several examples can be given to illustrate the utility of this approach. First, genotypes interact favourably in mixed populations of multilines or varieties, and increased yields of the order of 3% as well as stability in performance conferred by disease resistance are often experienced[5]. Second, the procedures normally used by plant breeders to select resistant genes are frequently of the monogenic type, which has the potential of bringing to bear intense natural selection on the host-specific pathogen, thereby leading to the emergence of a new, more virulent form of the selfsame pathogen through a single-locus mutation. However, the consequence of releasing crop cultivars with a variety of resistance genes is the establishment of an unstable equilibrium to the host-specific pathogen: consequently, the respective single resistance genes that may otherwise be ineffective in monocultures may still maintain some usefulness in crop mixtures[6]. Third, evidence is gradually accumulating that intercropping often leads to decreased pest incidence[4,7]. These and other examples point to the fact that whatever modern agricultural production systems are developed for the tropical regions of the world, crop heterogeneity in terms of multilines, multi-varieties, or even intercropping and complex rotations, is a basic requirement in order to confer genetic stability and stable crop performance. Non-observance of this ecological principle has resulted in disease or insect epidemics: for instance, the cultivation of a single rice genotype (IR36) in an area covering 10 million hectares in Asia has resulted in an extensive epidemic of tungro virus; similarly, intensive cereal monocultural production has increased incidence of fungal diseases[8] and outbreaks of virulent biotypes of the rice brown planthopper[7]. Conversely, using production methologies approximating those of the original climax vegetation have shown that the humid tropics can approach the high productivity potentially possible under these conditions (Table 2). Thus, the humid tropics have the highest productivity in terms of annual net growth of biomass[9], and can approximate this level under agroforesty cropping systems, for instance. In those cases in which this high level of productivity cannot be attained, it is presumed that the production methods have not adopted the climax vegetation scenario[8,9].

## The Primary Importance of Pest Management in Tropical Agriculture

A major factor in pest management usually only superficially considered by insect scientists is the central role of the host-plant. Insect pest management technologies have, conventionally, been insect oriented; indeed, the advent of synthetic insecticides has excacerbated this orientation. The concentration is on the mortality and morbidity of the resident insects, rather than on the responses of the host-plant to the

attentions of the insects feeding on or ovipositing in the plant, and the time horizon required for such responses to have an effect on the overall productivity of the plant. What seems to be gradually becoming evident as a more effective approach to insect pest management, is to adopt a system approach to the interactive planthost-insect relationships, in which the plant provides the principal reference point. It is only on this understanding, and the need to stabilize the crop production system by assuring genetic diversity, that a viable integrated pest management system (IPM) can effectively be established.

Table 2. Distribution of biomass in various vegetation zones (in t/ha) (modified from Weischet[9]).

| | Temperate humid (beech forest) | Sub-tropical | Tropical rain forest | Dry savannah |
|---|---|---|---|---|
| Biomass of stand | 370 | 410 | 500+ | 26.8 |
| Production during year | 13 | 24.5 | 32.5 | 7.3 |
| Biomass dying during year | 9 | 21 | 25 | 7.2 |
| Net growth of biomass during year | 4 | 3.5 | 7.5 | 0.1 |

It is on this basis that Odhiambo[10] has suggested a very cautious programme of IPM for African tropical agriculture:

First, locale-specific agricultural production methods should be developed, which will assure Africa of a stable and continuous productivity under existing resource-poor farmer knowledge base - but rationalised and upgraded to yield predictable results in a more technologically ordered manner. Such stably-performing crop varieties would have a sufficient range of productive potential to respond with higher output when environmental and other constraints are significantly reduced.

Second, an IPM for crop pests should be developed to bring down the yield losses to sub-economic levels on a continuing basis, without making conventional pesticides the centre-piece of the IPM scheme.

Components for IPM would include host resistance to pests, cultural methods, use of biological agents (parasitoids, predators, and pathogens), genetic techniques for modifying pest populations, and the development of more timely forecasting and surveillance of pest outbreaks.

Third, extensive use should be made of the enormous germplasm existing for the major tropical crops, to develop, modify, or create new cultivars having a range of characteristics which would fit more efficiently into the new, upgraded cropping systems that will arise from the rationalised traditional farming systems (intercropping, agroforestry, etc.). Such developments will naturally lead to more intensive use of land, and to a more commercial type of farming, when IPM interventions are essential, but must be based on a full understanding of ecological and evolutionary principles.

It has often been considered that IPM is an expensive luxury for developing countries, and that it would be impractical in most cases to employ it, especially in tropical Africa. Some recent detailed investigations in the control of a variety of insect pests on irrigated cotton in the Sudan has clearly demonstrated the cost-effectiveness of IPM in a situation where insecticides had failed to meet a major insecticide-resistance emergency and where previously minor pests had become a serious threat to the whole cotton production system. Over the last two decades, the number of chemical sprays for cotton pest control in the Sudan have increased, up to 12 per cotton season, and has resulted in new problems arising: pest resistance to insecticides, the emergence of cotton whitefly, *Bemisia tabaci* as a major pest, and dwindling cotton yields[11]. The reduction of sprays to 3 a season, which encouraged the prevalence of insect parasites and predators (e.g. *Campylomma*), the introduction of some pathogens (viz. *Bacillus thuringiensis* and nuclear polyhedrosis virus), and the introduction of rotational changes and other cultural practices, has resulted in a transformation of the pest situation. Indeed, it was shown clearly in the last two years that the IPM strategy for cotton not only worked but was cheaper than conventional chemical control (Table 3).

This example encompasses most of the components which are usually considered to have the best potentials in any effective IPM repertoire for crop protection in the tropics (Table 4);

Table 3. Cost of integrated pest management (IPM) of cotton in Gezira (Sudan), 1982-83 (modified from Bindra and Abdelrahman)

| | Pest Control Strategy | |
|---|---|---|
| | Conventional | IPM |
| Yield (kantars/feddan) | 5.54 | 7.44 |
| Value of increased yield/feddan (Sudan pounds) | | 190.00 |
| Cost of pest control/feddan (Sudan pounds) | 73.60 | 82.15 |
| 'Profit'/feddan (Sudan pounds) | | 181.45 |

Table 4. Major components of integrated pest management

1. Varietal resistance
2. Chemical control
3. Cultural control
4. Manipulation of insect behaviour
5. Biological control

Varietal resistance, which is regarded as comprising the basis of any IPM system for the resource-poor farmer[12].

Chemical control, which has served agriculture well when used selectively and discriminatively as a "curative" intervention, but has often caused major problems when used as a continuing "preventative" measure. Chemical pesticides are usually expensive to subsistence farmers, although it has been argued that natural products may well prove a cheap and convenient source for the farmer as well providing a variety of products (Table 5).

Cultural control, comprising elements such as intercropping, rotation, timely planting to escape pest infestation, and avoidance of excessive use of nitrogen fertilizers.

Manipulation of insect behaviour, in relation to the host-plant, is a relatively new approach and embraces such possibilities as diverting insects to trap crops (of no economic value).

Biological control, by the use of the parasites and pathogens of the target pests to control the latter's population or the use of genetic mechanisms (lethal genes, sterility factors, etc.) to the same end.

Table 5. Type of pest-control action reported in various plant species (modified from Grainge et al.[13]).

| Type of pest-control activity | Number of plant species | % (out of 2481 active spp) |
|---|---|---|
| Insecticidal | 1,005 | 40.5 |
| Anti-feedant | 384 | 15.5 |
| Repellent | 279 | 11.2 |
| Nematocidal | 108 | 4.4 |
| Fungicidal | 94 | 3.8 |
| Acaricidal | 39 | 1.6 |
| Growth-inhibiting | 31 | 1.2 |
| Attractant | 27 | 1.1 |
| Herbicidal | 13 | 0.5 |
| Antibacterial | 11 | 0.4 |
| Molluscidal | 8 | 0.3 |
| Chemo-sterilant | 4 | 0.2 |
| Others ("poisonous", "anti-vermin", anti-rodent, fish poison, arrow poison, etc.) | 478 | 19.3 |
| | 2,481 | 100.0 |

The various tactics employed under the various headings above are too numerous to describe in this short article. But suffice it to state that whereas the first two approaches (varietal control and chemical control) suffer from the disability of short-term durability under normal circumstances, the other approaches suffer the disability that

they are complex systems requiring a great deal of basic ecological, physiological and agronomic information before a stable and durable system can emerge.

A brief observation is in order in respect of some of the newer experimental approaches that could add to the efficacy of the future IPM methodologies.

## Some Experimental Approaches to Components of IPM

*B. thuringiensis* has been available for commercial use against plant insect pests (as well as certain insect vectors of human diseases such as mosquitoes and *Simulium*) since the 1950's. It does this by the production of several toxins, which directly affect specific insect groups. An exciting new possibility has recently been opened up by the isolation of the gene responsible for protein toxin production in *B. thuringiensis* and cloning it in another bacterium, *Escherichia coli*[14]. This step could make it possible to transfer the toxin-producing gene into plants, and so enable us to test whether the latter can make the toxin *in situ* for direct insect control[15]. Such a procedure would be an improvement on simply using the toxin, and applying it, as a biological pesticide.

The old technique of tissue culture has recently inaugurated a new method of selecting for resistance against a variety of environmental factors (high or low temperature, high salinity, drought, herbicides, etc.) in an extremely rapid manner, accelerating the process several million times by providing the capacity to expose millions (or even billions) of single cells to these factors[16]. Thus, by employing this callus tissue culture procedure, and utilising selected cell cultures, plant breeders have been able to develop sugarcane cultivars resistant to *Helminthosporium saccahari*, *Sclerospora sacchari* and sugarcane mosaic virus, employing the ability of single cells being capable of regenerating into complete plants after selective screening of the single cells exposed to the factors under test[16]. Similarly, promising potato and tobacco plants resistant to *Phytophthora* have been selected within 2 years using this callus tissue culture method, in contrast to the 6 years the conventional $F_2$ selection methodology carried out in greenhouses and on the field would normally have taken[16].

The last observation to be given concerns the experimental use of viruses, particularly the highly insect-specific baculoviruses, for the control of lepidopterous insects, which contain a major group of crop pests in the tropics. Baculoviruses are restricted largely to the

Lepidoptera, Hymenoptera and Diptera; as they variously produce polyhedral and capsular inclusion bodies, they appear ideal biological pesticides; and their safety has been positively evaluated by the U.S. Environmental Protection Agency, a body which has established some of the most stringent standards of environmental impact assessment. The prospects for using baculoviruses for crop protection are therefore high[17]. Already, of the 300 baculoviruses known, 50 have been produced in amounts sufficient for field testing, and 6 of these are being produced by industry: nuclear polyhedrosis viruses of 5 noctuid moths (*Autographa californica*, *Heliothis zea*, *Prodenia litura*, *Spodoptera exigua*, and *Trichoplusia ni*) and 1 sawfly forest pest (*Neodiprion sertifer*)[17]. For regular use to be assured, three problems need to be solved. Firstly, better persistence in the field needs to be guaranteed, perhaps through chemical protection or by genetic selection, as the virus particles are quickly inactivated by sunlight, especially ultraviolet radiation. Secondly, immediacy of impact on virus application is lacking: insect damage to crops is not immediately prevented in the first generation, although protection against future insect generations is usually good. Thirdly, multiple application of the virus is usually needed, simply because a single application is not adequate to trigger off an epizootic, nor to provoke a self-sustaining infection above the critical level needed for effective insect control.

## Conclusion

The way to future crop protection in the tropics is clear: it must take the IPM way, because this makes ecological sense and it is cost-effective. But it will require a great deal of basic research.

## LITERATURE CITED


1. Bixler, G. and L.W. Shemilt. Chemistry and World Food Supplies (CHEMRAWN II): The New Frontiers - Perspectives and Recommendations. International Rice Research Institute, Manila (1982).

2. Kawano, K. and P.R. Jennings. Tropical crop breeding - Achievements and challenges, pp. 81-99. In Symposium on Potential Productivity of Field Crops under Different Environments. International Rice Research Institute, Manila (1983).

3. Feeny, P. Coevolution of plants and insects, pp. 167-185. In Natural Products for Innovative Pest Management (ed. by Whitehead, D.L. and Bowers, W.S.). Pergamon Press, Oxford (1983).

4. Odhiambo, T.R. International aspects of crop protection: The needs of tropical developing countries. Insect Sci. Application 5(2), 59-67 (1984).

5. Simmonds, N.W. Plant breeding: The state of the art, pp. 5-25. In Genetic Engineering of Plants: An Agricultural Perspective (ed. by Kosuge, T., Meredith, C.P. and Hollaender, A.). Plenum Press, New York (1983).

6. Day, P.R., J.A. Barrett and M.S. Wolfe. The evolution of host-parasite interaction, pp. 419-430. In Genetic Engineering of Plants: An Agricultural Perspective (ed. by Kosuge, T., Meredith, C.P. and Hollaender, A.). Plenum Press, New York (1983).

7. Odhiambo, T.R. Linking basic research to crop improvement programs for the less-developed countries: Biological control of insect, pp. 153-172. In Linking Research to Crop Production (ed. by Staples, R.C. and Kuhr, R.J.). Plenum Press, New York (1979).

8. Kotschi, J., J. Pfeiffer and E. Grosser. A model sustainable agriculture. Applied Geography and Development 22, 108-127 (1983).

9. Weischet, W. Die Okologische Benachteiligung der Tropen. Stuttgart (1980).

10. Odhiambo, T.R. Advancing agricultural production in Africa: The effects of pest and non-pest constraints on the production and utilization of crops. Proceedings of the Symposium Advancing Agricultural Production in Africa (12-18 February, 1984). Commonwealth Agricultural Bureaux, London (1984, in press).

11. Bindra, O.S. and A.A. Abdelrahman. Technical cooperation programme GCP/SUD/025/NET FAO/Sudan project for development and implementation of integrated pest control for cotton and rotational food crop in the Sudan. Field Document N°11 (Integrated Pest Control for Cotton in the Sudan), Gezira Research Station (October 1983).

12. Odhiambo, T.R. Biological constraints on food production and on the level of efficient use of chemical inputs. In Chemistry and World Food Supplies: The New Frontiers. International Rice Research Institute, Manila (1982).

13. Grainge, M., S. Ahmed, W.C. Mitchell and J.W. Hylin. Plant Species Reportedly Possessing Pest Control Properties - A Database. Resource Systems Institute, East-West Center, Honolulu (1984).

14. Schnepf, H.E. and H.R. Whiteley. Cloning and expression of the Bacillus thuringiensis crystal protein gene in Escherichia coli. Proc. Natl. Acad. Sci. 78, 2893-2897 (1981).

15. McConnell, D. Improved agricultural and food products through genetic engineering and biotechnology. UNIDO, Vienna (ID/WG.-382/2/Add.5), Mimeo (1982).

16. Nowak, J. and G.W. Lawson. Plant hormones: The outlook for their application. The Outlook on Agriculture 12(4), 179-184 (1983).

17. Benz, G. Use of viruses for insect suppression, pp. 259-272. In Biological Control in Crop Production (ed. by Papavizas, G.C., 1983).

# The Need for Integrated Pest Management in Developing Countries

Fausto H. Cisneros

## I Introduction

One major constraint to increase productivity of agriculture is the loss of yields due to pests. An estimated 35 percent of all major food crops (32 percent for potatoes) are lost in the field to pest and disease organisms (Table 1). The most severe losses occur in developing countries of the tropics and subtropics, where pests are considered second only to drought as the farmer's greatest problem (Agriculture Production-1979). At present, 50-90% of the economy of most tropical countries remain dependent of agriculture.

The increasing pressure felt by developing countries to expand local food production forces them to adopt technologies of plant protection, such as intensive chemical control, which have been developed under very different conditions and for which they may not be prepared. Biological and ecological phenomena are magnified and more complex under tropical conditions; the number of pest and disease organisms for a given crop is larger than in temperate regions (Table 2) and growth of vegetation and pests is continuous. In addition, there are important differences in the overall level of training and literacy of field workers.

In the temperate regions, chemical control of pests are credited with 20-25 percent of the great increase in agriculture productivity during the last quarter-century. About 90 percent of the world's pesticide production (Tables 3 & 4) is used in this region. However, developed countries have already encountered very serious undesired side-effects of the use of pesticides, such as the induced pest resistance to pesticides, emergence of secondary pests, reduced population of beneficial insects, and human and environmental health problems. In addition, pesticides, which are based on petroleum are becoming increasingly expensive.

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Table 1

Losses from pests and potential benefits from control

| Crops | Percent of Loss | 20% of Current Loss Presented (Million tons) |
|---|---|---|
| Rice | 46 | 56 |
| Wheat | 24 | 23 |
| Corn | 35 | 31 |
| Potatoes | 32 | 30 |
| Sweet potatoes | 26 | 9 |

Source : Farm Chemicals, 1981.

Table 2

Number of crop diseases in temperate and tropical regions

| Crop | Temperate | Tropics |
|---|---|---|
| Rice | 54 | 500-600 |
| Corn | 85 | 125 |
| Beans | 52 | 250-280 |

Source: Farm Chemicals, 1981.

Table 3

World pesticide market (millions of U.S.1980 dollars)

| Pesticide | 1980 | 1982 | 1985* |
|---|---|---|---|
| Herbicides | 4,891 | 5,307 | 6,022 |
| Insecticides | 3,916 | 4,228 | 4,764 |
| Fungicides | 2,199 | 2,417 | 2,772 |
| Others | 559 | 654 | 758 |

* Projected
Source: Farm chemicals. International Edition.

Table 4

Potatoes and vegetables pesticide market 1980 (millions of U.S. 1980 dollars).

| Pesticides | US. | Western Europe | Japan & Far East | Rest of World | Total |
|---|---|---|---|---|---|
| Herbicide | 60 | 87 | 20 | 36 | 203 |
| Insecticides | 107 | 77 | 116 | 128 | 428 |
| Fungicides | 38 | 119 | 78 | 104 | 339 |

Source: Farm Chemicals, 1981.

A relatively new alternative approach to plant protection is IPM which offers the hope of reducing crop losses to economic tolerable levels reducing side-effects of heavy use

of pesticides and cutting costs of production. Unfortunately, pressures for survival in developing countries are such that commonly the short-term benefits derived from the increase use of pesticides are given priority over the longer term alternative methods of plant protection. This criterion is commonly shared by governmental officials as well as by some agricultural scientists not well aware of the general limitations of unilateral chemical protection and the additional problems of its adoption in developing countries.

## II Limitations of the Chemical Crop Protection

In the last thirty years organic chemical pesticides have been the dominant weapon against pests supplanting simpler poisons, human labor and farming practices, particularly in developed countries. In developing countries the use of pesticides is centered on export and cash crops resulting in a rapid increase in the quantity of pesticides being imported (Table 5).

Table 5

Pesticides used in Latin America

| Country | Year | Quantity (tons) |
|---|---|---|
| Brazil | 1964 | 16,200 |
| | 1974 | 101,000 |
| | 1980 | 123,500 |
| Colombia | 1964 | 8,000 |
| | 1975 | 33,000 |

Adapted from R. González, F.A.O. report, 1978.

The original success with which pests were controlled by pesticides have become threatened with the appearance of increasing number of pesticide-resistant strains and other

problems which are inevitably linked to the heavy use of pesticides in any part of the world. Having been developed under temperate crop protection conditions their introduction to tropical and subtropical areas poses additional problems related to new biological, technological, economic and social conditions.

Pesticides have important positive characteristics. Great benefits can be derived from them if used judiciously, particularly under situations of emergency and within the scheme of the Integrated Pest Management. Producers of pesticides consider that although the adoption of IPM practices should reduce the amount of pesticides applied by hectare of crop-land, the total use of chemicals in the world will increase during the next 20-50 years (Farm Chemicals, 1981).

Adverse consequences of the use of pesticides are: the development of resistance to pesticides, persistance of residues in food, emergence of new pests, destruction of beneficial organisms, human intoxication and contamination of the environment.

## Resistance

The development of pest strains that no longer can be controlled economically with chemicals because they have developed resistance is of great and sometimes critical importance for agricultural production. Resistant strains have arisen in each region where pests have been exposed to heavy chemical control. 393 species of arthropods were recorded as resistant in a survey made by FAO in cooperation with the University of California (WHO, 1980). This trend will continue, following an exponential rate of increase, as long as insecticides remain the principal tool for pest control, threatening agricultural production of the future.

The rate of discovery of new insecticides to counteract the problem of resistance does not keep pace with the emergence of new resistant strains. What is worse a pest strain may develop resistance to two or more pesticides as a result of exposure to a single pesticide ("cross resistance").

According to Georghiou and Taylor (1976) resistance develops more rapidly under the following conditions:

a) a residual insecticide is applied which is closely related to an earlier used chemical.

b) the compound has a prolonged environmental persistance or is applied in a slow release formulation.

c) applications are prescribed at a low threshold of the population (or under calendar intervals).

d) the treatment reaches and selects a high percentage of the population.

e) selection is directed against larvae or worse still against larvae and adults.

f) a thorough application is made.

g) a geographically large area is covered, and

h) selection is applied against every generation of the population.

Most of these conditions are considered "desirable" from the unilateral chemical point of view.

Many potato pests have already developed significant levels of resistance to pesticides. The Colorado potato beetle, Leptinotarsa decemlineata (Say), has developed resistance to organochlorine, organophosphorus and carbamate insecticides in many parts of the United States (Harris and Svec, 1981). The green potato-peach aphid, Myzus persicae, the most important vector of potato viruses, is now resistant to most insecticides registered on potatoes (Radcliffe et al., 1979). The potato tuber moth, Phthorimaea operculella, and related species have developed resistance to organochlorine, organophosphorus and pyrethroids in Peru and other parts of the world.

Insect populations become resistant because of the selection by pesticides of individuals with a genetic constitution that permits them to survive and reproduce. To reduce the magnitude of this problem it is necessary to significantly reduce the selection pressure exerted by pesticides, reducing their use as in IPM programs.

## Emergence of New Pests

Following pesticide treatments non-target insects may increase to damaging levels. These are insect populations that previously had the status of secondary pests, or were not pests at all, because of the controlling effects of their natural enemies. Once the natural enemies are destroyed, freed of their controlling effects insect populations increase rapidly in numbers. In many cases these new pests are more severe than the original primary pests. Potato leaf-miner flies were not important in potato fields of Peru up to the early sixties when intensive use of pesticides against the potato moth *Scrobipalpula absoluta* started. At present time most of the insecticide sprays are directed against leaf miner flies including pyrethroids which may potentially favor the increase of the white mite, *Polyphagotarsonemus latus*.

## Contamination of Food

Developed countries have special regulations to protect consumers from toxic pesticide residues in or on food commodities. Tolerance levels are established for each insecticide and food product according to the characteristics of the chemicals and the average diets. Ad-hoc programs monitor contamination levels of agricultural products that get into the market. Pesticides must be registered for their use on specific crops and the residue regulation forces the farmers to follow the directions for the use of pesticides including dosages, intervals periods between applications and the waiting period before harvest.

Developing countries usually do not have such regulations and if they do, commonly they are just direct adoptions from developed country legislation or from an agency of the United Nations (FAO or WHO), Unfortunately, the governmental agencies lack the means to have the regulations applied. Residue levels may be unrealistic because of great variations in diets and, in most cases, there are no monitoring programs for contamination levels (Exceptional cases are related to food commodities for export).

## Safety Considerations

Pesticide poisoning is usually under-reported in all parts of the world is assuredly higher in the developing countries (Table 6).

Table 6

W.H.O. survey of pesticide poisoning incidence and mortality from respondent countries, 1974.

| Year | Country | Cases/100,000 | Deaths/Million |
|---|---|---|---|
| 1972 | Cyprus | 2.3 | 3.1 |
| 1974 | Finland | 2.8 | 3.4 |
| 1974 | Rumania | 13.0 | 14.4 |
| 1971 | Syria | 16.3 | 25.6 |
| 1974 | Turkey | 4.3 | 4.0 |
| 1975 | United Kingdom | 0.3 | 0.3 |

Adapted from J.F. Copplestone, Academic Press, 1977.

In these areas it has increased considerably with the introduction of organophosphate and carbamate insecticides. In general, in order to reduce exposure to pesticides, it is recommended that applicators use protective clothing during the mixing and application of chemicals. However, climatic conditions in the tropics are such that applicators usually wear minimum clothing often barefoot, exposing them to dermal absorption. Inhalation is also high because the effectiveness of respirator masks relies on the closeness of fit and they are very uncomfortable under hot humid conditions. In some cases, the models are designed to fit caucasian features.

In case of poisoning accidents, it is difficult to get adequate help; treatment centers are usually far away, transportation is inadequate, health centers are usually staffed with personnel not trained in recognizing pesticide poisoning symptoms and antidotes are rarely available.

Many small farmers are functionally illiterate and may not understand clearly the instructions of pesticide labels. Under these circumstances the risk of exposure to insecticides is greater.

In most parts of the tropics, local distribution of pesticides is a purely commercial operation. This has caused the repeated appearance of chemicals which are banned for use in their country of origin and for which there may be safer alternatives. Sale of these chemical at a competitive price is possible in areas which may not have the adequate information, legislation, or the machinery to enforce safety regulations. On the other hand, the ban by temperate countries of DDT, BHC, and other organochlorine insecticides on the grounds of protecting the environment from persistant pesticides, have affected plant protection in developing countries. The alternatives, organophosphates, carbamates and pyrethroids prove to be more costly and usually more toxic.

### Additional Considerations

Tropical conditions affect chemical control technology in several ways. Most pests are multivoltine and remain active throughout the year with continuous reproduction that results in overlapping of generations and higher rates of pest increase. The persistance of chemical pesticides is markedly reduced due to the higher intensity of the biotic phenomena and the prevalent physical conditions, high temperature, high humidity, level of rainfall or intense ultraviolet light. For all these reasons pesticides must be applied more frequently and farmers may even arbitrarily increase dosages.

Different from temperate regions where severe climatic conditions affect significantly pest population increase, in tropical conditions natural enemies seem to play the most important role in reducing pest populations. Their destruction by pesticides has disastrous effects.

## III The IPM as an Alternative

IPM is a broad ecological approach to plant protection utilizing a variety of control technologies compatible in a single pest management system with the ultimate objective of producing an optimum crop yield at minimum cost. In this approach primary reliance is placed on naturally occurring mortality factors. These include such elements as crop varieties with inherent resistance to pests; natural predators, parasites and pathogens of pests, and, cultivation practices that discourage pest population build up; and, the selective use of chemicals when necessary to prevent significant crop damage. It is not simply

the juxtaposition of these techniques but rather their integration with the natural regulating and limiting elements of the environment. Natural compounds, or their mimics, that can disturb normal development of insects (hormones) or disturb their normal behaviour (pheromones) are becoming important in IPM programs.

Successful IPM programs have been developed against different pests of the world for a number of crops including cotton, sugar cane, rice, peanuts, sorghum, certain fruits, soybeans and alfalfa. In most of these cases farmers perceived a need for IPM because chemical control programs had failed mainly as a result of the development of strains of pests resistant to insecticides. A period of crisis has been considered the normal step towards the adoption of IPM by farmers (Smith, R.F. 1971).

In the implementation of certain IPM programs, particularly in developed countries, the systems seem to have proceeded with too much sophisticated and speculative emphasis on the use of computers, mathematical models, centralized organizations for analysis, etc. IPM programs for developing countries should have a different approach. It is important to consider that the earliest example of deliberate introduction of IPM programs occurred in a developing country, specifically in Peru. Here, resistance and new pest problems made cotton production virtually uneconomical in the early fifties. The application of a series of technical and legislative measures mostly aimed at safeguarding natural enemies doubled and even tripled production within a two-year period, while at the same time pesticide usage was strongly reduced. Some other countries implementing IPM include, Colombia, Nicaragua, El Salvador and Guatemala in cotton, Egypt in cotton and maize, India and Thailand in rice and Malaysia in rice, cocoa and oilpalm. Special mention must be made of the extensive application of IPM in China on various crops including cotton, rice, pines and a number of vegetables (IOBC Special Issue, 1980).

In carrying out specific IPM programs, the degree to which the various components will be used varies according to the crops and areas, depending on the crop/pest environment and the socio-economic conditions. In general, all programs are based on: a) utilization of workable economic damage

thresholds and effective pest sampling; b) maximum use of plant resistance and cultural control practices; c) maximum exploitation of naturally occurring parasites and predators, and d) judicious use of selective pesticides.

From the point of view of the research required to provide the information needed for structuring IPM programs, the following points should be considered.

1. Identify and breed plants for pest resistance in different environments.

2. Identify parasites, predators and pathogens that may be used for introductions or controlled releases.

3, Study cultivation practices in specific environments to discourage growth of pest populations.

4. Design simple methods for monitoring pest population levels and crop damage.

5. Evaluate under field conditions low-cost, pest-specific, short-live chemical pesticides.

6. Study the use of insect hormones and pheromones for disrupting the vital process and behaviour of pests.

IPM programs must be tailored to fit the specific conditions of an area. Once the program is available the widespread adoption depends largely on the success of demonstrating to farmers that the system works advantageously.

Best results usually occur in areas where growers have some kind of organization and there is a system to provide information and technical assistance.

From the above statements it is clear that there are two different phases involved in the implementation of IPM programs. The Research Phase, aimed to provide the basic components of IPM, requires research facilities such as those available at International Agricultural Centers. The Adoption and Adaptation Phase, at national level, should be mainly the responsability of National Programs.

Some Research Institutes of the Consultative Group of International Agricultural Research already devote considerable

efforts to the development of IPM components, in particular varietal resistance, cultivation practices and more recently biological control.

Thinking of the future, it is accepted that we cannot produce an adequate supply of food without improved pest control and we cannot maintain our environment if this control is not ecologically sound.

## References


1. Farm Chemicals, September 1981. International Edition.

2. Georghiou, G.P. and C.E. Taylor, 1976. Pesticide Resistance as an Evolutionary Phenomenon. Proceedings of the IV International Congress of Entomology. 759-785.

3. Harris, C.R. and H.J. Svec, 1981. Colorado Potato Beetle Resistance to Carbofuran and Several other Insecticides in Quebec. Journal Economic Entomol. 74:421-424.

4. IOBC Special Issue, 1980. Conference on future trends of Integrated Pest Management. Bellagio, 30 May-4 June.

5. Radcliffe, E.B., R.E. Cancelado, and W.S. Cranshaw, 1979. Establishing Action Thresholds for Insect Pests. Proc. Symp. IX Internat. Cong. Plant Protection. Washington D.C. 3: 477-480.

6. Smith, R.F., 1971. Fases en el Desarrollo del Control Integrado. Bol. Soc. Entomol. Peru 6:54-56.

7. World Health Organization, 1980. Resistance of Vectors of Disease to Pesticides. Fifth Report of the WHO Expert Committee on Vector Biology and Control. Technical Report Series 655.

# ASSESSMENT OF INSECT DAMAGE

By Marcos Kogan

## INTRODUCTION

Modern crop cultivars have the potential to yield far more than the average yield obtained in production fields. In developed countries this differential is between 2.5 to 6 fold for some major crops (Table 1). In developing countries, where production inputs and technology are more limiting, the differential may be far greater. The difference between the "actual yield" and the "attainable yield" (in FAO terminology, see Zadoks 1981) results from the sum of losses attributable to agronomic practices, interacting with on climatic and edaphic conditions, and to the sum total of biotic stress factors during the crop cycle. Under most growing conditions, the potential impact of crop-loss determining factors during the span from planting to harvest is a big question mark for the grower (Figure 1). To optimize economic crop production it is essential to reduce the impact of the controllable loss-determining factors hence the need for reliable crop loss profiles (see Teng and Krupa 1980, Chiarappa 1981, Wiese 1983).

Although my comments are limited to the assessment of losses caused by insect pests it must be stressed that pests seldom occur singly. The impact of pests must be appreciated within the holistic complex of the crop environment. Gross assessments of individual impacts of insects, diseases, nematodes, and weeds on a crop commonly result in combined estimated yield reductions exceeding 100 percent, i.e., the estimated total loss surpasses the reference yield. In the real world, however, there is always some yield, even under extremely stressful situations in which complexes of pests impinge simultaneously on a crop. Therefore, there are obvious problems in assessing damage by individual pests without taking into account interactions of pest complexes and other production factors. After discussing the measurement of injury by single insect pests I will touch upon recent attempts to measure interactions of pest complexes, i.e., different insect species attacking simultaneously, or in succession, different plant parts, or insect injury interacting with weed competition.

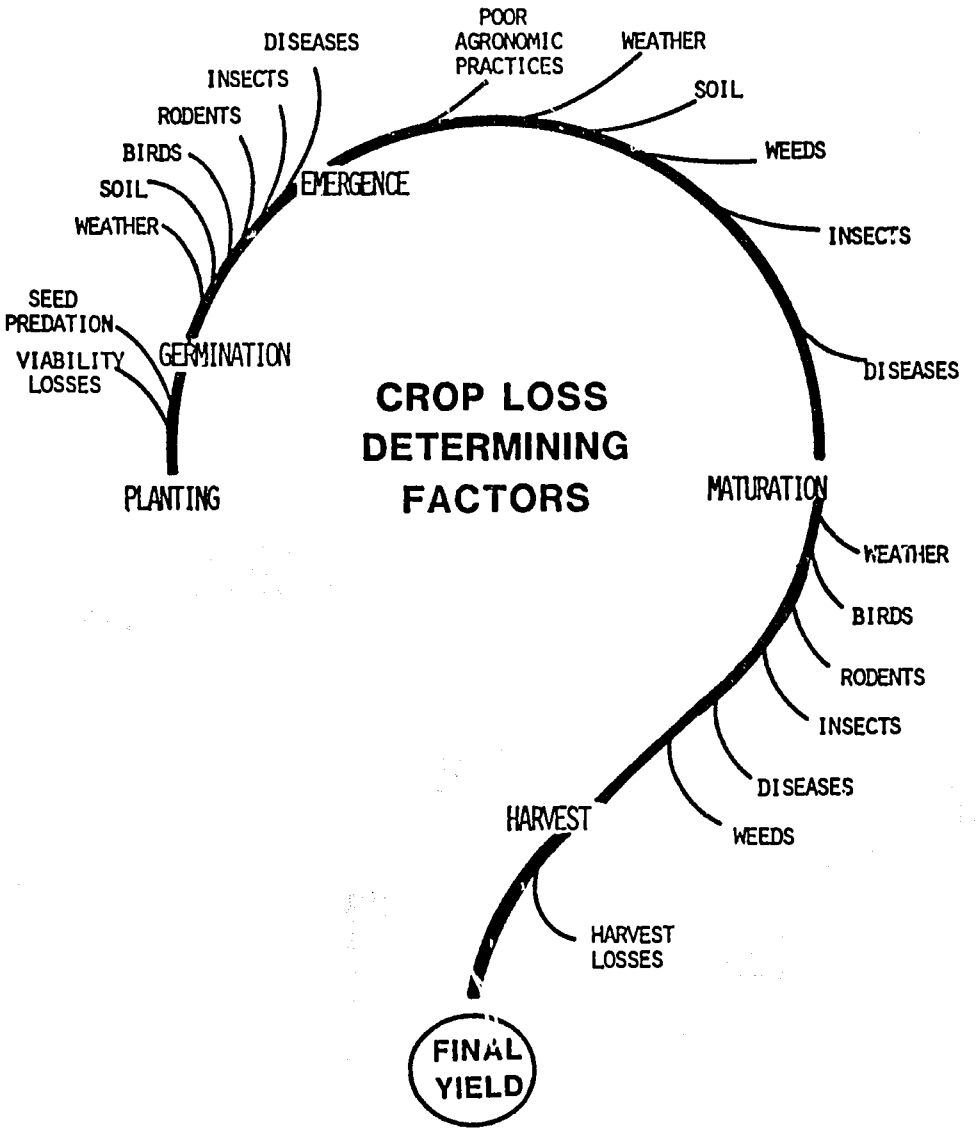


Figure 1. Sources of losses in yield during the various stages of crop development. The impact intensity of stress factors varies with stage of growth. Stress factors impinge on the genetic potential of the cultivar to limit expression of that potential. Given the uncontrollable nature of climatic factors the grower usually faces a high degree of uncertainty from planting to harvest.

Table 1. Average, best farmer production, and world record yields of major crops (in ton/ha). (After Wittwer 1983).

| Crop | Average 1981 (U.S.) | Best Farmers (U.S.) | World Record | Ratio Record/ Average |
|---|---|---|---|---|
| Maize | 7.1 | 14.6 | 22.1 | 3.1 |
| Wheat | 2.4 | 6.4 | 13.5 | 5.6 |
| Rice (unpolished) | 5.5 | 9.1 | 14.4 | 2.6 |
| Sorghum | 3.7 | 17.7 | 21.4 | 5.8 |
| Soybean | 2.2 | 3.6 | 5.7 | 2.6 |
| Potatoes | 30.9 | 67.9 | 96.0 | 3.1 |

## Objectives of Crop Loss Assessment Research

The Plant Disease Loss Committee of the American Phytopathological Society (see Chiarappa 1981) identified the main objectives in crop loss assessments as the need to provide support to:

a. Decisions to initiate, continue, or terminate agricultural science program;

b. Environmental impact decisions by various public and private groups;

c. Governmental agricultural policy decisions;

d. Economic decisions on the farm and in agricultural industry.

The first three objectives are clearly aimed at policy-makers at various administrative levels: institutional, regional, or national. The latter provides the bases for IPM decisions at the farm level, which is of most interest to us here.

Assessment of damage by insects is essentially a problem in sampling, consequently procedures used depend on the primary objective of the assessment program. From the standpoint of quality of information

sought, however, we may identify two main goals of the sampling program: a) to gather information aimed at providing fundamental knowledge of the system and b) to secure information needed in decisions leading to achieve some level of modification of the system. Practical uses of damage assessment information in IPM fall into this latter category. Success in crop management hinges on the outcome of a sequence of decisions made by the crop manager (Figure 2). The probability of making a correct decision increases with the quality of the information upon which those decisions are made. This information comes from adequate sampling either within the property fields or within representative fields in the region where the property is located.

The literature on crop loss assessment and on sampling is vast and growing at a steady rate (Chiarappa 1971, 1981; Walker 1975; Sterling 1979; Teng and Krupa 1980; Kogan and Herzog 1980; Ferris 1981; Pimentel 1981). Because of the extent of the subject and the availability of adequate references in the fundamentals of sampling I will restrict my comments to the experimental procedures commonly used in the evaluation of the impact of insect pests on crops. Although my examples are drawn mainly from the soybean literature, because this is the one I am most familiar with, my objective is to bring out some common factors that seem to permeate throughout the analysis of insect/annual-crop interactions, be they soybean, corn, tobacco, or potato.

## Components of Yield and Influences of Pests

A clear understanding of the crop matrix is essential for research in loss assessments. The impact of pests varies with the stage of development of the crop during which injury occurs. A descriptive system of crop growth stages is useful for the analytical procedures that follow. For soybean the standard descriptive system has been proposed by Fehr and Caviness (1977). This system uses a letter prefix V for vegetative stages, and R for reproductive stages. V and R are followed by numbers. V-stage numbers represent the sequence of foliar development by nodes, from the cotyledonary node, ($V_c$) to $V_n$ (the leaf at the nth node). At the R stages, numbers define the sequence from early bloom to harvest maturity. Several of these schemes for other crops have been published and are found in Chiarappa (1971). The system proposed by Sparks and Woodburg (1967) still seems in use by potato researchers.

The second important set of information on the crop matrix relates to the components of yield. For instance, in grain legumes the number of pods per plant, number of seeds per pod, and weight of seeds are directly related to the final yield. These parameters usually are taken into account in damage assessment analyses. In potato the number of tubers per plant, tuber size, and number of stems are the main yield parameters (Cho and Iritani 1983). To judge from Ewing's (1981) review it seems that in potato both tuberization and growth of tubers are directly correlated to the foliage area present. This relationship was experimentally

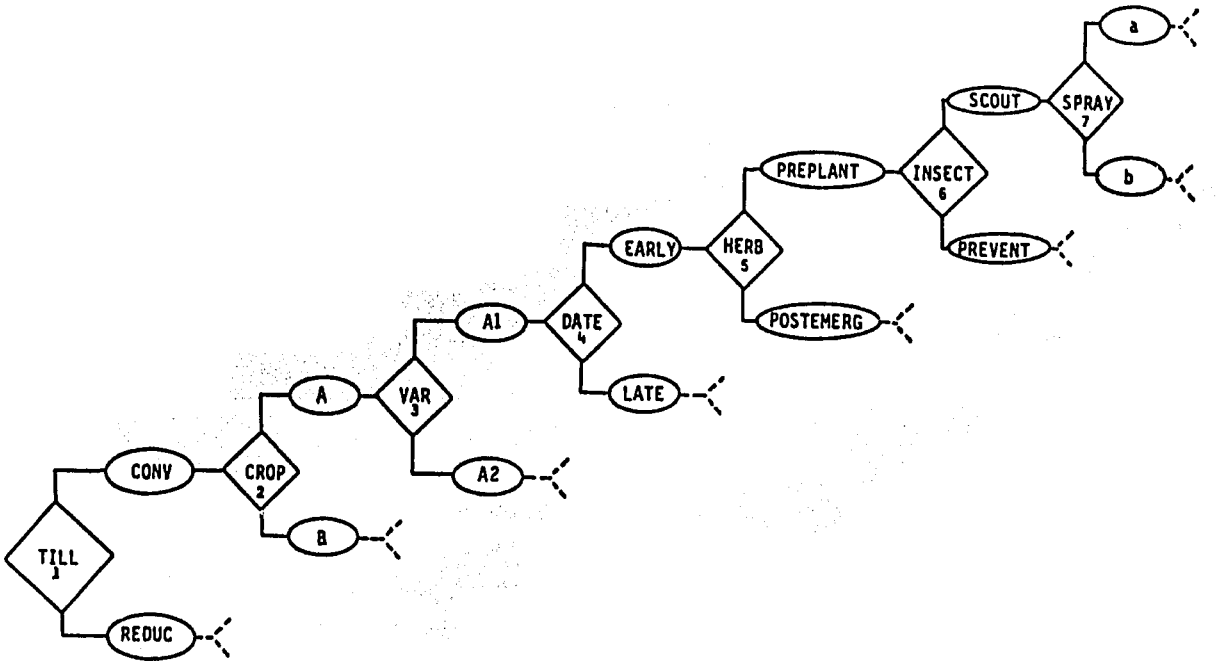


Figure 2. A farm manager is faced with a chain of decisions (diamonds) related to various alternative options available for optimal crop production. The probability of making the correct decision under a given set of circumstances depends on the reliability of the information upon which the decision is based. That information must come from sampling data obtained either during the cropping season or accumulated over historical time. Abbreviations: TILL = tillage systems; CONV = conventional; REDUC = reduced tillage; CROP = crop species A, B.....N adapted to the cropping system prevailing in the region; VAR = variety of the selected crop; DATE = planting date; HERB = herbicide selected for either preplant incorporation, postemergence appliation, or other; INSECT = insecticide application based on either scouting results or on a preventive mode; SPRAY = chemical insecticide of choice, a,b....n, applied at rate 1,2....n (Kogan and Kiritani 198).

determined by Takatori et al. (1952) and the values seem to apply to defoliating pests of potato (Tamaki 1981).

Although the types of injury that insects inflict on plants vary greatly the response of plants to injury usually can be classified into three major categories (Poston et al. 1983). These responses are: 1) susceptive, 2) tolerant, and 3) overcompensatory (Figure 3). Susceptive response is typical of insects feeding directly on the final product such as the tubers of potatoes or the seeds of soybeans (the so called direct pests). Tolerant response is typical of insects feeding on vegetative parts in which there is a threshold below which there is no influence of injury on yield; most annual crop plants such as cotton, soybean, and potato seem to be highly tolerant of defoliation, although the level of tolerance varies with stage of crop growth, in relationship to the yield factors mentioned above. Overcompensatory response is occasionally observed when early injury to vegetative parts results in plants thus injured to yield more than uninjured plants. In soybean, moderate levels of defoliation prior to flowering have been observed to induce 8 to 10 percent yield increases under certain experimental conditions, apparently as a result of greater light penetration into the canopy which increases total photosynthate production in otherwise non-functional shaded leaves.

Research on the determination of insect impact on yields must establish unambiguous relationships between type of injury and yield reduction. The methodology in this research will be briefly reviewed.

## Methods in the Assessment of Damage by Insects

The methodology to be adopted in insect damage assessment depends on the objective of the program, as mentioned before. The level of accuracy required in broad assessments for general policy making is not necessarily high. Often it is enough to establish assessments within a given order of magnitude. Research to define economic injury levels, on the other hand, require a much higher level of accuracy (or closeness to the real values). For most decision programs a level of accuracy of 25% is regarded as adequate, whereas for basic population parameter definition one would require about 10% accuracy; accuracy level measured as the ratio of the standard error to mean (Southwood 1978).

## Ad hoc Assessments

In ad hoc assessments of pest impacts one uses existing situations to derive the information. In gross ad hoc assessments data are expressed in the simplest and most general way. These assessments usually cover large regions and are the ones that yield additive effects often exceeding actual average yields for the region. Ridgway (1980) recognizes the following methods for ad hoc assessments: a) gross estimates based on surveys and demonstration plots, b) indirect

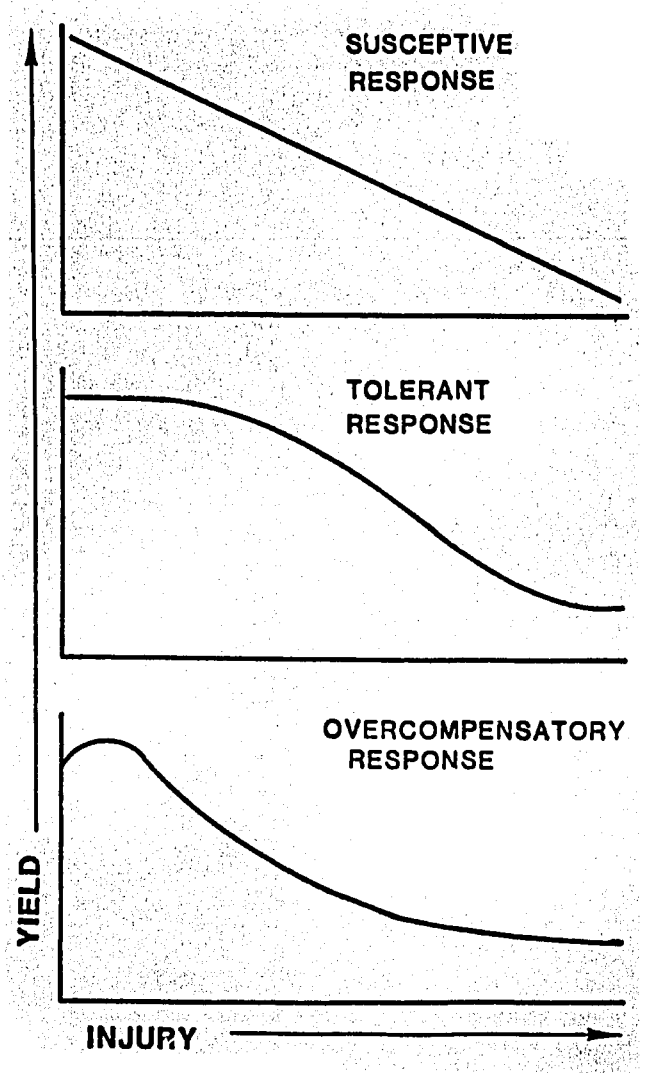


Figure 3. Categories of responses of plants to injury produced by insects (after Poston et al. 1983).

assessments based on insecticide use, and c) regressions of insecticide screening data.

Gross estimates often are based on subjective assessments of Extension and other field personnel. These assessments vary greatly with the amount of information available to the surveyor. Some gross estimates are based on paired plot comparisons (demonstration plots). These plots are not necessarily set up following a given experimental design. Farmers ready to apply an insecticide to control a pest are asked by an IPM advisor to leave a small area untreated for demonstration of effects. Comparisons based on these small check plots cannot be subjected to statistical analyses, and provide limited quantitative information.

Indirect assessments of pest impact based on insecticide use has four major limitations according to Ridgway (1980): a) subeconomic levels of injury may not trigger an insecticide application, b) insecticides may not be available when needed, c) losses may occur even when insecticides are applied and d) insecticides may be applied in a preventive way even though there would be no significant loss in the absence of an application.

Finally, pesticide screening data have been used to estimate the potential impact of pests. Extensive records are presented by Schwartz and Klassen (1981). In this study they use information published in the "Journal of Economic Entomology" from the years 1942-1978 and in "Insecticide and Acaricide Tests" published by the Entomological Society of America for 1976, 1977, 1978 for all crops except cotton which was done for 1965 and subsequent years. In these regressions the authors use results from experiments where yield data were presented with pest density data and the effect of insecticides and acaricides was determined by comparison to untreated controls. The summary of the results for potatoes is presented in Table 2 extracted from the tables in Schwartz and Klassen's paper.

## Experimental Approaches to Crop Loss Assessment

The choice of experimental procedures in crop loss assessment research is determined primarily by the patterns of pest incidence in the region where research is conducted and the characteristics of the crop. The three main types of experimental approaches are: a) pest exclusion techniques, b) pest inoculation techniques, and c) simulated injury techniques.

Exclusion techniques: If pest incidence and its spatial patterns assure a reasonably uniform infestation among experimental plots, the following techniques are then available. 1) Selective insecticides - applied at different rates to build various population and injury levels, 2)

cages - used to exclude pests from a given area that is previously treated and covered to prevent additional infestations, 3) mechanical barriers - used similarly as cages to prevent infestation by crawling insects; traps and cultural traps also can be used with similar results, 4) hand picking - occasionally used to remove conspicuous insects, 5) near isogenic lines of resistant varieties - if available, isolines can be used to build different levels of infestation, without further interference; this technique can be used in conjunction with insecticide applications.

Table 2. Losses of potato caused by insect pests estimated by regression of insecticide and acaricide test data (From Schwartz and Klassen 1981).

| Crop Pest | Calculated Yield Loss | |
|---|---|---|
| | Without Control | With Control |
| Aphids | 14.5 ± 8.1 | 0.6 ± 0.4 |
| Armyworms | 59.0 ± 17.0 | 1.3 ± 1.0 |
| Color. Potato to Beetle | 46.6 ± 10.4 | 1.0 ± 0.6 |
| European Corn Borer | 54.2 ± 26.6 | 1.5 ± 0.6 |
| Flea Beetles | 43.3 ± 10.3 | 0.7 ± 0.4 |
| Green Peach Aphid | 3.7 ± 3.7 | 0 |
| Potato Leafhopper | 43.2 ± 18.6 | 0.4 ± 0.2 |
| Potato Psyllid | 32.0 ± 17.2 | 1.0 ± 1.0 |
| Potato Tuberworm | 91 | 1 |
| Spider Mites | 5 | 4 |
| Wireworms | 4.9 ± 3.5 | 0.1 ± 0.2 |

Total estimated losses (yield loss + cost of control) for potato in the U.S. in 1977.

Area harvested ---- 550,600 ha
Production value ---- 1.275 billion (US$)
Yield loss + pest control costs ----1.848 million (US $)

Inoculation techniques: If natural infestations are sporadic or rare it is possible to take advantage of the situation by carefully manipulating pest populations through timely releases of eggs, larvae, or adults. Egg releases have been made by spraying suspensions of eggs of lepidopterous pests in a sticky solution; releases of *Heliothis* spp. eggs with this technique have been made to study EIL's in soybean (McWilliams 1979). Larval releases have been made using various techniques. One commonly used at CIMYT is the so called "bazzoka method" (Ortega et al. 1980). We have used releases of adult soybean loopers confined within cages to produce different levels of defoliation on soybean. In Louisiana releases of bean leaf beetles on soybean have been made in plots protected by ground barriers; the beetles had the elytra clipped to keep the from flying. The use of trap plants more attractive than the crop under study is commonly used to build populations of the Mexican bean beetle in soybean experimental fields. Other methods of trapping that have not been adequately tested but which may have some potential use are light traps and attractants. Methyl eugenol has been used in North Carolina to attract populations of the Japanese beetle and produce different defoliation levels on soybean.

Simulated injury: Most simulated injury studies have been conducted to simulate the effect of defoliation. Most early studies with many crops, have been conducted to determine the effect of hail injury. Some of these studies have been useful in evaluating the potential economic injury levels for crop defoliators. Those studies have shown that sensitivity of plants to defoliation varies with stage of crop development. In soybean the most critical stage is the beginning of pod set and pod fill. In potato it seems that the stage of full bloom is most sensitive to defoliation (Takatori et al. 1952, Cranshaw and Radcliffe 1980, Hare 1980). According to Radcliffe (1982), however, simulated injury by insects produce yield reductions in potato not as severe as those obtained in simulated hail injury studies. Until initiation of tuberization there is almost complete compensation for all levels of defoliation. Actual injury by various levels of Colorado potato beetle infestation had very little effect when it occurred early or late in the growing season; during the tuber growth stage yields were reduced two thirds as much as corresponding injury by simulated hail (Hare 1980). Simulated injury to other plant parts is more difficult to achieve. In soybean it is possible to adequately simulate deblossoming or injury that causes pod shedding, but injury to roots and stems has not been conveniently simulated.

## Sampling for Crop Loss Assessment

Research in crop loss assessment faces the same problems related to the choice of adequate sampling procedures as any other type of ecological or agronomic research. Essentially one is required to produce sets of data in which various pest population levels are correlated with

measurable effects on the plants. Both the pest population levels and the effects need to be determined with the desired level of reliability.

Measurements of pest populations: Sampling procedures for insect populations have been the object of extensive studies and there are adequate reviews in the FAO manuals for crop loss assessment (Chiarappa 1971, 1981). Southwood (1978) remains a valuable source of information, and Kogan and Herzog (1980) have compiled the extensive literature that has accumulated for soybean. That information, to a large extent, is applicable to other field and vegetable crops.

Measurements of effects on the crop: Most injury effects are measured by yield differentials. However, the detailed interpretation of injury impact may require a complete growth analysis which involves measurements of foliage area, foliage weight, total biomass of vegetative plants, root development, and growth rates. Finally, it is essential to measure not only the effects of injury on the quantity of the product but also on its quality. It has been reported that indirect injury to foliage of soybean may affect oil and protein composition of the seed. Similarly it seems that certain levels of defoliation in potato may affect the quality of the tubers formed (Takatori et al. 1952).

## Damage Assessment and Economic Injury Level Definition

If the experimental procedure used in damage assessment provides enough paired sets of data on infestation levels and yield and quality effects then it is possible to use these data for the definition of economic injury levels (EIL) a parameter that is fundamental for the implementation of IPM programs. Despite the recognition of this fact there is still a dire need for additional research on the establishment of EIL's for most agricultural pests. As recently as 1982 Radcliffe concluding his review article stated -- "Perhaps most limiting to formulation of sound pest management strategies is a dearth of experimentally determined economic thresholds."

Mumford and Norton (1984) in reviewing the economics of decision making in pest management identify four models: a) the economic threshold model, b) the marginal analysis or optimization model, c) the decision theory model, and d) the behavioral decision model. They conclude that the entomologists' economic threshold model, is an operational or working decision rule. It applies more effectively in situations in which only one treatment is required to control the pest. The economists' models have been developed mainly to address the question of multiple applications, and when other decision rules, such as uncertainty, become part of the model. I will limit the remaining of my comments to the economic threshold model of entomologists.

## Components of Economic Injury Level Analysis

There are two main approaches to determination of economic injury levels: a) the use of static models; and b) the use of dynamic models.

Static models: The functional components explicity used to compute economic injury levels are: a) the relationship between insect pest population and amount of injury produced; b) the relationship between amount of injury and yield loss; c) the relationship between amount of injury and loss in quality; d) the combined loss in crop value due to yield and quality decrease; e) the relationship between cost of control and reduction in pest population; and f) the relationship between cost of control and preservation of crop value. These relationships were defined by Southwood and Norton (1973) and applied to the specific case of soybean foliage feeding lepidopterous caterpillars and to pod feeding stink bugs (Kogan 1976). The sets of data necessary to measure these components of EIL's are the following: a) the amount of injury (foliage area removed, length of tunneling, number of punctures, etc.) produced by an individual insect pest during its life span on the plant; b) the amount of the plant part being injured present at a given stage of plant development (total foliage area, total length of stems, number of seeds, etc.); c) the relationship between the reduction in the amount of the plant component present and consequent reduction in yield or quality of the product; d) the expected yield attainable in the absence of injury; e) the market value of top quality product; f) the cost of treatment necessary to prevent injury. With these data it is possible to compute the expected population level (EIL) capable of causing a loss at least equivalent to the cost of an insecticide application necessary to prevent loss. A formula originally derived to compute EIL's of soybean defoliators (Ruesink 1975), is equally applicable to other crops. This formula based on the "break even" concept of EIL is:

$$P_k = \{(0.005\ L_k)/(\beta_k\ F)\}\{-\alpha_k + [\alpha_k^2 + (400C_2\ \beta_k)/(C,N)]^{1/2}\}$$

The meaning of the components and the values used to compute EIL's for the Colorado potato beetle feeding on potato at growth stages: 8-12 in., full bloom, and at maturity, are the following:

$P_k$ = population level of Colorado potato beetle larvae per $m^2$ at stage k of crop development;

$L_k$ - leaf area of potato plants per $m^2$ at stage k of plant growth; values used were based on Dawes et al. (1983) for 'Russet Burbank' potatoes in Idaho, and were as follows: 8-12 in. - 8,000 $cm^2/m^2$; full bloom - 40,000 $cm^2/m^2$; and at maturity - 38,000 $cm^2/m^2$, with 4.4 hills/$m^2$.

F = amount of foliage consumed by Colorado potato beetle larvae to complete development at 24 $\pm$ 7°C $\approx$ 28 $cm^2$, (Tamaki 1981);

$C_2$ = cost of spraying (US$/ha) - assumed @ US$15.00/ha.

$C_1$ = market value of US no. 1 potatoes; estimated on 1978 values of US$0.08/kg;

N = expected yield in the absence of pests; using the value of 39,000 kg/ha obtained in the study by Dawes et al. (1983) at Aberdeen.

$\alpha_k$ and $\beta_k$ = coefficients of the quadratic equations that correlated percent defoliation with percent yield reduction (Figure 4); computations were based on data presented by Takatori et al. (1952).

Using these parameters the values for the EIL of Colorado potato beetle larvae at the early vegetative stage was 8.35 larvae per square meter, at full bloom stage 7.65 larvae per square meter and at maturity 41.72 larvae per square meter. These values reflect the greater sensitivity of the plant to defoliation at the full bloom stage and also the small amount of leaf area present at the early vegetative stage despite the fact that the sensitivity of the plant is not much greater at this stage than it is at maturity. At maturity the plant has nearly 4 times more leaf area then in early vegetative stage, which is reflected in more than fourfold difference in EIL. As pointed out by Hare (1980) and Cranshaw and Radcliffe (1980) hail injury simulation in potato seems to show a much greater effect on yield then injury produced by insects. Hail data were used to compute these EIL's for the Colorado potato beetle and they probably are much lower than if insect injury data were applied. However, this exercise demonstrates that the model seems to be perfectly applicable to potato. It will require, however, that parameters used in the formula be reevaluated and validated through adequate field experimentation. Figure 5 shows the variation of the economic injury level with stage of growth, and also the effect of variation in the market value of the commodity and the cost of a pesticide application on the EIL. As it is clearly seen these relationships computed only for the full bloom stage are curvilinear and asymptotic for the market value. This shows that no matter how high the market value of the commodity may be, there is always a threshold population level below which there is no advantage in applying a control. Conversely the curve for pesticide treatment crosses the y axis at about 1 indicating that even if we have a free application of a pesticide there is no real gain in applying a treatment. In other words, a pesticide application can prevent a yield loss but cannot induce a yield gain.

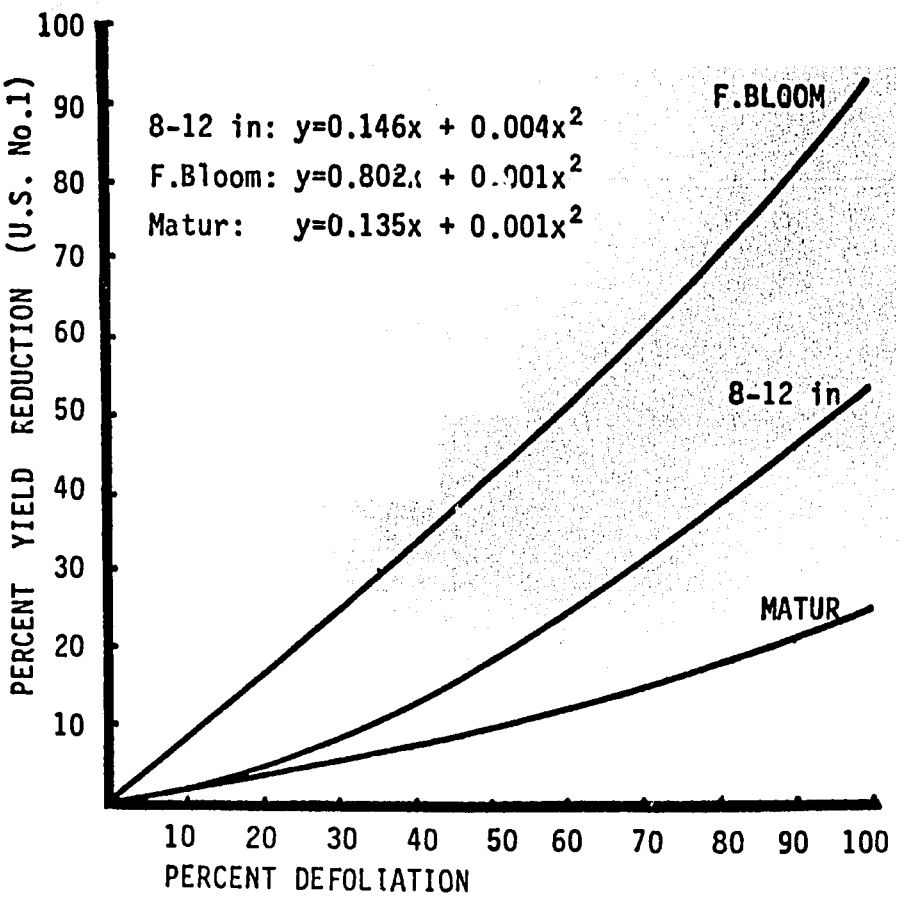


Figure 4. Correlation of percent defoliation and percent yield loss in potato based on simulated hail injury (data from Takatori et al. 1952).

The figure illustrates also the limitations of static models hence, the necessity to develop dynamic economic injury levels.

## Dynamic Economic Injury Levels

The static model described above has obvious limitations in that it cannot respond to fluctuating environmental conditions and it imposes rather rigid constraints. The systems approach to pest management provides a means for reconciling the need for reliable estimates of EIL's with the dynamic nature of the crop/pest system. A lucid review of the concepts and approaches used by modelers is found in Schumaker (1980) and in Getz and Gutierrez (1982). Using this approach, plant growth simulation and pest population simulation models are interfaced so that dynamic interactions can be built into the system. The various conceptual components of the model fit together to produce the parameters necessary for an optimal decision in a practical pest management program. Dynamic simulation models require a high level of accurate data to develop the model and to validate it after development. Some of these data are available in the literature but much more is usually necessary to make models realistic and useful for practical IPM purposes.

## Economic Injury Levels for Pest Complexes

If the status of EIL's for single pests is only now being defined with greater rigor, that of pest complexes (includinng plant pathogens, nematodes, and weeds) is still in its infancy. Unfortunately, pest complexes in soybean are the rule rather than the exception.

Attempts to simulate the combined effects of pod injury and foliage were made by Thomas et al. (1974). Experimental proof of these simulated results is still lacking. Dynamic simulation modeling is expected to render the problem of interactions of pest complexes more tractable although much experimental research in this critical area still needs to be performed. Recent experiments in our laboratory have led to the development of a method to test the interactions of weed competition with foliage injury. Preliminary data reveals that intense foliage injury favors biomass production of the weed, thus magnifying the effects of competition by the weed (Helm, Kogan and Jeffords, in preparation).

## Practical Uses of Economic Injury Levels

Schoonhoven and Kogan (1983) stress the fact that EIL's have been most useful for medium size soybean farmers, with farming units of 1 to 100 ha. Under these conditions scouting can be efficiently and economically performed, and control decisions can be reached in a timely way. Simple decision charts based on scouting data for various soybean foliage feeding pest are in current use in IPM programs in the USA, Brazil, Argentina, Mexico (e.g. Kogan and Kuhlman 1982).

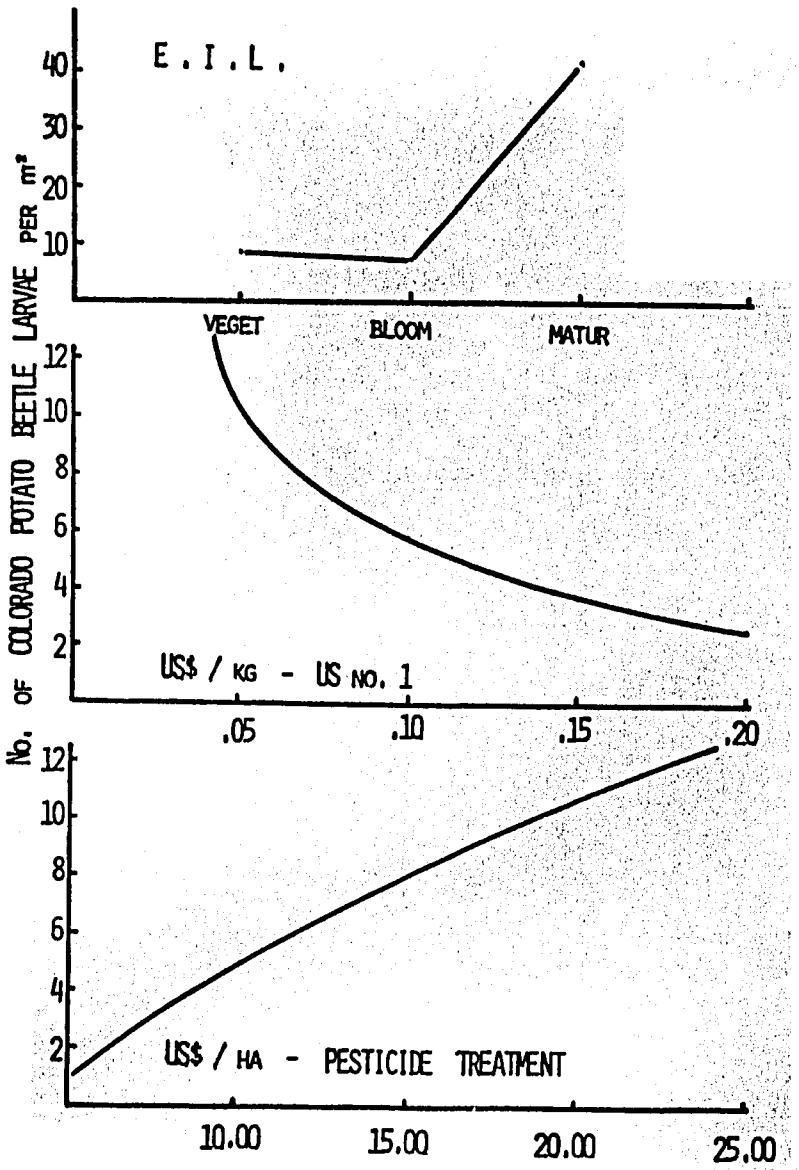


Figure 5. Economic injury levels for the Colorado potato beetle on potato. A. EIL's at three stages of plant growth; B. ratio of EIL to variation of market value of potato (at full bloom stage); C. ratio of EIL to cost of treatment.

For subsistence farmers and for very large farming operations, the direct use of EIL's for decision making may not be feasible. Subsistence farmers can seldom, if ever, use expensive chemicals in pest control; without access to corrective control measures EIL information is of little value. Under large farming operations the assessment of infestations over very extensive areas is often impractical. Nonetheless, information on EIL is still fundamental for the development of IPM programs for such production systems. Schoonhoven and Kogan (1983) suggest that EIL information can be forwarded to programs aimed at breeding more tolerant varieties adaptable to subsistence farming. For large operations, forecasting, modeling, and eventually remote sensing will lead to control strategies that take advantage of the most advanced technological achievements. Still, decisions will be made on the basis of cost/benefit analyses and the concept of EIL.

Regardless of the size of the farming unit the correct assessment of EIL's by experimental means and through dynamic simulation models is the very heart of sound IPM programs. Entomologists together with plant pathologists, nematologists, weed scientists, and agronomists must accept the challenge and work to solve the puzzle of EIL's of pest complexes. Only then will IPM systems operate on sound ecological and economic foundations.

## Conclusions

1. Correct assessment of damage by pests is essential for the establishment of priorities in research and for the development of decision rules in IPM programs.

2. There is a great deal of fundamental data available in the literature but much of these data are not directly comparable and are not easily retrievable; there is a need to establish adequate data bases that would make the wealth of information available in the literature readily accessible to researchers and there is a need for researchers to standardize their methods of presentation and compilation of data to make them useful for these types of studies.

3. Economic injury levels for single pests have been computed and they are useful in situations in which a single pest dominates and behaves as a key stress factor. However, the most common situation is that pests do not occur singly, therefore, there is a dire need to develop a methodology to determine economic injury levels for pest complexes.

4. Dynamic simulation models are extremely useful in helping conceptualize the interactive factors in a crop loss profile. There is an obvious need to develop realiable crop growth models upon which one can superimpose the effect of various pests.

5. No matter how good dynamic simulation models are there is still a need for much basic fundamental research to investigate the complex interactions among various pests. Only then, will the dynamic simulation models reflect real field situations with the capability of removing risk factors that are the main concern of producers.

## References Cited


Beresford, B.C. 1967. Effect of simulated hail damage on yield and quality of potatoes. Amer. Potato J. 44:347-354.

Chiarappa, L., ed. 1971. Crop loss assessment methods. FAO - Commonweath Agricultural Bureaux, Pub., pages unnumbered.

Chiarappa, L., ed. 1981. Crop loss assessment methods - Supplement 3. FAO - Commonwealth Agricultural Bureaux, Pub., Slough, England, 123 p.

Cho, J.L., and W.M. Iritani. 1983. Comparison of growth and yield parameters of Russet Burbank for a two-year period. Amer. Potato J. 60:569-576.

Cranshaw, W.S., and E.B. Radcliffe. 1980. Effect of defoliation on yield of potatoes. J. Econ. Entomol. 73:131-134.

Dawes, D.S., R.B. Dwelle, G.E. Klinkopf, and R.K. Steinhorst. 1983. Comparative growth analysis of Russet Burbank potatoes at two Idaho locations. Amer. Pot. J. 10:717-733.

Fehr, W.R., C.E. Caviness, and J.J. Vorst. 1977. Response of indeterminate and determinate soybean cultivars to defoliation and half-plant cut-off. Crop Sci. 17:913-917.

Ewing, E.E. 1981. Overview of potato physiology related to integrated pest management. Pages 1-12, in J.H. Lashomb and R. Casagrande, eds. Advances in potato pest management. Hutchinson Ross Pub., Stroudsburg, Pennsylvania. 288 p.

Ferris, H. 1981. Mathematical approaches to the assessment of crop damage. Academic Press, Plant Parasitic Nematodes, vol. 3, p. 405-420.

Getz, W.M., and A.P. Gutierrez. 1982. A perspective on systems analysis in crop production and insect pest management. Ann. Rev. Entomol. 27:447-466.

Hare, J.D. 1980. Impact of defoliation by the Colorado potato beetle on potato yields. J. Econ. Entomol. 73:369-373.

Kogan, M. 1976. Evaluation of economic injury levels for soybean insect pests. Pages 515-533 in, L.D. Hill, ed. World soybean research. Proc. World Soyean Research Conference, Interstate Printers, Danville, Illinois. 1073 p.

Kogan, M., and D.C. Herzog, ed. 1984. Sampling methods in soybean entomology. Springer-Verlag, New York. 587p.

Kogan, M., and K. Kiritani. 1984. Sampling, forecasting, and surveillance of pest incidence and intensity in legume crops. In, P. Matteson, ed. Proceedings of Int. Workshop in Integrated Pest Control for Grain Legumes, Goiania, Brazil April 4-9, 1983, (in press).

Kogan, M., and D. Kuhlman. 1982. Soybean insect: Identification and management in Illinois. Ill. Agr. Exp. Sta. Bull. 773:58p.

McWilliams, J.M. 1979. Heliothis spp. eggs: Spray application to establish larval infestation in experimental field plots of soybeans. Environ. Entomol. 8:1044-1046.

Mumford, J.D., and G.A. Norton. 1984. Economics of decision making in pest management. Ann. Rev. Entomol. 29:157-174.

Ortega, A., S.K. Vasal, J. Mihn, and C. Hershey. 1980. Breeding plants resistance to insects. Pages 371-419, in F.G. Maxwell, and P.R. Jennings, eds. Breeding plants resistant to insects. John Wiley & Sons, New York, 683 p.

Pimental, D., ed. 1981. Handbook in pest management in agriculture. Vol. 1. CRC Press, Boca Raton, Florida. 597p.

Poston, F.L., L.P. Pedigo, and S.M. Welch. 1983. Economic injury levels: Reality and practicality. Bull. Entomol. Soc. Amer. 29:49-53.

Radcliffe, E.B. 1982. Insect pests of potato. Ann. Rev. Entomol. 27:173-204.

Ridgway, R.L. 1980. Assessing agricultural crop losses caused by insects. Pages 229-233, in P.S. Teng, and S.V. Krupa, eds. Crops loss assessment. Proc. E. C. Stackman Commemorative Symposium, Univ. of Minnesota, Agr. Exp. Sta., Misc. Pub. 7, 327p.

Ruesink, W.G. 1975. Analysis and modeling in pest management. Chapter 10, p. 353-376, in R.L. Metcalf, and W.H. Luckmann, eds. Introduction to Insect Pest Management. John Wiley & Sons, NY

Schoonhoven, A. van, and M. Kogan. 1984. Economic thresholds of pest infestations in grain legume crops. In, P. Matteson, eds. Proc. Int. Workshop in Integrated Crop Protection for Grain Legumes, Goiania, Brazil, April 4-9, 1983, (in press).

Schwartz, P.H., and W. Klassen. 1981. Estimate of losses caused by insects and mites to agricultural crops. Pages 15-77, in D. Pimentel, ed. CRC Handbook of pest management in agriculture. Vol. 1, CRC Press Inc., Boca Raton, Florida, 597p.

Southwood, T.R.E. 1978. Ecological methods. Halsted Press, John Wiley & Sons, New York. 524p.

Southwood, T.R.E., and G.A. Norton. 1973. Economic aspects of pest management strategies and decisions. Mem. Ecol. Soc. Australia 1:168-184.

Sparks, W.C., and G.W. Woodburg. 1967. Stages of potato growth. A guide in estimating losses from defoliation. Univ. of Idaho, Agr. Exp. Sta., Bull. 309, 22p.

Sterling, W.L., ed. 1979. Economic thresholds and sampling in Heliothis species on cotton, corn, soybeans and other host plants. So. Coop. Ser. 231, Texas A & M Univ., College Station, Texas. 159p.

Takatori, F.H., W.C. Sparks, and G.W. Woodburg. 1952. A study of simulated hail injury on potatoes. Univ. of Idaho Agr. Exp. Sta., Res. Bull. 22, 15p.

Tamaki, G. 1981. Biological control of potato pests. Pages 178-192, in J.H. Lashomb, and R. Casagrande, eds. Advances in potato pest maagement. Hutchinson Ross Pub., Stroudsburg, Pennsylvania. 288p.

Teng, P.S., and S.V. Krupa. 1980. Crop loss assessment. Proc. E. C. Stackman Commemorative Symp., Univ. of Minnesota, Agr. Exp. Sta., Misc. Pub. 7, 327p.

Thomas, G.D., C.M. Ignoffo, K.D. Biever, and D.B. Smith. 1974. Influence of defoliation and depodding on yield of soybeans. J. Econ. Entomol. 67:683-685.

Walker, P.T. 1975. Pest control problems (pre-harvest) causing major losses in world food supplies. FAO Plant Prot. Bull. 23:70-77.

Wiese, M.V. 1983. Loss assessment: A requisite for corp research and production. Plant Dis., Aug/1983:839.

Wittwer, S.H. 1983. The new agriculture: A view of the twenty-first century. Pages 337-367, in J.W. Rosenblum, ed. Agriculture in the twenty-first century. John Wiley & Sons, New York. 415p.

Zadoks, J.C. 1981. Crop loss today, profit tomorrow: An approach, to quantifying production constraints and to measuring progress. Pages 5-11, in L. Chiarappa, ed. Crop loss assessment methodss. Supplement 3. FAO - Commonwealth AGricultural Bureaux, Slough, England. 123p.

# The Role of Cropping System in Potato Insect Control

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## INTRODUCTION

In this presentation I refer to cropping system as the pattern of growing crops in terms of crop combinations and sequences in addition to the practices and technologies with which the crops are produced. Since this paper deals with the role of cropping systems in potato insect control, I will restrict my presentation to the subject. We should, however, bear in mind that insect control is but one of the numerous technologies that varies with the type of cropping system in use. Several of the examples which will be cited are on crops other than potato since pest control works on the potato crop are mostly restricted to few types of cropping systems, e.g., as sole crop in large commercial fields.

## POTENTIAL DEVELOPMENT OF PESTS IN DIFFERENT CROPPING SYSTEMS

A cropping system may involve one or more crops. It may involve different spatial and temporal crop arrangements of a given crop or of various crops. In general, varying magnitudes of vulnerability to pest damage characterize different cropping systems. This relationship is illustrated in Figure 1 (Litsinger and Moody, 1976).

### Crop itself.

Plant species differ in their attractiviness and suitability as host to pests. We can say for instance that crops like ginger have fewer pests than tomato and possibly most other solanaceous crops. Varieties of a given crop species may be susceptible, tolerant or resistant. It is generally held that natural enemies of pest sustain themselves better in perennial than in annual crops. In general, a short-maturing crop is less exposed than a long-maturing crop and therefore tends to be less vulnerable to pest attack.

### Crop arrangement in time.

Growing of one crop species continuously in the same land is still practiced in some parts of the world. With the advent of short-duration, photoinsensitive rice varities and assured water supply through improved irrigation systems, many rice farms in Asia are planted to the crop with virtually no break between crop cycles except for brief periods for land preparation after each harvest season. This situation reduces pest diversity and the few species that prevail tend to explode in numbers. A case in point is the huge swarms of the rice virus disease vector, Nilaparvata lugens, causing virus outbreaks among rice fields in

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Fig. 1

High Pest Potential → Low Pest Potential

**CROP ITSELF**

Large Pest Complex Not Competitive with Weeds → Crop Species → Small Pest Complex Highly Competitive with Weeds

Susceptible Variety → Tolerant Variety → Resistant Pure Line → Resistant Multigenic

Annual → Perennial

Long-Maturing → Short-Maturing

**CROP ARRANGEMENT IN TIME**

Monoculture → Crop Species Rotation

Continuous Planting → Discontinuous Planting

Asynchronous Planting → Synchronous Planting

Season Favorable to Pest → Season Unfavorable to Pest

**CROP ARRANGEMENT IN SPACE**

Sole Cropping → Row or Strip Intercropping → Mixed Intercropping

Low Planting Density ↔ High Planting Density

Large Field ↔ Small Field

Large Host Crop Area ↔ Small Host Crop Area

Host Fields Aggregated ↔ Host Fields Scattered

Kinds of crops and their arrangement in time and space evaluated as to potential development of pests.

Source: Litsinger and Moody 1976

many parts of Asia.

The pest reducing effects of crop rotation is widely known. Identification of efficient rotation schemes usually involve choice of sequence of crops with few pests in common. Effective as it may be in controlling the target pest there are other important considerations before useful crop rotation schemes are identified and implemented (Raymundo, 1984).
Among the more important considerations are:

(a) usefulness of the crops.
(b) adaptability of crops to local environment.
(c) effective control of other major pests.
(d) place/applicability of rotation scheme to local condition.
(e) availability of resource to meet normal growth requirements of rotation crops.

Presumably pests would build up with successful planting of crop hosts until growth is impaired, Ratoon cropping would be equally disastrous. It is possible, however, that given the condition that favor multiplication of effective parasites, predators and/or antagonistic organisms continuous cropping may lead to reduce pest problems. Reduced severity of take-all disease of cereals during the fourth year of monoculture was atributed to enrichment of soil microflora such as Phialophora radicola exhibiting antagonisms to the take-all fungus, Galumannomyces graminis (Baker and Cook 1974). If only a few species exist, it is possible that continuous cropping may create stability needed for entomophagous insects. Synchronous planting reduce the exposure time of the host to the pest whereas asynchronous planting between adjacent or nearby fields tend to favor pest build up. This effect, however, becomes important in the context of multiple cropping system when two different cropping pattern exists side by side. The effect of season on pest abundance is well-known and adjustment of planting date is an inexpensive means of preventing some destructive pests. In the formulation of cropping pattern the specialist should take this into account in order not to aggravate pest attack by providing suitable hosts for vast populations of the pest in question.

Crop arrangement in space.

Litsinger and Moody (1976) stated that pest reducing effects would be maximal in mixed intercropping because plants of the same crop are more randomly distributed and hence more isolated from their own kind under mixed than under row intercropping. Several works on reduced pest damage in more diverse intercrop plots compared with damage on sole crop plots have been published (Tokahirwa and Coaker 1982, Raymundo and Alcazar 1983, Buranday and Raros 1974, Lewis 1956, Smith 1969). Tables 1 to 5 and figures 2 to 4 illustrate greater reduction in pest intensities on both inter and intra-crop species diversity compared with solid crops

Table 1

Mean number of pupae per plant and root damage index on cabbage alone or cabbage mixed with other crops

| 1977 | pupae/plant 2/ | Root Damage Index 3/ |
|---|---|---|
| Cabbage | 24.0 | 60.9 |
| Cabbage + beans | 10.2 | 46.4 |
| 1978 | | |
| Cabbage | 22.0 | 14.0 |
| Cabbage + grass | 59.0 | 56.7 |

1/ Source: Tokahirwa and Coaker 1982

2/ *Delia brassicae*

3/ Cabbage rootfly

Table 2

Percentage of plants infected with cowpea mosaics virus and cowpea chlorotic mosaic virus (vectored by Chrysomelids notably *Ceratoma* and *Diabrotica* spp.) in different cropping systems 1/

| | Cropping System | | | |
|---|---|---|---|---|
| Days after planting | Cowpea monoculture | Cowpea + corn | Cowpea + cassava | Cowpea + plantain |
| 24 | 8.4 | 9.0 | 5.6 | 5.3 |
| 45 | 14.1 | 16.2 | 15.7 | 15.0 |
| 66 | 29.2 | 25.5 | 21.5 | 23.1 |
| 87 | 31.8 | 33.4 | 35.0 | 25.9 |

1/ Source: Moreno 1978

Table 3

Incidence of *Plutella xylostella* on cabbage in a plot of solid cabbage and cabbage-tomato intercrop 1/

| Days after transplanting | Adults | | Eggs | |
|---|---|---|---|---|
| | sole cabbage | cabbage-tomato | solid cabbage | cabbage-tomato |
| 16 | 11 | 3 | 1381 | 1432 |
| 31 | 25 | 2 | 203 | 53 |
| 44 | 6 | 0 | 52 | 5 |
| 59 | 1 | 0 | 21 | 0 |

1/ Source: Buranday and Raros 1975; figures are total numbers observed on 50 plants.

TABLE 4

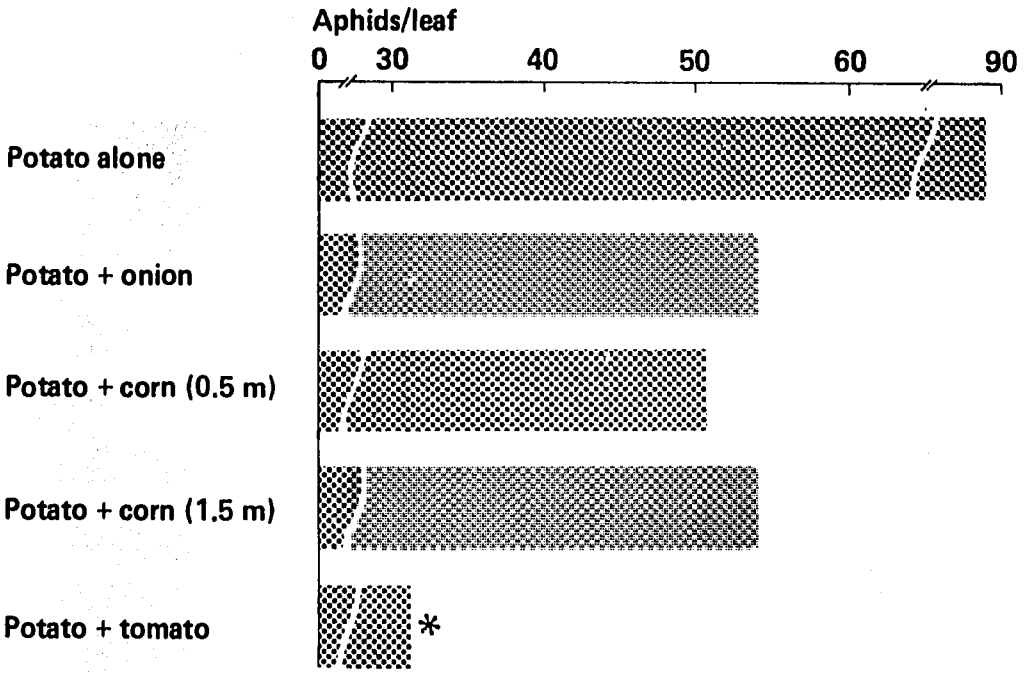
EFFECT OF CROP ASSOCIATION ON THE INCIDENCE OF POTATO TUBER MOTH

| | PERCENT DAMAGED TUBERS | |
|---|---|---|
| | 1981 SAN RAMON | 1982 LA MOLINA |
| POTATO ALONE | 14.0 | 21.6 |
| POTATO-TOMATO | 11.3 | 6.0 |
| POTATO-ONION | - | 8.4 |
| POTATO-CORN | - | 12.7 |
| POTATO-SOYBEAN | 9.6 | 12.4 |
| POTATO-*PHASEOLUS* BEANS | 10.6 | 12.5 |
| LSD | N.S | 4.9 |

TABLE 5

EFFECT OF CROP ASSOCIATION ON THE INCIDENCE OF *DIABROTICA* SP. (YURIMAGUAS 1982)

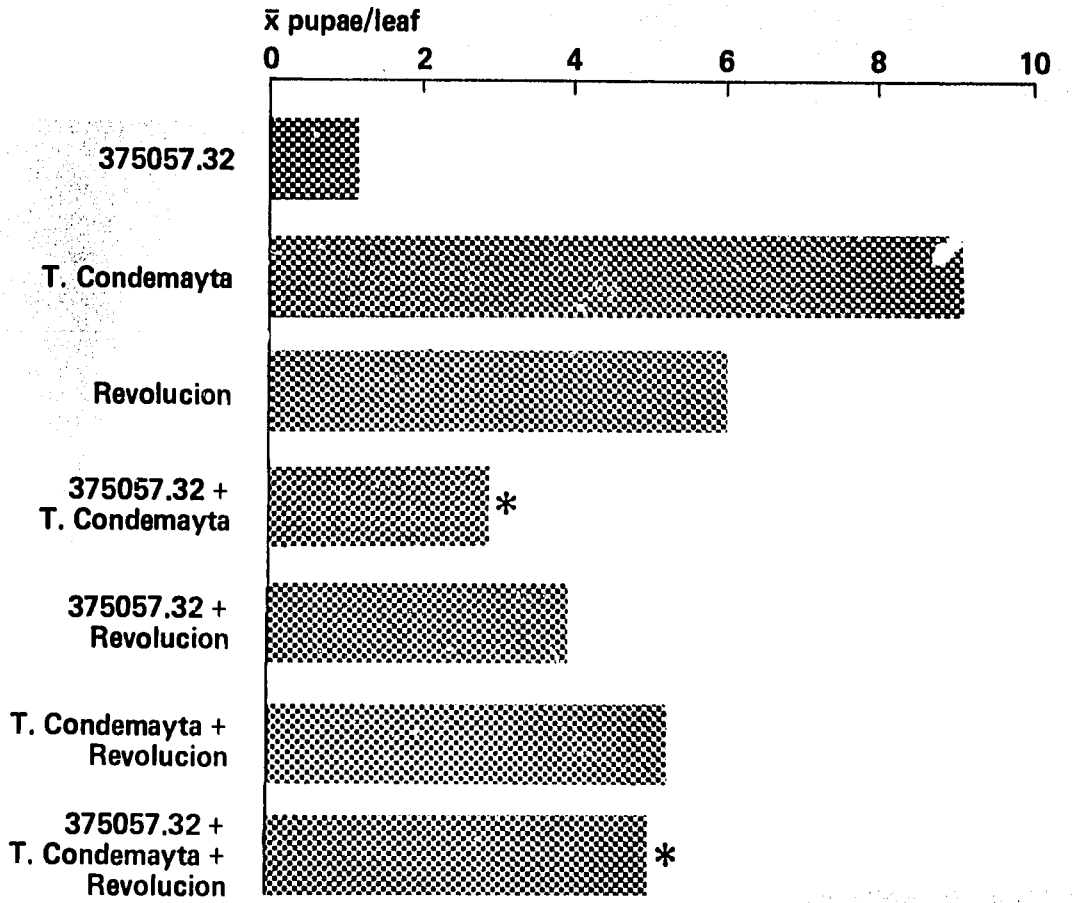
| | PERCENT DAMAGED TUBERS | |
|---|---|---|
| | ALLUVIAL SOIL | ACID SOIL |
| POTATO-ALONE | 7.9 | 64.0 |
| POTATO-RICE | 1.8 | 37.0 |
| POTATO-CORN | - | 28.0 |
| POTATO-SOYBEAN | 9.2 | 35.0 |
| LSD | 5.7 | |




* Significantly less (5%) than potato alone.

Fig. 2

Myzus persicae infestation on potato cv. Desirée alone and associated with other crops, San Ramon, Peru, 1983.




* Significantly different (5%) from T. Condemayta alone.

Fig. 3

**Effects of mixing potato cultivars on infestation by *Liriomyza huidobrensis*, La Molina, Peru, 1983.**

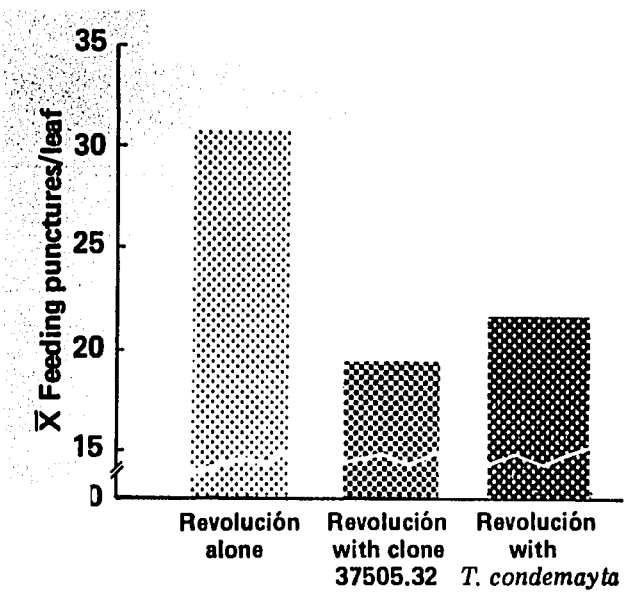



Fig. 4 Damage by leafminer fly (*L. huidobrensis*) on potato cv. Revolucion when planted alone or in mixture with other potato cultivars.

or monocultures. After reviewing a number of published studies Risch et al. (1983) confirmed that herbivore population and species are less abundant in diversified agroecosystems compared with monoculture (Table 6). From the review 62% indicated that herbivores were less abundant among perennial crops compared with 49% among annual crops (Table 7). However, a fairly high percentage (25%) indicated no definite trend of herbivore population among the annual crops. Another finding was that polyphagous species outnumbered monophagous species. The survey found 44% reported more abundant polyphagous species whereas the corresponding figure for monophagous species was only 10%.

Pest intensity relationships along diversity gradient is illustrated in the plant diversity continuum in agroecosystem (Figure 5) described by Perrin (1980). The extent and crop components of diversified farming, a very conspicuous feature of West African cropping system was illustrated by Okigbo (Figures 6 and 7). The relationship relates both spatial and temporal diversity. As the figure shows regional monoculture of perennials consisting of forest and orchard crops have the least temporal and spatial diversity. Several perennial crops regionally, e.g., coconut/oil palm/tropical rain forest have high spatial diversity but still minimal temporal diversity. Maximum diversity (spatial and temporal) is found in local subsistence farming in which several annual crops are intercropped locally. I would like to add that such diversity is often further intensified by the presence of widely scattered perennial tree crops including Fieus, Ceiba, Mangifera, Anona and Leucaena species.

Risch et. al. (1983) hypothesized that the pest reducing effects of diversified systems may be grouped in two: (a) Predation hypothesis (b) Food source concentration hypothesis.

(a) Predation hypothesis.- This postulates that the diversity results in the augmentation of natural enemies. An increased population of natural enemies results to greater control of herbivores. Recent developments have also shown that there may also be direct plant-natural enemy interactions. Altieri et. al. (1981) demonstrated that extracts of a common weed (Amaranthus sp.) sprayed on soybean, cotton, cowpea, and tomato significantly reduced the parasitization of Heliothis zea egg by Trichogramma spp.

(b) Food source concentration hypothesis.- In here the associated plant species affect host finding and host utilization. More precisely two things may take place:

1. the associated plant species mask host finding stimuli leading to reduced colonization.
2. there is a subtle alteration of microhabitat resulting in higher emigration from the host plant.

TABLE 6

NUMBER OF INSECT HERBIVORE POPULATIONS AND SPECIES MORE OR LESS ABUNDANT IN DIVERSIFIED AGROECOSYSTEM COMPARED TO MONOCULTURES. A/.

| HERBIVORES | MORE ABUNDANT | LESS ABUNDANT | NO DIFFERENCE | VARIED | TOTAL |
|---|---|---|---|---|---|
| POPULATIONS | 89% (11%) | 496 (62%) | 207 (26%) | -- | 792 |
| SPECIES | 36% (18%) | 105 (53%) | 18 (9%) | 39 (20%) | 193 |

A/ 150 STUDIES WERE REVIEWED

SOURCE: RISCH ET. AL., 1983

Table 7

Number of monophagous and polyphogous herbivore species more or less abundant in diversified agroecosystem compared with monocultures for annual and perennial cropping systems. a/

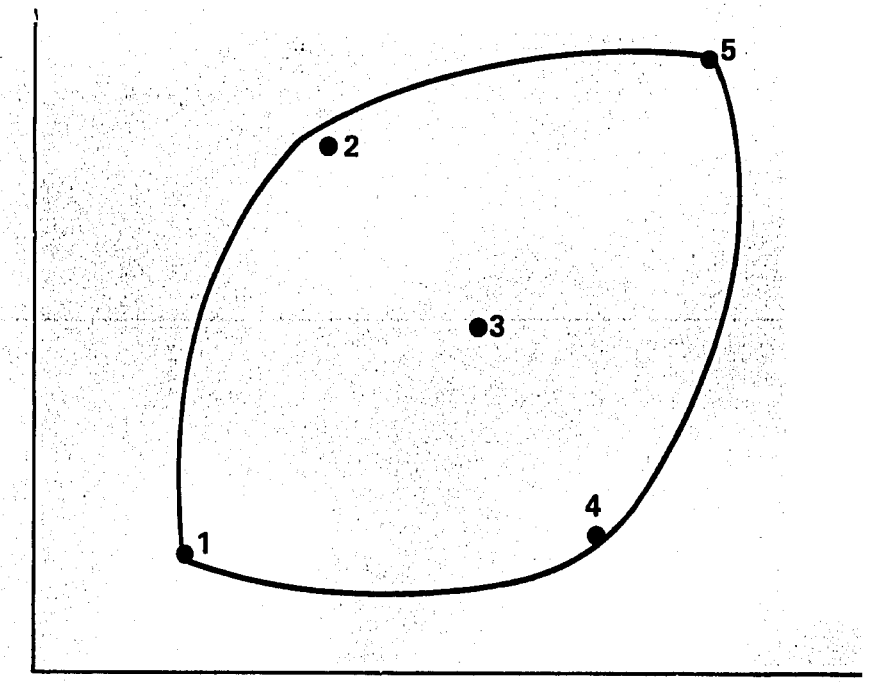
| System | More abundant | No defference | Less abundant | Varied | Total |
|---|---|---|---|---|---|
| ANNUAL | | | | | |
| Monophagous | 3 | 15 | 58 | 23 | 99 |
| Polyphagous | 16 | 2 | 11 | 12 | 41 |
| TOTAL ANNUAL | 19 (14%) | 17 (12%) | 69 (49%) | 35 (25%) | 140 |
| PERENNIAL | | | | | |
| Monophagous | 12 | 1 | 34 | 4 | 51 |
| Polyphagous | 5 | 0 | 2 | 0 | 7 |
| TOTAL PERENNIAL | 17 (29%) | 1 (2%) | 36 (62%) | 4 (7%) | 58 |
| TOTAL MONOPHAGOUS HERBIVORE | 15 (10%) | 16 (11%) | 92 (61%) | 27 (18%) | 150 |
| TOTAL POLYPHAGOUS HERBIVORE | 21 (44%) | 2 (4%) | 13 (27%) | 15 (25%) | 48 |

a/ Perennial systems is one where at least one component crop is a perennial. 150 studies were reviewed.

Source: Risch, et. al. 1983

Fig. 5.

Temporal diversity




Spatial diversity

The plant diversity continuum in agroecosystems:

1. perennial crop regionally, e.g. monoculture forests & orchards
2. monoculture rotation of annual crops regionally, e.g.: wheat, rape, barley
3. some annual/perennial intercrops, e.g. okra/legumes/maize/ sugar cane
4. several perennial crops regionally, e.g. coconut/oil palm/tropical rain forest
5. intercropping of many annual crops locally, e.g. tropical subsistence farming.

Source: Perrin 1980

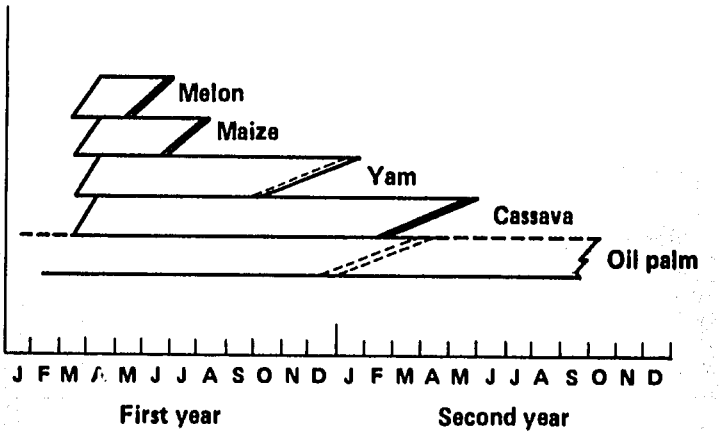



Fig. 6. Mixtures of annuals (short and long duration), semi-perennials and perennials.

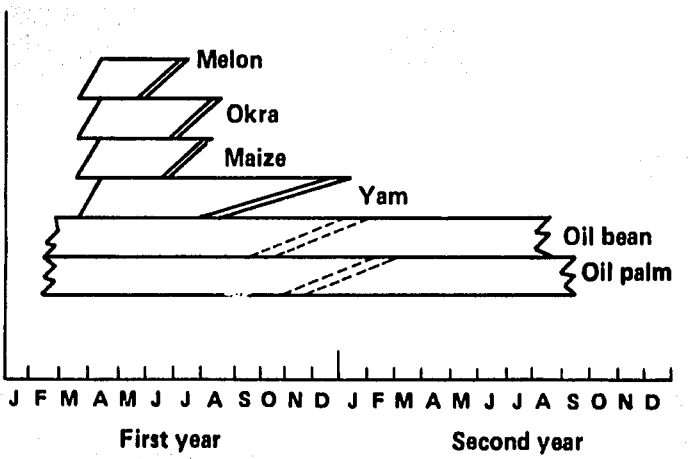



Fig. 7. Mixtures of annuals and perennials.

The extent to which the predation hypothesis or the food source concentration hypothesis influence the resulting pest intensity in a diversified system depends upon the components of that system. Some authors claim that natural enemies are generally more important in controlling herbivorous insects on plants in less disturbed habitats (perennial plants) than on plants in more disturbed habitats (annual plants). Feeny (1976) and Rhoades and Cates (1976) wrote that the strategy of plants in disturbed habitats is to escape from herbivores in space and time (be hard to find) and that these plants tend to be protected by so-called qualitative toxic chemical defenses. This results in: (1) herbivore population outbreaks in annual monocultures because they can more easily find the host plant and (2) the herbivore being relatively protected from natural enemies having sequestered some of the plants's chemical defense. Thus, patterns of resource availability should be more important than natural enemies in diversified disturbed habitats. Plants in more stable habitats, however, are more predictable in space and time and are therefore "bound to be found" by their herbivores; they are more "apparent". These plants tend to be protected by quantitative defenses such as tannins, which reduce herbivore growth rates. Price et.al. (1980) pointed out that this growth rate reduction in herbivores should result in increased effectiveness of natural enemies in these late successional systems, since: (1) greater herbivore polyphagy on these apparent plants results in more apparent herbivores, (2) longer herbivore development time results in longer exposure of immature stages to predators and parasites, and (3) herbivores will not have sequestered toxic chemicals. Thus, enemies should be more important than the patterns of resource availability in diversified perennial systems.

Risch et. al. (1983) summarized the relationship and characteristics of crop diversity, and pest control.

1. Plant diversification of agricultural habitats frequently lowers pest populations.

2. Herbivore movement patterns are more important than activities of natural enemies in explaining the reduction of monophagous pest population in diverse annual system.

3. Beneficial effects of reduced insect population on crop yields are greatest when plant competition between the component plant species is low.

4. Agricultural diversification will tend to be restricted in less developed countries since it tends to be capital-restricted, labor and management intensive production system.

5. Diversified system may provide many long-term benefits and advantages over monocultures including land conservation, reduced pollution by pesticides and slowing down rate of evolution of insecticide resistance.

PREVAILING CROPPING SYSTEMS WITH POTATO AS COMPONENT CROP (TRADITIONAL POTATO GROWING AREAS).-

To a great extent the agricultural farm types of Mantaro Valley, Perú, described by Mayer (1979) gives a fairly representative description of the different cropping systems worldwide of which potato is a component.
Where multiple cropping is practiced, the non-potato component could vary depending upon local importance or unique climatic and edaphic factors. In his paper, Mayer described that the high agro-life zones (3950-4250 m) have upper boundaries which are mostly natural pasture and lower boundaries which are more intensively cultivated. The zone has a sub-humid and semi-frigid climate with high frequency of frosty nights. Main crops are frost-resistant bitter potatoes with few fields planted to oats and some andean tubers. Land is in production only one or two years in a rotation cycle of 4 to 10 years or even more. Thus in vast expanse of land, one sees only a few cultivated fields scattered over huge landscapes. From the preceding description it is logical to expect that insect pests damage are of minimal importance primarily because of to extremes of weather condition as well as high temporal as well as spatial crop diversity.

In the intermediate life zones (3500-4000 m) climate is generally moist and cold. However, it can be quite variable depending upon altitute and topography. A great diversity of crops including potatoes, andean tubers, cereals and grain legumes are found. Crops are planted in varying systems of rotation and fallow cycles: three cropping years plus four years of fallow, four cropping years and three fallow. An ideal complete cropping and fallow cycles is 7 years. Crop mixing including potatoes/andean tubers/legumes and grains is quite common in some parts of this zone.

Small variations in altitude produces differences in climate which are reflected in increasing diversity of crops as well as intensity of land use as one moves from higher to lower areas. Eastern zones have characteristics crop sequences of potatoes-andean tubers-barley with an optional fourth year of European grains (tuber dominant). Western zones are cereal dominant where potatoes barley-barley and often a fourth year of barley is the common crop sequence. Land preparation technology differ between the tuber and grain zones, the footplow being a dominant feature of the tuber zone whereas the oxplow and occasional tractors are used in the cereal zone.

The low agro-life zone (3000-3500 m) is characterized by terrain conditions which are generally favorable and climate is milder making the zone the most extensively used and most productive. Different crop production systems ranging from growing crops in mixtures (peasant dry zone) to the commercial irrigated zone which are basically market-orien

ted enterprises with sizeable capital inputs, heavy chemical fertilizers and insect control. Land fallow is virtually non-existent.

CROPPING SYSTEMS IN NON-TRADITIONAL POTATO GROWING AREAS.

Except for the differences in crop species and/or varieties the prevailing cropping systems in non-traditional potato growing areas would be essentially the same as that of the traditional areas. One end is that practiced by the subsistence peasant farmer who grows a diversified mix of crops in order to meet most if not all his needs. On the other end is commercial and intensive monoculture cropping system requiring sizeable capital investment and high level technology. In between is an array of multiple cropping systems in varying farm sizes and range of spatial and temporal diversity, and employing what I regard intermediate production technologies. The widely practiced multiple cropping through intercropping among many farms in tropical Asia and Africa is an example of this type of cropping system. The system is also widely adopted in China where potato is already an established component crop. Another example is planting tobacco after paddy rice in some parts of the Philippines, a practice which remarkably reduce root-knot nematode damage (Sikora R., 1984 , personal communication).

There is a growing interest in studies to better understand and identify components of multiple cropping systems, not only from the standpoint of reducing pest damage but also other known benefits like weed control, better use of available nutrients, better use of solar radiation, soil fertility amendment, improved soil tilth, use of residual moisture, soil conservation, improved yields, risk aversion, etc.

The range of crops currently grown in non-traditional potato areas are numerous and varied. Among the more important ones are rice, corn, wheat, sweet potato, pineapple, cassava, various vegetables as well as orchard and industrial tree crops.

PEST CONTROL ON NON-TRADITIONAL POTATO GROWING AREAS.

As the place of potato in varying cropping systems continue to be better understood and appreciated, it is imperative that there will be corresponding expansion of areas put into potato production. Van der Zaag and Horton (1983) wrote that the area under potato production in the developing market economies of Africa and Asia increased almost 7% and 4% per year from 1966 to 1980 as opposed to Eastern Europe where the area under production decreased by 1% during the same period. Quite likely the increase in acreage of production in Africa and Asia is at least in part due to the expansion of potato cultivation in non-traditional potato growing areas in these regions.

I believe that one way to insure the successful expansion of the cultivation of a crop grown in a limited scale, or the successful introduc-

tion of a crop into new areas is by blending it with the prevailing cropping systems of the area of intended introduction. To the majority of the small farmers in the developing world this means growing potato in diverse (spatial and temporal) multiple cropping schemes. The usefulness of diversity in regulating pest populations and in mitigating population explosion of harmful pests were detailed in earlier parts of this paper.

The useful knowledge gained in the process of blending non-traditional crops to existing cropping practices is immensely useful in a step by step evolution of suitable technology which depending upon various factors including availability of effective and useful pest control methods, may or may not lead to the crops intensive monoculture. As one author wrote, "Cropping practices evolve to become agriculturally convenient and economically aceptable..... In the developed world agronomic considerations are generally paramount, the "inevitable" pest problem associated with monoculture being so far accepted as a "minor burden" especially because chemical pesticides mostly provide simple means of control".

RELATIVE IMPORTANCE OF DIFFERENT PEST CONTROL APPROACHES IN VARIOUS CROPPING SYSTEMS.

The relative importance of different pest control approaches in varying cropping systems is described in Table 8. The intent of this over simplified tabulation is to make the reader aware of the degree of importance which is presently attached to these approaches in various cropping systems. As understanding of cropping system-pest population dynamics relationships advance, more precise information on the contribution of natural control should become available.

It is seen from Table 8 that where continuous monoculture is practiced, one is virtually dependent upon chemical control. Once rotation, be it fallow or crop rotation becomes a part of the pest control strategy pesticides are still important but sometimes to a lesser degree because of the built-in cultural control component of fallow rotation and natural cultural control component of crop rotation. As a whole genetic resistance is only a minor component of the pest control system for the monoculture crop grower, because as stated earlier, are inexpensive and convenient.

Among spatially diverse cropping systems natural control plays a highly conspicuous role, while the use of pesticide diminishes or it is entirely absent. Mix cropping system of the subsistence farmer utilizes high degree of natural and cultural control, and it can be argued that if he plants native varieties (which he often does), many such varieties possess adequate degree of resistance to the local pests.

Table 8. Relative importance of different pest control approaches in various cropping systems.

| | PEST CONTROL APPROACHES | | | | |
|---|---|---|---|---|---|
| | Genetic Control | Chemical Control | Natural[a] Control | Cultural Control | Novel Approaches |
| **Temporally Diverse Cropping Systems** | | | | | |
| continuous monoculture (no diversity) | *[b] | *** [d] | * | * | |
| monoculture with fallow | * | ***/** | * | ** | |
| monoculture with crop rotation | **[c] | ***/** | ** | ** | |
| **Spatially Diverse Cropping Systems** | | | | | |
| strip cropping | ** | ** | ** | * | |
| row intercropping | ** | * | *** | ** | |
| mix cropping | **/*** | * | *** | *** | |

a/- includes biological control
b/- little importance
c/- moderate importance
d/- great importance

REFERENCES.


Altieri M.A., W.J. Lewis, D.A. Nordlund, R.C. Gueldner and J.W. Todd. 1981. Chemical interactions between plants and Trichogramma wasps in Georgia soybean fields. Prot. Ecol. 3: 259-263.

Baker K.F. and R.J. Cook. 1974. Biological control of plant pathogens. W.H. Freeman, San Francisco, CA, 433 pp.

Buranday R.P. and R.S. Raros. 1975. Effects of cabbage-tomato intercropping on the incidence and oviposition of the diamond back moth, Plutella xylostella (L.) Phillipine Entomologist 2(5): 369-374.

Feeney P.P. 1976. Plant apparency and chemical defense. Rec. Adv. Phytochem. 10: 1-40.

Lewis T. 1965. The effect of an artificial windbreak on the distribution of aphids in a lettuce crop. Ann. Appl. Biol. 55: 513-518.

Litsinger J.A. and K. Moody. 1976. Integrated Pest Management in Multiple Cropping Systems. In: R.I. Papendick, P.A. Sanchez and G.B. Triplet (ed.) Multiple Cropping. Special Publication No. 27, p. 293-316. American Society of Agronomy, Madison, Wisconsin.

Mayer E. 1979. Land use in the Andes: Ecology and agriculture in the Mantaro Valley of Peru with special reference to potatoes. International Potato Center, P.O. Box 5969, Lima, Perú, 115 pp.

Moreno R.A. 1978. Crop protection implications of intercropping. International Workshop Proceedings, Travandrian, India, 27 Nov. - 1 Dec. Ed. by Weber, E. IDRC Pub. 142 e.

Nickel J.L. 1973. Pest situation in changing agricultural systems - a review. Bull. Entomol. Soc. Anm. 19(3): 136-142.

Okigbo B. 1976. The importance of mixed stands in tropical agriculture. In: Papendick, R.I. Sanchez P.A. and Triplett G.B. Eds. Multiple Cropping. American Society of Agriculture Publ. No. 27.

Perrin R.M. 1980. The role of environmental diversity in crop protection. Protection Ecology 2: 77-114.

Price P.W., C.F. Bouton, P. Gross, B.A. McPheron, J.N. Thompson and A.E. Weiss. 1980. Interaction among three tropic levels. Ann. Rev. Ecol. Syst. 11: 41-65.

Raymundo S.A. 1984. Cropping systems and root-knot nematode control. An advance Treatise on Meloidogyne (In Press).

Raymundo S.A. and J. Alcázar. 1983. Sixth Symposium of the International Society for Tropical Root Crops, February 20-25, CIP, Lima, Perú, p. 72 (abstr.).

Rhoades D.F. and R.G. Cates. 1976. Toward a general theory of plant antiherbivore chemistry. Rec. Adv. Phytochem. 10: 168-213.

Risch S.J., D. Adnow and M.A. Altieri. 1983. Agroecosystem Diversity and Pest Control: Data, Tentative Conclusions and New Research Direction. Environmental Entomology 12(3): 625-629.

Smith J.G. 1969. Some effects of crop background on populations of aphids and their natural enemies on brussel sprouts. Ann. Appl. Biol. 63: 326-330.

Tukahirwa E.M. and T.H. Coaker. 1982. Effect of mixed cropping on some insect pests of Brassicas; reduced Brevicoryne brassicae infestations and influences epigeal predators and the disturbance oviposition behaviour in Delia brassicae. Ent. exp. of appl. 32: 129-140.

Van der Zaag D.E. and D. Horton. 1983. Potato production and utilization in world perspective with special reference to the tropics and sub-tropics. Proceedings International Congress "Research for the Potato in the Year 2000", International Potato Center, P.O. Box 5969, Lima, Peru, 44-58.

# MANAGEMENT OF POTATO INSECTS IN STORES

Dr Robert H. Booth

## INTRODUCTION

My presentation is divided into two parts. The first attempts to discuss general problems of the management of stored potato pests and the second refers to CIP research accomplishments in this field. While I must personally accept responsibility for the views put forward in the first section, the results referred to in the second section are those of an interdisciplinary team. Included in this team were CIP entomologists, virologists, bacteriologists, seed production specialists, and myself as storage specialist.

## MANAGEMENT OF POST-HARVEST INSECT PESTS

### Insects and post-harvest losses

Reliable statistics on post-harvest losses in perishable crops are few and for most commodities, including the potato, it is possible to find well recorded individual cases with losses ranging from negligible to 100%. The extent of loss is highly variable, depending on a large number of conditions and factors. The very understanding and definition of loss can vary with location, time, and use of the stored product. While numerous authors have pointed out the dangers of, and have resisted generalizations of loss estimates, the National Academy of Science (1978) cited minimum overall post-harvest losses of 10% for durable crops and 20% for perishables. In potatoes, the opinions of professionals working in this field would indicate that on a global basis a loss of 25% would not be an exagerated figure (Booth and Burton , 1983).

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What role do insects play in creating this loss? According to Bottrell (1980), who refers primarily to the United States of America, harvested agricultural products and their byproducts are commonly attacked by 25-30 species of insects, 50 less common species may cause severe damage, and 100 others create problems in given regions or under special circumstances.

However, Bottrell (1980) draws no distinction between durable and perishable produce. While damage caused by both diseases and pests are considered to be the major cause of loss in stored perishables, attack by rodents and stored-product insects are usually considered of relatively minor importance in comparison to decay caused by microorganisms (National Academy of Science, 1978). This opinion is supported by the fact that the majority of the scarce scientific literature on the management of post-harvest insect pests refers to the more familiar grain storage pests. In referring to all agricultural products in the USA, Bottrell (1980) concluded that "integrated management of pests affecting agricultural products in storage and transit has not received the emphasis that it deserves considering the magnitude of the problem". How much more true this is where perishable crops which have post-harvest insect pests are concerned. For example, in the index of the Commonwealth Agricultural Bureaux, Potato Abstracts, only ten citations can be found using the key words insect pests and storage during the years 1976 to 1982. Of these ten references seven refer to studies on potato tuber moth, one each to the presence of aphids and mealy bugs on stored potatoes, and one to the fumigation of stores for the control of nematodes. It is of course probable that many references on specific pests refer to storage problems but the extent of key wording and indexing in this field is perhaps an indication of the generally low priority and understanding of this topic.

The majority of references dealing with insect pests of stored perishable produce refer specifically to means of controlling the pest concerned and pay no heed to integrating pest management practices with the overall requirements of storage. If one correctly considers the management of, rather than the control or

eradication of storage insects, then clearly an extremely wide range of socio-economic, biological, and physical factors are involved. Hence, an interdisciplinary systems approach is necessary and in which an equally or even more complex array of disciplines must be involved as are required in the pre-harvest sector. On the other hand, it is considered by some that the relatively closed storage environment could simplify the application of integrated pest management principles and readily create promising alternatives which could not be considered in an open field environment.

## Food additives

To counter this, and before discussing the application of integrated pest management principles to the storage phase of a crop production or food delivery system, we must pause and mention the special problems related to the post-harvest use of chemicals and food additive regulations. While attempts to reduce spoilage are desirable, the direct application of toxic chemicals to food products is undesirable. Thus, very few chemical pesticides are approved for direct use on human food. However, substantial quantities of pesticides are used, particularly as fumigants or surface sprays, to protect stored agricultural produce. For example, Bottrell (1980) in referring principally to the USA estimates that 85% of grain stored in commercial facilities is protected with pesticides and many of us have seen unrealistic amounts of toxic insecticides applied to stored potatoes in several countries.

## Economic thresholds

One of the basic concepts of integrated pest management programmes is that of the economic threshold. How can this basic principle be applied to the post-harvest sector. Clearly the concept of economic thresholds is important when we are attempting to manage rather than eradicate key post-harvest pests. However, it is, I believe, well accepted that the determination of economic thresholds is especially complex when more than strict profit-loss relationships are involved, as is commonly the case during the storage of perishable

produce. In particular, the concept of loss and quality is highly variable and it thus becomes difficult to fix a value per unit to the stored crop. For example, resulting from the severe drought in the 1982/83 potato growing season in the Peruvian highlands, not only were yields low but tubers were commonly highly infested with potato tuber moth. Thus, during the period of scarcity in August and September, consumers were paying high prices for stored tubers which in other years would have been considered fit only for animal feed. Additionally, the value of the stored crop is greatly influenced by its appearance and thus insects which only affect appearance may be of equal economic importance to those which adversely affect the usability or palatability of the stored crop. Such factors, which make it extremely difficult to predict the value of stored produce and hence economic thresholds, undoubtedly explain the absence of scientific literature on this subject. Following the storage period, when the crop has been sold and its value determined, it is relatively simple to apply the economic threshold concept and determine what should have been spent on insect pest, and other, management practices. Not withstanding these and other difficulties in predicting actual economic thresholds for key storage insects, it is considered important to attempt to apply the basic concept to their management.

Type of damage and key pests

The identity of key potato storage pests, their economic thresholds, and the necessary management practices will vary with the purpose and duration of storage. Different storage insects cause different types of damage to the stored tuber and their importance and economic value will vary according to many factors.

CIP considers that aphids, because of their role as vectors of severe viruses, and potato tuber moth are, internationally, the key insect pests of stored seed tubers. Information is also accumulating which suggests that mealy bugs are also 'becoming' key pests in seed tuber stores in many regions. During the storage of consumer potatoes, potato tuber moth is considered the key pest. During the production and handling of genetic materials for export purposes, all insects pests are considered as key and measures to reduce the risk of insect contamination are routinely taken at CIP.

The decision to work on these selected key pests has been arrived at through a broad based CIP decision making process, taking into account available resources. These key pests have not been identified by any specific post-harvest loss assessment methodology or survey. The latter methods are not considered the most cost effective for CIP, with its global network and responsibilities, for deciding upon priority stored insect problems. However, it is accepted that greater attention to post-harvest loss assessments and the required methodologies may merit further attention at the national level although the dangers of exhausting all resources in loss assessment programmes leaving nothing for intervention programmes must be guarded against. The single most important factor in the broad based CIP decision-making process has been the accumulation of feedback information from farmers via national scientists and the CIP regional network. In the specific case of the generation, transfer, adaptation and adoption of the diffused light technology for storing seed tubers, the application and continued recycling of the farmer-back-to-farmer model (Rhoades and Booth, 1982) and the involvement of farmers in this research process has given us direct experience of the most important and commonly encountered insect pests causing damage in this storage system.

## CIP's RESEARCH APPROACH AND ACCOMPLISHMENTS

### Integrating insect management with storage needs

In researching and developing management practices for stored potato insect pests, it is clear that these must be compatible with other storage and management practices aimed at fulfilling the needs of storage, which, as discussed, may be multiple and varied. Such needs clearly change as the purpose of storage changes. Thus, in the case of the storage of seed tubers, the overall objective is to provide viable and productive seed tubers in optimum condition at the time required for planting. For the storage of consumer potatoes the aim is to provide consumers with an acceptable product and at the same time avoid health hazards caused either by product deterioration or the use of toxic chemicals. Different storage technologies and accompanying management practices are thus more or less appropriate in different circumstances. This necessitates the research and adaptation of underlying basic principles to specific needs.

The specificity of the needs of each storage situation has greatly influenced the nature of CIP research. Core research, conducted here at CIP headquarters, has concentrated on the application of both storage and insect pest management principles to the development and testing of components. These are then further researched, manipulated and adapted in CIP's regional research network which works with national scientists and farmers in order to develop complete storage systems appropriate to local needs.

Much of the CIP research on the application of storage principles has concentrated on the generation and transfer of the diffused light technology for storing seed tubers. From an entomological point of view this technology is seen to have one major disadvantage as well as numerous advantages. The major disadvantage is the greater exposure of the stored tubers to the environment, including beneficial natural diffused light and harmful insect pests. On the other hand, the very nature of these diffused light stores means that the stored tubers and the attacking insect pests can readily be seen; this is obviously not the case in dark stores. A simple but important point in increasing awareness to the importance of storage pests. Furthermore the greater exposure of the tubers to the environment also means that they are more exposed and accessible to control measures.

Research on the entomological components, which have been shown to be necessary for the development of storage systems appropriate to farmers' needs, has been concentrated in two CIP projects. More fundamental issues of insect biologies and control systems have been investigated in a project on the management of major foliar ant tuber infesting insect pests of potatoes. Information emerging from this project, and other non CIP sources, are then incorporated into a project on the control of post-harvest pests and diseases, alongside the storage projects.

## Aphids

Based on reports from Kenya (Anon, 1976) and on observations by CIP seed production and storage scientists in different countries, CIP research on aphid infestation

of stored seed tubers has concentrated on their importance in disseminating severe viruses during the storage phase and on developing suitable control measures. This research was initiated in 1980 in cooperation with a visiting entomologist and CIP seed production, virology and storage specialists. Results have indicated that, although possibly more exposed to initial infestation, the total number of aphids infesting sprouts increased at the same rate in diffused light and dark stores, but, that more winged aphids were evident on tubers stored in darkness (Parker 1981; Parker et al, 1983a). Spraying the stored tubers every fifteen days with the insecticide Monitor controlled aphid build-up (Parker et al, 1983b) and the dissemination of the aphid transmitted severe viruses PLRV and PVY. Where aphid infestation of sprouts was not controlled, in either light or dark stores, the increase in the incidence of both PLRV and PVY was significant in the subsequent crop from both highland and coastal stored seed tubers (Parker et al, 1983a). During the 1982/83 season it was observed that while the insecticide Monitor was effective in reducing the build-up of PLRV and PVY in two varieties stored in diffused light in the highlands, it was only effective with one of the same two varieties similarly stored on the coast of Peru. For this reason additional trials are continuing using chemical insecticides, antifeedants and repellents to determine efficient control measures in different environments and which may be compatible with the management of other storage insects such as potato tuber moth and mealy bugs.

Virus build-up

To illustrate the potential magnitude of the build-up of aphid transmitted severe viruses during the storage phase, the incidence of PLRV, as detected by ELISA, increased in the 1982/83 trials from a base level of 3.0% to 72.5% and 89.7% in one clone stored unprotected for six months in open diffused light stores in Huancayo and Cañete, respectively. In the same trial the incidence of PVY increased from 9.0% to 55.0% and 28.8% in the highland and coastal sites, respectively.

This information confirms the importance of the storage phase in maintaining the health standards of seed tubers. Thus if attention is not paid to the risk of aphid

dissemination of severe viruses during storage, the expensive results of several years seed multiplication may be lost in just a few weeks. Additionally, the potential for virus build-up during the storage period may help explain common reports of the considerable reduction in virus health standards from one crop season to the next and which have previously been explained only by late season aphid activity in the field.

Potato tuber moth

Potato tuber moth (PTM) has been identified repeatedly as a major pest of stored seed and consumer potatoes, particularly in warm climates but also increasingly in cooler highland potato producing areas, for example in Colombia and Peru. Research to date at CIP has concentrated on identifying and testing potential components of an integrated PTM management system for seed stores which will minimize reliance on the use of toxic insecticides.

Again it is worth repeating that the nature of many natural diffused light seed stores creates greater exposure of the stored seed tubers to this pest. With PTM the barrier effect, that can be provided by different store designs and construction materials, has been shown to be significant in its influence on infestation levels (Parker, 1981). Thus, store design and the nature of building materials play a greater role in the management of PTM in stores that with aphids. It is extremely difficult to make a practical storage building aphid proof. But, as with aphids, once infestation is established damage levels appear similar in diffused light and dark stores. However, because of the open nature of diffused light stores, they have the advantage that the manager can readily see what is happening and also that individual tubers are more accessible for the application of appropriate control measures.

Integrating post-harvest with pre-harvest PTM management practices

Because tuber infestation can occur in the field prior to harvesting and during exposure between harvesting

and storage, it is clear that any post-harvest management practices must be linked to and integrated with appropriate pre-harvest management practices. It is well established that one of the major factors influencing the success or failure of any storage operation is the quality of tubers placed into the stores. Such post-harvest factors must thus be borne in mind when establishing the economic thresholds of such pests in the field. Adequate pre-harvest management coupled with rigorous pre-storage selection must be included as integral components of any post-harvest or storage management system. In the case of PTM, the relative importance of field and post-harvest infestation of tubers has not been establihsed and while this is likely to vary with circumstances it is clearly advantageous to reduce the former through appropriate field management and the latter through the use of appropriate store designs and building materials.

## Evaluation of PTM damage

During the testing of PTM control components appropriate for use in diffused light seed stores under high natural infestation pressures at the CIP field station at San Ramon, considerable emphasis has been placed on the viability of tuber sprouts at the end of the storage period as a means of assessing the efficacy of the particular control measure. Thus, while we are confident about the applicability of many of the tested components to a management system for the storage of consumer potatoes they do require re-evaluation according to the specific needs of stored consumer potatoes.

## PTM control components

Control components which merit specific mention include the use of various types of physical barriers including water, the use of natural insect repellents, use of sex pheromones, and the use of biological and low mammalian toxicity chemical insecticides. Several of these control components will be discussed in greater detail by other speakers during this meeting, so I will restrict myself to a few general comments.

## Physical barriers

As mentioned earlier, physical barriers can act at the store level, for example, the covering of all openings with moth proof screen, but they can also act at the tuber level. Enclosing tubers in containers, covering them with straw, and dusting tubers with materials such as lime, woodash and sawdust has been shown to lower infestation levels (Parker, 1981; Raman and Booth, 1983a).

## Repellents

Research at CIP has shown that the effectiveness of such physical barriers at the tuber level can be greatly enhanced if combined with the use of natural insect repellents. Thus, for example, covering the stored seed tubers with dried and crushed leaves of the weed *Lantana* sp. reduced sprout damage from over 70% in control treatments to below 20% and compared to about 40% with woodash or lime alone (Raman and Booth, 1983a). Other plants which have shown useful PTM repellent properties in Peru include *Minthostachys* sp. and *Eucalyptus* sp.. Similarly, the use of such natural repellents is greatly enhanced when they are applied as a dust to the tubers, as opposed to covering with whole foliage, thus combining repellent and physical barrier effects.

## Water

The presence of water, either on the store walls or on the tuber surface, considerably reduces tuber damage by PTM (Parker, 1981). Although the control mechanism is not fully understood, these observations are consistent with the reduction of PTM damage in the field under natural rainfall or overhead irrigation conditions. It is possible that the water film acts as a type of physical barrier or that it enhances PTM disease invasion and/or renders the environment less suitable for PTM development. Research to extend the use of water at the tuber level with oils proved unsuccessful due to increased tuber rotting (Raman and Palacios, 1983). Use of water is now confined to wetting store walls. For example, irrigation water is made to fall, in a curtain like manner, down the nylon screen walls of one diffused light store at San Ramon. By this

means alone, sprout damage has been reduced to 50% of that found in similar dry stores (Parker, 1981; Raman and Booth 1983a). Use of water in this manner can also be beneficial from the storage point of view. In hot dry climates it will provide for some natural evaporative cooling. Even in the humid conditions of San Ramon, store temperatures in the hottest period of the day may be reduced by up to 4°C.

## Pheromones

The use of sex pheromones in simple funnel traps (Raman, 1982; Raman and Booth, 1983b) has consistently reduced sprout damage to about 10% from over 60% in control treatments (Raman and Booth, 1983a). The number of traps required will vary with infestation pressure, but experience indicates that in stores where heavy losses have been experienced two traps per 10 m2 of store area are required.

## Biological and chemical pesticides

During trials at San Ramon, a single pre-storage application of the biological insecticide Dipel, containing active spores of the bacterium *Bacillus thuringiensis*, gave a similar level of protection as eight applications of the synthetic pyrethroid Fenvalerate applied every 15 days throughout a 120-day storage period. Applications of synthetic pyrethroids at 15 day intervals give significantly reduced damage over 30 day applications (Raman and Booth, 1983a).

## Continuous protection

To maximize the benefit to be derived from the application of some of these control components to the management of seed tubers in stores, consideration needs to be given to the continued protection of the growing sprouts. This may require the repeated application of chemicals, repellents and physical barriers to the sprouts. However, in order to prolong the potential usefulness of insecticides such as synthetic pyrethroids with low mammalian toxicity, their use should be limited and because of the potential development of insect resistance their extensive and indiscriminate use in

either fields or stores should be discouraged. The continued application of repellent dust barriers may in some circumstances create a conflict with the desire to expose growing sprouts to natural diffused light to prevent excessive elongation. Fortunately, in the hotter areas where PTM is most prevalent, high temperatures alone reduce sprout elongation. Where PTM is causing damage in cooler areas, a compromise will need to be sought between PTM control by such means and the desire to keep sprouts short and sturdy through exposure to light.

## Technology transfer

To assist in the transfer of these technologies to farmers, through CIP's regional research network and national scientists, a technology evaluation guide has been prepared (Raman and Booth, 1983b) and training is being conducted. The technology evaluation guide indicates our present state of knowledge and suggests research methodologies as to how these individual PTM control components may be integrated together to form an appropriate PTM management system in accordance with local infestation pressures and storage needs. The management of PTM in stores is included as part of several CIP training courses and in 1984 the first international specialised course on PTM was given at CIP headquarters. Similarly, a combined PTM and storage regional course will be held later this year in Thailand.

## PTM and soft rotting

As these tested components are being transferred to national potato programmes, through the CIP Regional Research and Training network, for testing in actual storage management systems, research here at CIP is commencing to investigate the interaction of PTM with *Erwinia* spp. in the development of storage soft rots. Soft rotting in stores is one of the most important factors limiting potato storage, particularly the bulk storage of consumer potatoes in warm humid environments. Observations indicate an important role of PTM, either as a simple agent of tuber damage and/or as a disseminator of the bacterial causal agents. As with the studies on PTM alone, this research, which commenced in San Ramon in the 1983/84

season, requires both pre- and post-harvest studies and involves inputs by CIP bacteriologists, entomologists and storage specialists.

Tuber resistance

No mention has been made of the use of host plant resistance as a component of systems for the management of insect pests in stores. Host plant resistance clearly has an important role to play and in the case of PTM we have observed clear differences in tuber damage in different clones when stored together in the same store. The topic of breeding for PTM resistance is to be discussed this week so suffice it to say that we look forward to the opportunity of receiving and testing resistant clones in our storage work. In the case of aphids, one can envisage that genetic differences in sprout morphology and hairyness could well influence aphid infestation and virus transmission but to date we have not researched such issues.

## CONCLUSION

The management of insect pests in stored perishable produce has received little attention and hopefully this meeting will help stimulate additional research. Although the damage caused by insects is generally less in stored perishable than in stored grain crops, it can in certain crops, like the potato, reach very significant levels, both in the storage of seed and consumer tubers.

CIP has identified and concentrated its efforts on aphids, PTM, and more recently mealy bugs as the key storage insect pests. Our approach has been to first research the biology of the pest species concerned, where this was not previously known, and then to investigate and test individual control components. These components then enter our Regional Research and Training programme where they are developed into integrated pest management systems for transfer by national scientists to farmers. Such systems must be compatible with the specific storage needs and hopefully will provide alternatives to the present reliance on chemical insecticides.

## REFERENCES


Anon. 1976. Aphid populations and virus spread in seed potato stores. In Potato Research in Kenya 1970-1976. Technical report on the Potato Research Scheme of the Ministry of Overseas Development, London, p. 25-26.

Booth, R. H. and Burton, W. G. 1983. Future needs in potato post-harvest technology in developing countries. Agriculture, Ecosystems and Environment, 9: 269-280.

Bottrell, D. G. 1980. Integrated Pest Management. Council on Environmental Quality, December 1979, U. S. Government Printing Office, 1980-0-330-831, Washington DC, 120 pp.

NAS. 1978. Post-harvest Food Losses in Developing Countries. National Academy of Sciences, Washington DC, 206 pp.

Parker, B. L. 1981. Post Harvest Technology, Aphids and Tuber Moth. Internal Document, International Potato Center, Lima, Peru, 66 pp.

Parker, B. L., Booth, R. H. and Bryan, J. E. 1983a. *Myzus persicae* (Sulzer) in diffuse light and dark rustic storages and resultant PLRV transmission. American Potato Journal, 60: 65-74.

Parker, B. L. Booth, R. H. and Bryan, J. E. 1983b. Methamidophos, Salithion, Phenthoate, and R & H 0994 for control of *Myzus persicae* (Sulzer) on tubers in Peru. American Potato Journal, 60: 55-59.

Raman, K. V. 1982. Field trials with the sex pheromone of the potato tuber worm. Environ. Entomol., 11: 367-370.

Raman, K. V. and Booth, R. H. 1983a. Integrated Control of Potato Moth in Rustic Potato Stores. Sixth Symposium of the International Society for Tropical Root Crops, Lima, Peru, February 1983.

Raman, K. V. and Booth, R. H. 1983b. Evaluation of technology for integrated control of Potato Tuber Moth in field and storage. Technology Evaluation Series No. 10, International Potato Center, Lima, Peru; 18 pp.

Raman, K. V. and Palacios, M. 1983. Approaches to integrated control of Phthori aea operculella. In proceedings of the congress "Research for the Potato in the Year 2000", February 22-26, 1982, International Potato Center, Lima, Peru; 155-156.

Rhoades, R. E. and Booth, R. H. 1982. Farmer-back-to-farmer: a model for generating acceptable agricultural technology. Agricultural Administration, 11: 127-137.

# UTILIZATION OF HOST PLANT RESISTANCE IN PEST MANAGEMENT

F.G. Maxwell

## Introduction

My first attempt to address this topic was in an early paper entitled "Host Plant Resistance to Insects - Nutritional and Pest Management Relationships" (Maxwell, 1972). There was also a short section on utilization of resistant varieties in the chapter prepared by Beck and Maxwell (1976). We stated in that chapter that the greatest use of resistant varieties for the future will undoubtedly be as one component part of a pest management system and that the value of even low levels of resistance can be high because the resistance works as just one of many suppressent factors integrated to prevent the pest population from attaining an economic threshold level. Certainly much has happened since that time that convinces me of the importance of HPR as a component of the IPM system.

In fact, the very foundation of any IPM program should begin with the variety to be grown. Hopefully, a variety resistant to the key pest would be available, but if not, certainly the susceptibility of existing varieties should be carefully evaluated and one selected that would be best from an economic (not necessarily yield) standpoint as conditioned by susceptibility or resistance to key pests, positive or negative interactions with other components of the IPM or production system standpoint. Examples would be fertilization and irrigation programs, cultivation, planting dates, harvesting, etc.

## HOST PLANT RESISTANCE IN PEST MANAGEMENT

It is not my intent to review the role of host plant resistance (HPR) as a principal control method. There are a number of excellent reviews on that subject. It is sufficient to say that plant resistance has been used successfully for many years and as a single pest management factor has achieved an outstanding record. It might be well to review, however, the principal advantages HPR because these relate intimately to the broader role in integrated pest management. Kogan (1982) listed the following as among the most desirable features of plant resistance from the broader ecological viewpoint: 1) specificity - plant resistance is usually specific to a pest or complex of pest organisms and seldom has

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direct detrimental effect on beneficial insects; 2) cumulative effectiveness - high resistance is not necessary, because the effect on the pest population will be compounded in successive generations; 3) persistence - most resistant varieties maintain high levels of resistance for a long time, despite the occasional upsurge of biotypes; 4) harmony with the environment - since no unnatural elements are used, there is no danger of contaminating the environment or endangering man or wildlife; 5) ease of adoption - once developed resistant varieties can easily be incorporated into normal farm operations at little or no extra cost; and 6) compatibility - plant resistance is compatible with other tactics in pest management, being an ideal adjuvant when resistance alone cannot maintain a pest below the economic threshold. Kogan (1982) also noted the following limitations that need to be recognized: 1) time of development - because of the long time (3-15 years) necessary to identify sources of resistance and to breed resistant varieties, the method is not adequate for solving sudden or very localized pest problems; 2) genetic limitations - the absence of preadaptive resistance genes among available germplasm may deter use of the method; induced mutations, although possible would make development programs longer and more complex; 3) biotypes - the occurrence of biotypes may limit, in time and space, the use of certain resistant varieties, but so far breeders have been able to circumvent this problem by using polygenic resistance or breeding varieties resistant to certain biotypes; 4) conflicting resistance traits - certain plant characteristics may act as resistance factors for some species but induce susceptibility to others.

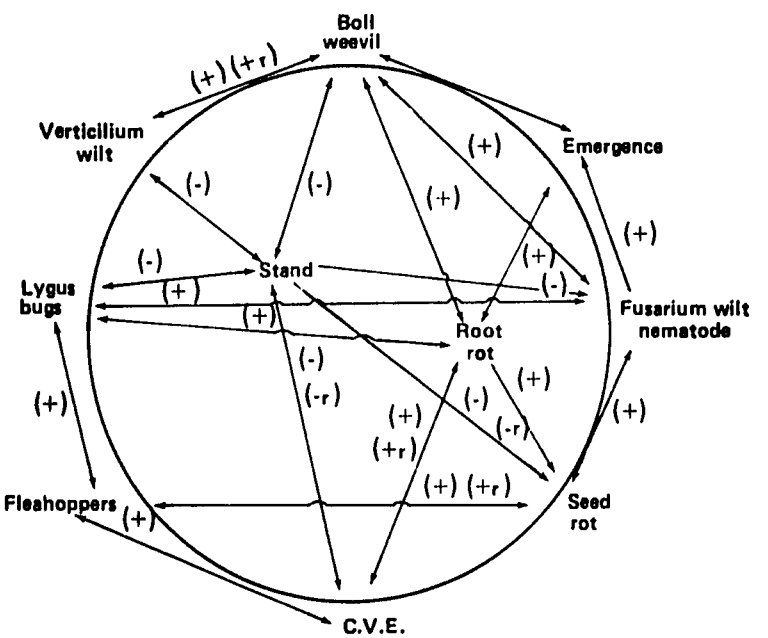
A few additional comments may be in order concerning certain of the advantages and disadvantages of HPR. In regard to specificity, there are more instances appearing where there is some cross resistance. For example, in the breeding program in Texas for multiple adversity cottons, boll weevil, *Anthonomus grandis*, fleahopper, *Pseudatomoscelis seriatus* and plantbug *Lygus lineolaris* and bollworm *Heliothis zea* resistance has been increased through a recurrent selection scheme focused principally on developing resistance to seedling disease and bacterial blight *Xanthomonas malvacearum* (Bird et al 1982; Bird 1982).

The MAR system uses four traits (seed coat resistance to mold, a reduced rate of germination at 56°F, high resistance to races of the bacterial blight pathogen and resistance to seedling pathogens) for selection in order to gain favorably for resistance to many adversities along with improved yield and earliness. This procedure, in addition to producing MAR varieties resistant to diseases, has in recent years indicated that insect resistance traits were also being selected along with disease resistance. Figure 1 illustrates the model of genetic interrelation-

ships between various traits. Of the ten traits, direct selection is applied only for germination (C.V.E.) and STAND (seedling disease resistance) to make favorable progress in the MAR system for disease, insect and nematode resistance as well as yield and quality.

Also, it has been found that in breeding for increased levels of certain phenolic and other toxic compounds in plants, that these compounds affect more than one species of pest species as well as potentially affecting parasitoids and predators feeding on surviving pest species that may have high levels of the toxic chemicals in their bodies. Examples are gossypol and tannins in cotton which affect a number of pest species.

Fig. 1. Genetic interrelationship model showing important favorable associations (those having a likelihood of being significant) among ten host traits which are used in the system of multiadversity resistance in cotton. Arrows indicate whether the association is one or two directional, and the sign of the partial regression coefficient is given. When significant, the sign of the simple correlation coefficient is given. Of the ten traits, direct selection is applied only for C.V.E. and STAND (seedling disease resistance) to make favorable progress in the MAR system. Bird and El-Zik (1984) personal communication.



The impact on affect of resistance traits on pest species can now be effectively used through models on computers to determine potential cummulative effectiveness without expensive field plots once the models are validated. This technology will enable us to study more effectively, not only the cummulative effectiveness of lower levels of resistance, various combinations of resistance, but effects on beneficial organisms as well as effectiveness of other IPM tactics on total population suppression.

Persistence or permanence of resistance has generally been good depending upon number of genes involved. Biotypes, however, are becoming increasingly troublesome as evidenced by the sudden appearance of Biotype E, Porter et al (1982) which apparently developed on tolerant sorghum but was also capable of handling genes for antibiosis transferred to Amigo wheat from "Insave" rye (Secale cereale). The Amigo wheat was never released or planted to large acreage before the discovery of Biotype E which was first found in test cultivars but later widely dispersed over several States in the Midwest. This is an exception to the commonly held belief that biotypes develop as a result of selection pressure from the resistant variety. This troublesome find indicates the great plasticity of the greenbug and emphasizes the need for basic insect and plant genetic work to determine the biochemical and genetic interrelationships between insect and host that brings about such dramatic unexplained host changes.

In relation to limitations on the use of HPR the genetic limitations that exist with some crops may in the future be overcome through new tissue culture and genetic engineering techniques now under development. These tools may serve as an extremely helpful technique to create greater diversity in germplasm for selection. The use of these techniques in HPR will be challenging and will require concerted efforts by more applied plant breeders and entomologists to communicate and cooperate with very basic molecular scientists. This will not be easy and the diverse material produced must still go through the long road of development to varietal release.

The fourth limitation listed for HPR, conflicting resistance traits is certainly important for researchers in HPR to be constantly aware. It is absolutely critical that resistance (chemical or physical) be checked against all other pests in the crop system for affect, both arthropods and diseases. Increasing or decreasing certain levels of chemicals or changing the morphological or physical aspects of a plant may create a super susceptible host to an organism not currently a pest. Niles (1980) discusses this subject in some detail on cotton and gives several excellent examples.

## PLANT RESISTANCE AND CHEMICAL CONTROL

The reduction in pest numbers achieved through resistance is constant, cummulative and practically without cost to the farmer. The reduction in pest numbers makes control by chemicals and cultural methods usually easier. There is some indication recently, however, (Plapp and Benedict, personal communication) that surviving insects previously exposed to high levels of toxic natural chemicals (tannins and phenolics like gossypol) may be more difficult to kill with certain synthetic chemicals. More information is needed before it is known how serious this might be but it does signal caution and researchers developing resistant lines with high levels of toxic natural chemicals should be aware of this possibility.

Adkisson and Dyck (1980) have illustrated through use of simple mathematical models the potential impact of varieties having low or moderate levels of resistance on insect populations over several generations and years. The use of chemicals in conjunction with the resistant variety makes control of surviving populations much easier. Also, once the pests are controlled, future increase will be slower. Moreover, if the pest population should be subjected to a natural calamity, such as a disease epidemic, heavy attack by parasites and predators, or adverse weather, insecticides may not be needed because resurgence to original levels will occur slowly, if at all.

Rice is an excellent example where resistant varieties have been used in combination with insecticide treatments to produce economical yields. Adkisson and Dyck (1980) and Dyck et al (1976) have documented the great advantages that resistant varieties of rice, in combination with insecticides, has played in management of pests in the Philippines and Southeast Asia.

McMillian et al (1972) reported on the advantage of resistance to corn earworm in a sweetcorn hybrid in increasing effectiveness of chemical control. The susceptible hybrid without insecticide had only 22% damage free ears, whereas the resistant hybrid had 78% damage free ears. When both hybrids were sprayed with insecticides, the susceptible hybrid was 86% damage free and the resistant hybrid over 93% damage free.

Another advantage of growing a resistant variety is that the reduced rate of pest increase may greatly prolong the time required by the pests to reach the economic threshold for crop damage. This is especially true if the resistance in the variety produces mortality to the immature stages and prolongs the developmental period of the survivors. This area is just now beginning to receive the attention it deserves.

Obviously resistant plants do change the economic threshold for target pests yet in most instances we still use the economic threshold established for susceptible varieties. Hallman et al (1984) has redefined economic thresholds for sorghum midge Contarinia sorghicola (Coquillett) on resistant sorghum hybrids for Texas. This has resulted in the saving of 1-3 applications of insecticide in heavy midge areas. The moderate level of resistance is usually sufficient in light midge areas to eliminate the need for any insecticide applications.

Benedict and Zummo (1984) and Zummo (1984) studied economic injury levels (EIL) for Heliothis spp. as a function of resistant and susceptible cotton cultivars. The cotton cultivars included "Stoneville 213" a commercial Delta long-season, "Tamcot SP-37" a commercial short-season and "TAMCOT CAM-E" a commercial short-season variety that has moderate levels of bollworm resistance (Zummo et al 1983), and RDC-102 a short season glandless advanced breeding line. In summary, susceptibility of the four cotton cultivars to H. zea damage was found to vary with the cultivar and with stage of growth. On these bases predictive equations were developed for the different cultivars at three stages of growth. Dynamic cost/benefit EIL tables were determined for the different cultivars and growth stages thus forming a series of EIL schedules for use in applying insecticides in the Texas Gulf Coast IPM Program. CAM-E, the resistant cultivar had the lowest regression stage indicating a high level or resistance to damage which allows a greater limit of error in timing of insecticide applications.

Other ways in which plant resistance enhances the effectiveness of insecticide treatments is through 1) morphological changes in the plant that provide resistance (i.e., frego bract, okra leaf cottons) may also allow better insecticide coverage of the fruiting structures; 2) changes in plant morphology may cause the insects' predators to be more active on the plant, thereby increasing their contact with pest species; and 3) toxic substances or nutritional inadequacies in the resistant plant may make the pest more susceptible to certain chemicals or naturally occurring pathogens (Maxwell 1972).

The above listed characteristics of resistant plants may be used to reduce the number of insecticide treatments, as well as amounts applied. This reduces the expense of producing the crop, conserves beneficial insects, preserves environmental quality and slows the rate of development of insecticide resistant pest strains.

## VARIETIAL RESISTANCE WITH BIOLOGICAL CONTROL

Classical biological control as well as microbial control is usually

compatible with plant resistance. In varieties that have high resistance (antibiosis) there may be instances where the pest is so reduced by resistance that natural enemies cannot find an adequate host population. Also, there are situations where some toxic compounds responsible for resistance to the pest may affect the parasite or predator. An example is the alkaloid α tomatine, which is an antibiotic factor in tomato to several lepidopterous pests, and is toxic to the endoparasitoid Hyposoter exiguae (Viereck) (Campbell and Duffy 1979).

Van Emden (1966) showed in a model that even very low levels of resistance may have a dramatic effect on the efficiency of natural enemies, i.e., .05% resistance which is difficult to even measure can turn an inefficient predator into a highly effective one. Price et al (1980) also discussed the influence of the host plant on interactions between phytophagous insects and their natural enemies.

Starks et al (1972) demonstrated that resistant varieties of barley and sorghum complemented the activity of the parasite Lysiphlebus testaceipes (Cresson) in reducing damage to plants and in the production of greenbugs Schizaphis graminum (Rondani).

By reducing the pest population to a degree, varietal resistance enables the natural enemies to be more effective because of an improved pest/natural enemy ratio. This may be especially useful if the crop contains tolerance which enables the pest species to build to populations that attract and allow natural enemies to increase to effective levels.

Resistance mechanisms that disrupt normal behavior patterns or cause the insect to be more restless and move around more may expose them more readily to natural enemies.

One excellent example is frego bract cotton (Maxwell 1972) which causes abnormal behavior of the boll weevil by increasing the searching time to locate a suitable oviposition site. Mitchell et al (1973) suggested that the expression of resistance was due, in part, to the increased efficiency of predation (i.e., longer exposure time to predators). Frego bract was also determined to profoundly affect the ability of the native boll weevil parasite, Bracon mellitor (Say) to successfully attack the boll weevil. Percent parasitism of the boll weevil in frego bract fruits was 50% compared to 74% in abnormal bract fruit (McGovern and Cross 1976). Conflicting results from pest studies on the expression of boll weevil resistance in frego bract cottons may be in part, to variation in beneficial arthropods.

Pathak (1970, 1975) and Dahms (1972) gave additional examples where re-

sistance increased searching time or slowed nymphal development which increased exposure time to potential parasites and predators. High gossypol and high tannin lines of cotton for example, slow larval development of surviving bollworms.

Glandless cotton, where gossypol has been removed genetically, appears to aid in biological control. In glandless plants the Heliothis larvae appear to remain in the upper third of the plant, whereas on glanded cultivars, young larvae tend to move downward sooner. This change in behavior coupled with the tendency of predators to be concentrated in the upper 1/3 of the plant (Wilson and Gutierrez 1980) could also result in higher levels of predation on Heliothis spp. on glandless cotton.

Pubescense may also impact adverse effects on natural enemies (Bergman and Tingey 1979). At Texas A&M, Zummo et al (1984) studied the effect of cotton pubescense on the abilities of the parasitic wasp Trichogramma pretiosum (Riley) and the predatory larvae of Chrysopa rufilabris (Burmeister), to parasitize or consume Heliothis zea (Boddie) eggs. They found that, of the total H. zea eggs present, 57.2, 45.4 and 6.2% were parasitized on TAMCOT SP-21S Smooth leaf, TAMCOT SP-37 hirsute and TM-1 ($H_2$) Pilose, respectively. All parasitism levels were significantly different (P=0.05, DMR). In addition, there was a significant inverse correlation coefficient ($R^2$=.88) between the number of eggs parasitized and trichome density.

Trichome density affected the ability of different C. rufilabris instars to find and destroy H. zea eggs. For first instar larvae, 18.1, 10.9 and 2.1% of the total H. zea eggs present, were destroyed on TM-1 Smooth, TM-1 normally hirsute and TM-1 ($H_2$) Pilose, respectively; for second instars, 69.1, 56.0 and 25.9% and for third instars 71.5, 65.7 and 47.5%, respectively.

Zummo et al (1984) concluded from this data that increasing cotton trichome density reduces the abilities of T. pretiosum and C. rufilabris to find and destroy H. zea eggs.

It is important to realize that biological control and Host Plant Resistance can have many beneficial interactions and perhaps some negative possibilities in an integrated pest management program.

We must also be aware that the crop species can by design be changed to alter pest behavior and/or plant habitat; thus making the pest more susceptible to predation and parasitism. With more understanding, researchers may favorably manipulate present populations of beneficial insects to maximize their efficiency and consequently raise action

threshold levels. This can be very important in marginally resistant cultivars in total IPM program.

## VARIETAL RESISTANCE AS A SUPPLEMENT TO CULTURAL CONTROL METHODS

The use of resistant varieties combined with good cultural management is a powerful tool in managing pests. Examples are early season cottons, (planting dates) coupled with fertilizer and irrigation management, defoliation, strip harvesting and early stalk destruction for boll weevil, bollworm, cotton fleahopper and pink bollworm control in Texas. The nectariless character coupled with planting and plow-up dates in Arizona is another example. The use of resistant crops in providing physical barriers to migrating insects has been effectively used, i.e., Atlas Sorgo highly resistant to chinchbug, *Blissus leucopterus leucopterus* (Say) to protect susceptible yellow dwarf milo.

Strip cropping of a more susceptible plant species to manage or attract the pest species out of a crop has been used successfully in California and Mississippi (alfalfa, stripping with cotton). The use of alfalfa, sesame and wild mustard in cotton to manage bollworm and *Lygus* spp. are being actively explored.

More attention in the future should be devoted to planting resistant crops to limit population spill-over into more susceptible crops that follow in the season, i.e., resistant corn to limit bollworm in cotton, resistant cotton to limit bollworm in soybeans, etc.

In summary, plant resistance does have a vital role in Integrated Pest Management in many crops. It should provide the foundation on which to build pest management programs. It is extremely important to understand the interactions and complementary effects of other components of the system with resistance (biological, chemical and cultural). Pest management programs will accentuate the importance of host plant resistance, particularly the utilization of lower levels of resistance that have not been properly emphasized in the past.

## LITERATURE CITED


Adkisson, P.L. and V.A. Dyck. 1980. Resistant varieties in pest management systems. IN: Breeding Plants Resistant to Insects. pp. 233-251. F.G. Maxwell and P.R. Jennings (Editors). John Wiley and Sons, New York.

Beck, Stanley D. and Fowden G. Maxwell. 1976. Use of plant resistance. IN: Theory and Practice of Biological Control. pp. 615-31. C.B. Huffaker and P.S. Messenger (Editors). Academic Press, New York.

Benedict, John H. and Guy R. Zummo. 1984. Economic injury levels for Heliothis spp. as a function of cultivar. So. Coop. Ser. Bull. In Press.

Bergman, J.M. and W.M. Tingey. 1979. Aspects of interactions between plant genotypes and biological control. Bull. Entomol. Soc. Am. 25:275-79.

Bird, L.S. 1982. Multi-adversity (diseases, insects and stresses) resistance (MAR) in cotton. Plant Dis. 66:173-76.

Bird, L.S., K.M. El-Zik, P. Thaxton and R.G. Percy. 1982. Further progress in developing multi-adversity resistant (MAR) cotton. Proc. Beltwide Cotton Prod. Res. Conf., Cotton Disease Council 42:40-41.

Campbell, B.C. and S.S. Duffey. 1979. Tomatine and parasitic wasps: Potential incompatibility of plant antibiosis with biological control. Science 205:700-02.

Dahms, R.G. 1972. The role of host plant resistance in integrated insect control. IN: Control of Sorghum Shoot Fly. M.G. Jotwani and W.R. Young (Editors). pp 152-67. Oxford and IBH Publishing Co., New Delhi.

Dick, V.A., E.A. Heinrichs, M.D. Pathak and R. Feuer. 1976. Insect pest management in rice. Paper presented at the Seventh Natl. Conf. Pest Control Council Philippines, Cagayan de Oro City. Mimeographed. 29 pp.

Hallman, G.J., G.L. Teetes and J.W. Johnson. 1984. Relationship of sorghum midge (Diptera: Cecidomyiidae) density to damage to resistant and susceptible sorghum hybrids. J. Econ. Entomol. 77:83-7.

Kogan, Marcus. 1982. Plant resistance in pest management. IN: Introduction to Insect Pest Management 2nd Ed. pp. 93-134. Robert L. Metcalf and W.H. Luckmann (Editors). Wiley-Interscience, John Wiley and Sons, New York.

Maxwell, F.G. 1972. Host plant resistance to insects - Nutritional and pest management relationships. IN: Insect and Mite Nutrition. pp. 599-609. J.G. Rodríguez (Editor). North-Holland, Amsterdam.

Maxwell, F.G. 1972. Morphological and chemical changes that evolve in the development of host plant resistance to insects. J. Environ. Qual. 1:265-70.

McGovern, W.L. and W.H. Cross. 1976. Affects of two cotton varieties on levels of boll weevil parasitism (Coleoptera: Curculionidae). Entomophaga. 21:123-25.

McMillian, W.W., B.R. Wiseman, N.W. Widstrom and E.A. Harrell. 1972. Resistant sweet corn hybrid plus insecticide to reduce losses from corn earworms. J. Econ. Entomol. 65:229-31.

Mitchell, H.C., W.H. Cross, W.L. McGovern and E.M. Dawson. 1973. Behavior of the boll weevil in frego bract cotton. J. Econ. Entomol. 66:677-80.

Niles, G.A. 1980. Breeding cotton for resistance to insect pests. IN: Breeding Plants Resistant to Insects. pp. 338-69. F.G. Maxwell and Peter L. Jennings (Editors). John Wiley and Sons, New York.

Pathak, M.D. 1970. Genetics of plants in pest management. IN: Concepts of Pest Management. pp. 138-57. R.L. Rabb and F.E. Guthrie (Editors). North Carolina State University, Raleigh.

Pathak, M.D. 1975. Utilization of insect-plant interactions in pest control. IN: Insects, Science and Society. pp. 121-48. D. Pimentel (Editor). Academic Press Inc., New York.

Porter, K.B., G.L. Peterson and O. Vise. 1982. A new greenbug biotype. Crop Sci. 22:847-50.

Price, P.W., C.E. Bouton, P. Grows, B.A. McPheron, J.N. Thompson and A.E. Weis. 1980. Interactions among three trophic levels: Influence of plants on interactions between insect herbivores and natural enemies. Annu. Rev. Ecol. Syst. 11:41-65.

Starks, K.J., R. Muniappan and R.D. Eikenbary. 1972. Interaction between plant resistance and parasitism against greenbug on barley and sorghum. Ann. Entomol. Soc. Am. 65:650-55.

Van Emden, H.F. 1966. Plant insect relationships and pest control. World Rev. Pest Control 5:115-23.

Wilson, L.T. and A.P. Gutiérrez. 1980. Within plant distribution of predators on cotton. Comments on sampling and predator efficiencies. Hilgardia 48:3-11.

Zummo, Guy. 1984. Interaction between Heliothis zea (Boddie) and selected cotton cultivars. Ph.D. Dissertation, Texas A&M University. 75 p.

Zummo, G.R., J.H. Benedict and J.C. Segers. 1983. No-choice study of plant-insect interactions for Heliothis zea (Boddie) (Lepidoptera: Noctuidae) on selected cottons. Environ. Entomol. 12:1833-36.

Zummo, G.R., M.F. Treacy and J.H. Benedict. 1984. Interactions of host plant resistance in cotton with predators and parasites. Prot. Ecol. In Press.

# Breeding and Screening for Resistance to Major Potato Pests

M. Scurrah and K. V. Raman

## Introduction

One of CIP's priority areas of research is the utilization of cultivated and wild genetic resources to develop potato populations with good agronomic characteristics and resistance to important diseases and pests. It is only in recent years, after becoming aware of the shortcomings of chemical control, that CIP has given attention to insect pests. Although it takes a very long time to develop resistance, if successful, it is likely to benefit farmers more than chemical control. Priority has been given to the potato tuber moth *Phthorimaea opercullela* Zeller, because of its worldwide importance, attacking potatoes in developing countries where most of the damage is reported as storage losses.

There are other important pests localized in different potato production areas. However, CIP has not embarked on breeding programs for these, although whenever possible CIP will provide expertise and support to National Programs. Table 1 summarizes the key pests, their distribution, and CIP's involvement.

Table 1. Key pests in developing countries

| Pest | Distribution | CIP's involvement |
|---|---|---|
| Potato tuber moth *P. operculella* | Worldwide | Screening and breeding in La Molina and San Ramon |
| Andean Potato weevil *P. suturicallus* (comp) | Andean countries | Screening methods, no breeding, backstopping Colombia through PRACIPA |
| Leaf Miner Fly *L. huidobrensis* | Peru, Brazil | M.S. thesis on screening methods, no breeding, involvement through PRACIPA Possible use of glandular trichomes and sticky traps |
| Aphids, mites (*M. persicae*) thrips (*P. latus*) | Worldwide | Cornell contract for breeding with glandular trichomes, at CIP screening of Cornell developed material with spider mite and PPO tests |

## Source of resistance and screening methods for potato tuber moth

Because most damage by the tuber moth is reported in stored potatoes, a laboratory test to identify resistance in tubers was developed with the objective of identifying genotypes which show less damage and reduce reproduction of the potato tuber moth. In the first test, the first instar larvae are inoculated on individual tubers in closed containers. The number of larvae varies with tuber size (one larvae per 5 gr of tuber weight) according to the maximum number of larvae which a particular tuber size can support. Table 2 gives the evaluation scales utilized.

## Material screened

A number of 3,747 accessions of cultivated native varieties comprising mostly *S. tuberosum* ssp. *andigena*, but also *S. chaucha*, *S. curtilobum*, *S. juzepczukii*, and *S. stenotomum* were evaluated.

A total of 452 accessions of wild material obtained from Sturgeon Bay, Wisconsin, was tested including some interspecific hybrid populations.

Table 2. Screening methods for tuber moth resistance

| Assessment | Evaluation | Time (days) | Scale | Classification |
|---|---|---|---|---|
| Damage | $\bar{x}$ holes on tuber | 15 | 1 | Highly resistant (HR) |
| | | | 1-2 | Resistant (R) |
| | | | 2-4 | Susceptible (S) |
| | | | 4 | Highly susceptible (HS) |
| Inhibition to pupation | $\bar{x}$ pupae/tuber | 21 | 0-.5 | Highly resistant (HR) |
| | | | .5-1 | Resistant (R) |
| | | | 1-2 | Susceptible (S) |
| | | | 2 | Highly susceptible (HS) |

## Results

Twenty-two highly resistant clones were identified in the cultivated material and 25 clones comprising 11 wild species including three resistant clones from an interspecific hybrid population involving *S. chacoense* (chc), *S. phureja* (phu), and *S. sparsipilum* (spl) (Raman et al. 1982).

The inheritance of the three chc-spl-phu resistance was studied by Raman et al.; the resistance of *S. stenotomum* was studied by Egúsquiza; and the resistance of ssp. *andigena* was utilized but not systematically studied. In the following, the main results are summarized:

The resistant clones in the interspecific hybrids were crossed to three susceptible clones from the same population, and the progeny of the different crosses were tested with the closed container method. Based on the frequency of resistance in the progeny it was concluded that resistance was mostly dominant and controlled by few genes. In one reciprocal cross cytoplasmic effects on resistance were observed. Resistance was transferred to the tetraploid level through two clones with 2n eggs (Table 3). Twenty clones of this tetraploid progeny (P'S) showed resistance. This population was one of the base populations for the tetraploid breeding program.

Table 3. First tetraploid populations derived from resistant spl-chc-phu diploid hybrid.

| Family | Pedigree 2x (♂) | | 4x (♀) |
|---|---|---|---|
| $P_1$ | 120.13 | x | CFL 69.1 |
| $P_2$ | 120.13 | x | R-268.12 |
| $P_3$ | 120.13 | x | 377019.5 |
| $P_4$ | 120.13 | x | BR-63.74 |
| $P_7$ | 120.13 | x | 700024 |
| $P_9$ | 120.13 | x | 6.1 |
| $P_{13}$ | 120.13 | x | 432 |
| $P_{15}$ | 120.13 | x | Atzimba |
| $P_{16}$ | 120.13 | x | 377019.5 |
| $P_{17}$ | 116.36 | x | 432 |
| $P_{19}$ | 116.36 | x | 702060 |

Egúsquiza, working with the phu-chc-spl hybrids, also found a high percent (average 40%) of resistant segregants, however, he did not detect any cytoplasmic effects in his reciprocal crosses. In the next generation the lack of cytoplasmic effects was confirmed. S. stenotomum resistant clone OCH 10409 was studied in the S x R crosses. Resistance in the progeny ranged from 7.18% to 18.75%. Quantitative and minor gene effects were hypothesized to control resistance. He also showed that material tested 90 days after harvest showed a higher susceptibility ratio than when tested 60 days after harvest.

The remaining wild species were studied by Chávez. Upon retesting them, he reduced the resistant entries to 4 species: S. comersonii, S. sucrense, S. tarijense, and clones from an interspecific hybrid of S. sparsipilum, x S. phureja. With these he generated a large hybrid population mostly with tuberosum haploids. The progeny showed 25% resistance when screened in closed containers. However, tests in storage resulted in only 2% of resistant selections. This material is being multiplied for more detailed tests in order to include it into the main tetraploid populations. It is of special interest that the spl-phu hybrids gave progenies with highest resistant levels and frequencies.

Work with diploid populations is continuing. The objectives are to further elucidate the inheritance of resistance, increase the frequencies of resistance genes, and to obtain diploids with 2n gametes in order to incorporate the resistance into the tetraploid breeding population.

## Tetraploid breeding progress

Two tetraploid populations were planted in the Winter of 1981. Thirty families consisted of 4 resistant P clones utilized as male crossed to clones with earliness and heat tolerance. Nine additional families were derived from resistant S. tuberosum ssp. andigena clones crossed with a bulk pollen of the same population.

At harvest, 472 clones from the hybrids of P x Tropical clones and 173 from the andigena population were selected for agronomic characteristics, and five tubers of each were submitted to a resistance test in an infested store at San Ramon.

Results of the family performance, percentage selection and results of the store test of the two populations are given in Table 4 and 5. A higher frequency of resistance was found in the andigena population, 17 clones were identified as resistant in the material originating from the spl-chc-phu hybrids. It was evident that the resistance identified at the diploid level was not expressed at the tetraploid level.

Table 4. Resistant selections in tetraploid population where resistance is the pollen parent

| Code | Family | No. tested | Number* Resistant |
|---|---|---|---|
| 281601 | 375512.3 x Bulk $P_1$ | 13 | 1 |
| 281602 | 375568.2 x Bulk $P_1$ | 28 | 2 |
| 281604 | 377892.2 x Bulk $P_1$ | 29 | 1 |
| 281605 | 377892.2 x $P_1$-1 | 22 | 1 |
| 281606 | 379222.27 x $P_1$-4 | 24 | 1 |
| 281611 | BR69.84 x $P_1$-8 | 25 | 4 |
| 281617 | LT-2 x $P_1$-4 | 7 | 1 |
| 281620 | DTO-2 x $P_1$-8 | 11 | 1 |
| 281621 | DTO-28 x $P_1$-1 | 5 | 1 |
| 281624 | DTO-33 x $P_1$-1 | 4 | 1 |
| 281627 | 275024.12 x Bulk $P_1$ | 12 | 1 |
| 281630 | 275062.39 x $P_1$-4 | 7 | 2 |
| Total families | 36 | 475(14% select) | 17 |

*infested store test

Table 5. Selection and result of resistance test of andigena population

| Code | Accession Number | Selected* | Resistant** |
|---|---|---|---|
| Iw1 | H/3 196 | 12 | 5 |
| Iw2 | 702607 | 18 | 7 |
| Iw3 | OCH 4830 | 17 | 6 |
| Iw4 | 702330 | 44 | 4 |
| Iw5 | 702020 | 10 | 2 |
| Iw6 | 700124 | 32 | 1 |
| Iw7 | 701122 | 14 | 9 |
| Iw8 | 700502 | 36 | 2 |
| Iw9 | 702701 | 4 | 1 |
| | | 173 (19%) | 38 (21%) |

*mostly poor tuber shapes - many small tubers
**infested store test

Another population was grown in the summer of 1982, utilizing the P clones as females crossed again to early maturing, heat-tolerant material. The objective was to harvest the material under tuber moth pressure when the insect population was at its peak, and at the same time select for adaptation under warm conditions. The results (Table 6) were presented at a Post Congress Workshop on Insects in February 1982. It was then suggested that selecting seedlings under PTM pressure would help in rapidly identifying resistant genotypes in the field.

Table 6. Selection and resistance in PTM resistant clones x lowland tropic material in a field exposure trial

| Code | Cross | Number Evaluated | No. selected February'82 (no damage) | 10 days later | 30 days* later |
|---|---|---|---|---|---|
| PTM-1 | $P_1$-8 x 377877.5 | 180 | 14 | - | - |
| PTM-2 | " x 378015.18 | 30 | 5 | 3 | 2 |
| PTM-3 | " x 379920.37 | 150 | 8 | 2 | - |
| PTM-4 | " x 378013.6 | 53 | - | - | - |
| PTM-5 | $P_1$-4 x 379920.37 | 148 | 4 | 2 | 1 |
| PTM-6 | " x 3778-7.25 | 84 | 2 | 1 | - |
| PTM-7 | " x LT-1 | 7 | - | - | - |
| PTM-8 | $P_1$-13 x 377877.25 | 154 | - | - | - |
| PTM-9 | " x 378015.18 | 30 | - | - | - |
| PTM-10 | $P_1$-26 x 377920.37 | 180 | - | - | - |
| PTM-11 | " x 377877.25 | 181 | 2 | - | - |
| PTM-12 | " x 378015.18 | 85 | - | - | - |
| | | 1,282 | 35 | 8 | 3 |

* rated resistant

Although the frequency of selection has been extremely low it was hoped that through intercrosses of resistant genotypes and the use of larger populations a fair number of resistant genotypes would be identified. Intercrossing to produce the next (second) cycle of selection took place. The progenitors utilized were the 17 resistant clones from the phu-chc-spl x tub (281) population, 15 andigena $F_1$ resistant selections, and a few backcrosses to S. tuberosum, to andigena, and to the $P_1$ population. A total of 160 crosses were made and 105 families planted in November, 1982. By this time the 17 selections were retested in a field trial

and only 2 were reported as moderately resistant. The andigena clones did not tuberize in this field trial. Families that did not involve these two resistant clones were discarded. The harvest and resistance results are summarized in Table 7. Families including early-heat-tolerant parents showed higher yield.

Table 7. Summary of field results and resistance of 1982 population - November 82-March 83

| | |
|---|---|
| Number of families | 105 |
| Number of genotypes | 20,000 |
| TYPE OF SELECTION | |
| 1) Tuberization | 3,400 clones |
| 2) Selection in field | 500 clones |
| 3) Selection for PTM | |
| a) Damage 10 days after harvest | 16 clones |
| b) After inoculation with larvae | 7 clones |

When the 16 clones that showed no damage in the field were inoculated with larvae, 7 were selected which showed less than 1 pupae. The pedigree of these clones is given in Fig. 1.

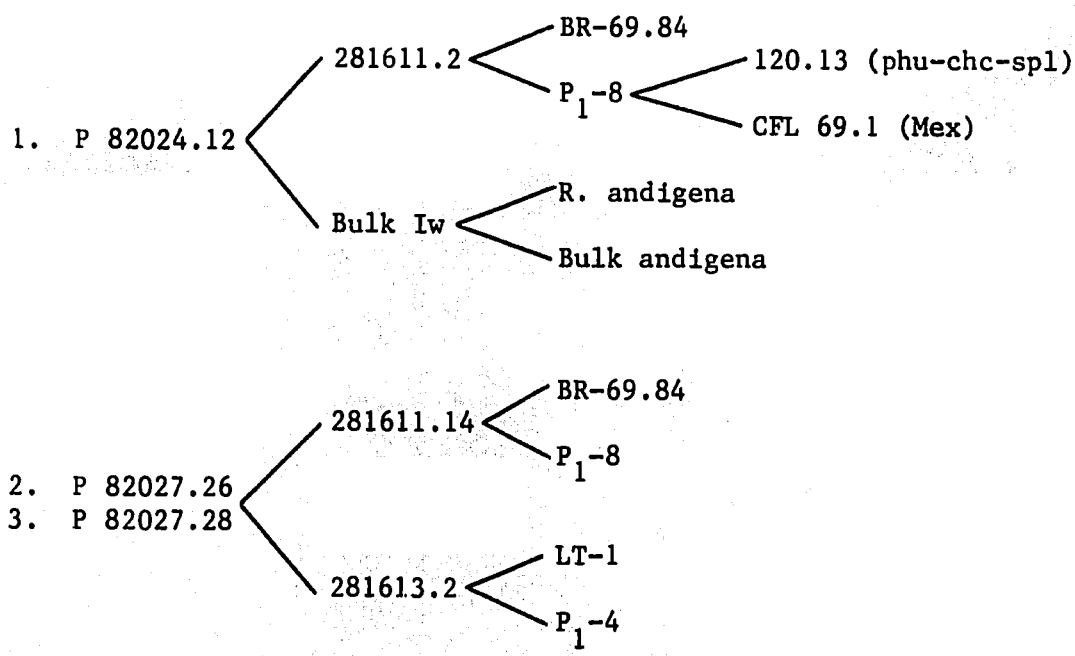



Fig. 1. Pedigree of 7 resistant clones

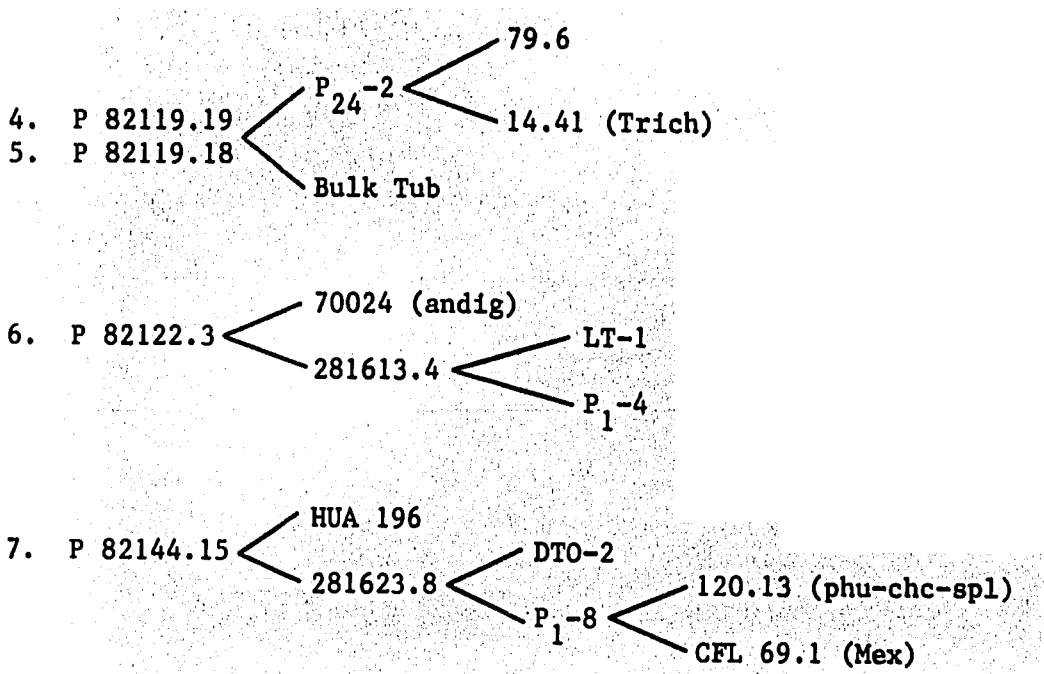



Fig. 1. Pedigree of 7 resistant clones (cont.)

Further laboratory tests with the 7 selections (Table 8 and 9) indicated that all tubers showed differing levels of resistance as compared to the susceptible check Parda Pastusa. The main difference mechanism seemed to lie in the skin of tubers, and the clone P 82144.15 presented the highest level of resistance.

Table 8. Relative preference of 7 clones (choice experiments)

| Clone | Relative preference in tuber corks (%) | Relative preference in whole tubers |
|---|---|---|
| P 82024.12 | 38.46 | 66.67 |
| P 82027.26 | 115.38 | 50.00 |
| P 82119.18 | 30.77 | 50.00 |
| P 82119.19 | 69.23 | 25.00 |
| P 82027.28 | 100.00 | 75.00 |
| P 82144.15 | 0.00 | 25.00 |
| P 82122.3 | 92.31 | 50.00 |
| Parda Pastusa (check) | 100.00 | 100.00 |

Table 9. Number of pupae in corks and whole tubers in three best clones (no choice experiments)

| Clone | Corks | Whole tubers |
|---|---|---|
| P 82144.15 | 1.2 | 0.8 |
| P 82119.18 | 3.0 | 0.4 |
| P 82119.19 | 1.0 | 0.2 |
| Control | 3.2 | 1.8 |

L. Valencia (personal communication)

Failure to increase frequencies of resistance could be due to the fact that hybridization to susceptible material was undertaken before resistant genes had been sufficiently accumulated. Therefore, it was planned to return to the original resistant tetraploid and andigena clones.

We also abandoned field screening for resistance selection as too little was known about mechanisms of tuber resistance in the field. It is also difficult to grow material during the summer at La Molina. A population generated by recycling original materials as mentioned above, was planted in the winter of 1983. A summary of the performance characteristics of this population is given in Table 10.

Table 10. Characteristics of Cycle 1 intercrosses with andigena accessions

| | |
|---|---|
| No. of families | 123 |
| No. of genotypes | 10,000 |
| Percentage survival | 70 |
| Percentage tuberization | 61.5 |
| $\bar{x}$ yield/plant | 320 grs. |
| $\bar{x}$ yield of selected | 731 grs. |
| Percentage selection for agronomic characteristics | 18 |
| No. of genotypes tested for resistance | 920 |
| No. resistant genotypes | 14 |
| Percentage resistance | 1.6 |

After harvest 920 selections were exposed for 1 month to tuber moth in-infestation. Those with no damage were then tested twice under closed container conditions in the laboratory for inhibition of pupation. Thirty-seven clones (1.8%) showed no or little damage, of these 17 clones showed little pupation on the first test and 4 on the second test (Table 11).

Table 11. Levels of resistance of 14 selected clones

| Code | Cross | $\bar{x}$ holes* | $\bar{x}$ pupae** |
|---|---|---|---|
| P 83601.7 | $P_1$-2 x Iw 7.16 | 0.50 | 0.40 |
| P 83611.1 | $P_1$-8 x Iw 8.11 | 0.75 | 0.20 |
| P 83611.7 | " | 1.80 | 0.70 |
| P 83612.10 | $P_1$-8 x Iw 13.5 | 0.30 | 0.40 |
| P 83614.5 | $P_1$-11 x Iw 7.16 | 1.50 | 0.60 |
| P 83628.4 | $P_2$-4 x Iw 13.5 | 1.70 | 0.80 |
| P 83651.6 | $P_{24}$-2 x Iw 7.16 | 1.40 | 0.15 |
| P 83655.20 | Iw 1.14 x $P_1$-13 | 0.10 | 0.60 |
| P 83693.15 | Iw 7.16 x $P_1$-13 | 1.20 | 1.50 |
| P 83698.11 | Iw 7.18 x $P_3$-5 | 0.00 | 0.05 |
| P 83706.6 | Iw 8.11 x $P_1$-13 | 0.05 | 0.00 |
| P 83707.6 | Iw 8.11 x $P_2$-5 | 0.80 | 0.15 |
| P 83751.2 | OCH 2330 x 281611.4 | 4.70 | 0.70 |
| P 83756.3 | 702020 x $PTM_1$-11 | 1.70 | 0.40 |
| Revolución | | 5.10 | 2.80 |

* results of one month exposure to tuber moth (damage)

** average of two laboratory tests

In this experiment it is of interest to point out that going back to the first cycle did not again increase significantly the frequency of resistance. The explanation may lie in the fact that the original ex spl-phu-chc tetraploid P-clones were not properly screened, or alternatively that resistance per se has a very low heritability. No correlation has been found between the controlled laboratory tests and infested store tests indicating that our understanding of the host-pest relationship needs further improvement. A possible cause of the difference lies in

reinfestation in the store test as well as possibly in differential reactions with increased physiological age of tubers. Thus, the genetic data of the diploid population was based on tests which differ from the tests in stores used to select tetraploids derived from the diploids. The store tests are more realistic, but the levels of infestation may have been too severe in some tests.

## Future breeding strategy

There is a need to better understand the mechanisms of resistance and to apply screening methods relevant to the pest's mode of attack in field and store environments. In this regard, a high priority should be placed on critical studies of resistance in specific genotypes and the expression of resistance in progenies. Environmental factors may alter screening results. A sufficient level of repeatability should be obtained before large scale breeding should begin again. If trichomes are found to protect the plant against foliar attack, this feature will also have to be incorporated into the population.

## Reference Cited

Raman, K. V. and M. Palacios. 1982. Screening potato for resistance to potato tuberworm. J. Eco. Entom. 75: 47-49.

Raman, K. V., M. Iwanaga, M. Palacios, and R. Egúsquiza. 1981. Breeding for resistance to potato tuberworm Phthorimaea operculella (Zeller) Am. Potato J., Vol. 58, p. 516 (abstract).

# Research Progress: Potato Glandular Trichomes and Steroid Glycoalkaloids

Ward M. Tingey, Peter Gregory, Robert L. Plaisted, and Maurice J. Tauber

## 1.0 INTRODUCTION

The potato, a crop plant of international importance, is subject to yield and quality losses by arthropod pests or the pathogens they transmit, virtually everywhere the crop is grown. The exploitation of natural defense mechanisms through selective breeding offers the promise of another tactic for management of arthropod pests. This paper is focused on progress in determining the role of two specific phenomena in defense of Solanum species against arthropods, and progress in utilizing these resistance factors in potato breeding.

## 2.0 GLANDULAR TRICHOMES

The glandular trichomes of wild, tuber-bearing Solanum (Tourn.) species defend against many potato-infesting pests (Gibson and Turner 1977) and offer exceptional opportunity for exploitation in breeding resistant potato cultivars (Tingey 1981). Gibson (1971) was among the first to associate glandular pubescence with insect resistance of the wild potato species, S. berthaultii, S. polyadenium, and S. tarijense. These 3 species have high densities of tetralobulate (Type A) and/or ovoid (Type B) glandular trichomes on their foliage; upon contact by an arthropod, a viscous exudate is discharged and transferred to the arthropod's body. For the green peach aphid, Myzus persicae (Sulzer), potato aphid, Macrosiphum euphorbiae (Thomas), Colorado potato beetle, Leptinotarsa decemlineata (Say), and two-spotted spider mite, Tetranychus urticae (Koch), the exudate typically accumulates on tarsi, impeding movement or entrapping the insect on foliage (Gibson and Turner 1977). Adhesive immobilization leads to arthropod mortality within several hours of confinement. Tingey and Gibson (1978) have demonstrated similar entrapment of the potato leafhopper, Empoasca fabae (Harris), by glandular trichomes of S. polyadenium and S. berthaultii, and have also shown that trichome exudate accumulates on leafhopper mouthparts, preventing feeding and introducing mortality. In addition to the pest species cited above, glandular trichomes of Solanum species have been associated with host resistance to Epitrix cucumeris (Tingey and Sinden 1982), E. harilana rubia (Gibson 1978), a tarsonemid mite, Polyphagotarsonemus latus (Gibson 1978), and a thrips, Thrips tabaci (Gibson 1979).

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## 2.1 Defensive Impacts Against Key Pests

Green peach aphid. Aphid mortality and immobilization due to encasement of tarsi and labia by trichome exudate increase with a rise in Type A and Type B trichome density and volume of Type A trichome glands (Tingey and Laubengayer 1981). Plants bearing both Type A and B trichomes are more resistant to insect infestation than those bearing Type A trichomes alone (Tingey and Sinden 1982). Type B exudate enhances entrapment properties of Type A trichomes by accelerating discharge of the latter, thus increasing rates of insect immobilization (Tingey and Laubengayer 1981). Glandular trichomes provide greater levels of defense against immature aphids and leafhoppers than against adults. Mortality of the green peach aphid varies inversely with age, peaking at 91% for 2nd stadium nymphs. Encasement of tarsi and labia by trichome exudate is greatest on nymphs and least on adults (Tingey and Laubengayer 1981). The presence of trichome exudate on tarsi significantly hinders aphid mobility. Aphids lacking trichome exudate on their tarsi rapidly leave foliage of susceptible cultivars, whereas escape times of exudate-encumbered aphids on resistant glandular pubescent plants are ca. 3 times longer (Tingey et al. 1982).

Feeding behavior of the green peach aphid (GPA) on S. berthaultii is characterized by delay in time to first probe, i.e., increased preprobe time, compared to susceptible potato cultivars. More than 50% of aphids failed to probe S. berthaultii during 45 minutes of access. The causal factor in this abnormal behavior is associated with exudate of Type B trichomes. This conclusion is supported by three observations: (1) mechanical removal of Type B droplets from foliage of S. berthaultii led to decrease in preprobe time, (2) preprobe time on an S. tuberosum x S. berthaultii hybrid lacking Type B trichomes did not differ from that on susceptible S. tuberosum cultivars, (3) transfer of Type B exudate from S. berthaultii to foliage of a susceptible S. tuberosum cultivar resulted in a significant delay to the first probe (Lapointe and Tingey 1984).

Gunenc and Gibson (1980) reported that Type B trichomes of S. berthaultii interfered with acquisition of potato virus Y by the green peach aphid. Subsequently, Lapointe (1983) investigated vector potential of GPA for PVY using glasshouse-grown populations of S. berthaultii and S. tuberosum, cv. 'Chippewa." Eight weeks after introduction of the vector, incidence of PVY infection in S. berthaultii was 18% (13/71), compared to 52% (38/72) of cv. 'Chippewa.' Infection of S. berthaultii was confined to plants adjacent to the PVY source plant, whereas infection of cv. 'Chippewa' was widespread throughout the experimental block. These findings suggest that the glandular trichomes

of S. berthaultii act in reducing PVY infection, at least in part, by limiting the rate of virus spread from plant to plant.

Colorado potato beetle. Casagrande (1982) reported reduced oviposition by CPB on S. berthaultii and on an S. tuberosum x S. berthaultii hybrid in laboratory studies. Larval survival and developmental rates were also adversely affected on S. berthaultii. A two-year field study in New York (Wright et al. 1984) indicated that numbers of overwintered CPB adults and defoliation levels were significantly reduced on S. berthaultii compared to S. tuberosum. Hybrid families had intermediate levels of defoliation and CPB densities. During the second CPB larval generation, densities of small (1st and 2nd instars) and large (3rd and 4th instars) larvae were reduced 90% and 87%, respectively, on hybrid families, and 96% and 97%, respectively, on S. berthaultii compared to CPB densities on S. tuberosum.

Through use of controlled environment rearing procedures, Dimock (unpubl. data) observed increased mortality, lower stage-specific survivorship, delayed development, and reduced fecundity on Solanum berthaultii and S. polyadenium compared to performance on commercial potato cultivars. Extremely high mortality of first instars on S. polyadenium was associated with high densities of Type A glandular trichomes, confirming the observations of Gibson (1976). Tarsi of more than 95% of dead larvae on S. polyadenium were encased in Type A exudate, compared to 14% on S. berthaultii. Similarly, adults on S. polyadenium acquired large quantities of trichome exudate on their tarsi and experienced difficulty in locomotion and attachment to the plant. Mobility and attachment behavior of adults on S. berthaultii did not appear impeded by trichomes.

## 2.2 Integration of Glandular Trichome Resistance with Biological and Chemical Control Tactics

Integration with predators and parasitoids. Glandular pubescence of S. berthaultii adversely affected 11 aphidophagous species in glasshouse trials. The negative impacts included reduction in searching time by adult coccinellids, decreased mobility of newly hatched chrysopid and coccinellid larvae, reduction in oviposition of Chrysopa oculata, and decreased survival of the parasitoid, Aphidius matricariae (Obrycki and Tauber 1984). These findings, however, greatly overestimated the magnitude of adverse effects on predators and parasitoids under field conditions. Mechanical exclusion studies over two field seasons demonstrated that naturally occurring aphid predators (primarily Coccinellidae and Chrysopidae) and parasitoids (largely

Aphididae) produced greater than 65% reduction in aphid population levels on potato clones bearing moderate densities of glandular trichomes. In the absence of natural enemies, aphid populations were directly related to density of glandular trichomes. Glandular trichomes effectively reduced aphid population growth early in the season while natural enemies exerted their effect during late July and August (Obrycki and Tauber 1984). These findings indicate that biological control and resistance to aphids conferred by glandular pubescence are compatible and complementary tactics in integrated pest management of potato (Obrycki et al. 1983).

Compatibility with insecticides. Field trials during 1983 in a commercial production area on Long Island, N.Y. indicated that three to four applications of oxamyl and endosulfan (1.12 kg AI/ha of each) were sufficient to maintain acceptably low levels of defoliation by the Colorado potato beetle on three hybrid families, one application was needed on *S. berthaultii*, but three applications failed to control CPB on *S. tuberosum*. At least two additional applications of oxamyl and endosulfan would have been necessary to provide CPB control on *S. tuberosum* similar to that of the other plant families. These findings are equivalent to a 20-40% reduction of insecticide usage on the hybrids, and an 80% reduction on *S. berthaultii* compared to commercial potato cultivars (Wright et al. 1984).

## 2.3 Inheritance of Glandular Trichomes and Breeding Progress

Gibson (1974) was the first to report successful hybridization of *S. berthaultii* and *S. tuberosum*. In studies of trichome inheritance in *S. berthaultii* and *S. tarijense*, Gibson (1979) reported that the presence of Type B trichomes is controlled by a single dominant gene, but in crosses with *S. phureja* and *S. tuberosum*, at least one set of recessive genes is necessary for optimum secretory capacity. Mehlenbacher et al. (1983) also studied the inheritance of Type B droplet size, as well as density of Type A and B trichomes. Contrary to findings of Gibson (1979), Mehlenbacher et al. (1983) concluded that the variation observed for each of the three traits studied could not be explained by hypotheses based on the segregation of one or two loci. Mehlenbacher et al. (1983) obtained heritability estimates of 20-30% for density of Type A and B trichomes and 60% for Type B droplet size, and proposed the use of breeding systems adapted to quantitatively inherited traits.

Interspecific hybrids of *S. berthaultii* and *S. tuberosum* were first produced at Cornell in 1977 (R.L. Plaisted, pers. comm.). The initial phase of varietal development has been the production of a germplasm

base encompassing several sources of S. berthaultii and a broad series of disease-resistant S. tuberosum subsp. tuberosum and S. tuberosum subsp. andigena clones. A valuable and unique genetic base has been created in these efforts. Currently available are ca. 15,000 clones (15 families), four generations removed from the S. berthaultii parents, and expected to yield plants equal to S. berthaultii in levels of insect resistance and glandular trichome traits. An additional 1500 clones are available that are closer in lineage to S. berthaultii than the population of 15,000, and whose parents were selected on the basis of their superior field resistance to the green peach aphid. Seven parental accessions of S. berthaultii are represented in these 1500. This population is unique, not only for the insect resistance derived from S. berthaultii, but also for its resistance to the golden nematode, potato virus Y, and potato late blight. The latter attributes were contributed by resistant S. tuberosum subsp. tuberosum and S. tuberosum subsp. andigena parental clones. Several elite clones resistant to aphids, golden nematode, potato virus Y, and potato late blight, and free of potato spindle tuber viroid (PSTV), potato virus S (PVS) and potato leafroll virus (PLRV) are maintained in vitro as meristem cuttings and available for distribution to others for multiplication and research purposes.

At present we are one cycle into the second phase, i.e., alternate year outcrossing of insect-resistant clones to quality S. tuberosum germplasm, followed by intercrossing of progenies in these families. Progenies are selected for yielding ability, earliness and appearance, as well as for disease resistance, phenolic oxidation activity of Type A trichomes, and density of glandular trichomes. This breeding approach should facilitate rapid development of insect-resistant clones with good yields of attractive tubers. Clones at this level of development will be attractive to other potato breeders for use in variety development.

Another facet of the Cornell program is the discovery of clones within these populations bearing resistance to the Colorado potato beetle. The significance of this pest in northeastern U.S. potato production exceeds that of aphids because control options for CPB are extremely limited. As noted previously, resistance of S. berthaultii and interspecific S. tuberosum x S. berthaultii hybrids to CPB does not appear to be conditioned by entrapment in trichome exudate. For this reason, we will initiate a separate program of breeding for resistance to CPB. Until the CPB-limiting factors in S. berthaultii are identified, we will utilize defoliation ratings and population growth parameters for selection of resistant clones.

Hybrid clones produced in the Cornell breeding program have reduced population levels of the green peach aphid in field trials as much as 81%, compared to infestation levels of S. tuberosum cultivars. Similar levels of control of the Colorado potato beetle have been achieved with corresponding reductions in yield only one-half that of S. tuberosum cultivars.

## 3.0 STEROID GLYCOALKALOIDS

Steroid glycoalkaloids are found in all tissues of the potato plant. The chemical diversity, biosynthesis, toxicology, inheritance, and analytical properties of these compounds have been recently reviewed by Coxon (1984), Gregory (1984), Kuc (1984), and Sinden et al. (1984). The role of potato glycoalkaloids in resistance to insects, pathogens, and nematodes was reviewed by Tingey (1984).

These steroid glycosides have been associated with defense against two major insect pests of potato, Leptinotarsa decemlineata and the potato leafhopper, Empoasca fabae. Certain key potato glycoalkaloids are noted for their repellent and deterrent properties, particularly with regard to host acceptance and feeding behavior of these pests (Schreiber 1957, Raman et al. 1979). In addition, some evidence suggests a role in metabolic disorders (Koch 1960). Leptine I, commersonine, tomatine, and demissine appear to be the most biologically active of the potato glycoalkaloids against L. decemlineata (Sturchow and Low 1964, Sinden et al. 1980).

The use of foliar glycoalkaloids in breeding for resistance to L. decemlineata was initiated in Europe (Ross 1966), but efforts were eventually abandoned because of the parallel association between foliage and tuber glycoalkaloid levels, as well as difficulty in maintaining acceptable levels of resistance in adapted germplasm. Unfortunately, the major species used as donors for elevated foliar glycoalkaloids (Solanum chacoense and S. demissum) are highly polymorphic for specific and pooled glycoalkaloid content (McCollum and Sinden 1979, Gregory et al. 1981), and breeding for increased pooled glycoalkaloid level does not necessarily result in a corresponding increase in resistance (Sinden et al. 1980).

In contrast, the pooled foliar glycoalkaloid level is a relatively effective predictor of resistance to Empoasca fabae in wild Solanum species (Tingey et al. 1978), although as with the Colorado potato beetle, specific glycoalkaloids differ in defensive activity. Leptine I and tomatine, for example, produce much greater nymphal mortality on diets, than does solanine (Dahlman and Hibbs 1967).

Although breeding for glycoalkaloid-conditioned insect resistance is potentially promising, practical implementation of this insect control tactic is currently limited by several extremely important considerations. First, the qualitative and quantitative glycoalkaloid content of foliage and tubers is usually highly correlated (Deahl et al. 1973). This phenomenon introduces the potential for development of insect-resistant germplasm with undesirable or even hazardous properties as food and feed, in view of the mammalian toxicity of some of these compounds (Willimot 1933). This problem might be circumvented through selective use of the leptines -- a group of insect-active glycoalkaloids (Sturchow and Low 1961) apparently limited in distribution to foliar tissues (Kuhn and Low 1961).

Second, while evidence suggests that breeding for specific glycoalkaloids is likely to be a productive approach, the current feasibility of this tactic is limited by incomplete knowledge of glycoalkaloid inheritance and by the unavailability of rapid methodology for analysis of specific glycoalkaloids. Recent advances in immunological technology may improve our ability to routinely identify and quantify levels of specific glycoalkaloids in segregating germplasm (Coxon 1984).

## 4.0 LITERATURE CITED


Casagrande, R.A. 1982. Colorado potato beetle resistance in a wild potato, Solanum berthaultii. J. Econ. Entomol. 75:368-72.

Coxon, D.T. 1984. Methodology for glycoalkaloid analysis. Amer. Potato J. 61:169-83.

Dahlman, D.L. and E.T. Hibbs. 1967. Responses of Empoasca fabae (Cicadellidae: Homoptera) to tomatine, solanidine, and demissidine. Ann. Entomol. Soc. Amer. 60:732-40.

Deahl, K.L., R.J. Young, and S.L. Sinden. 1973. A study of the relationship of late blight resistance to glycoalkaloid content in fifteen potato clones. Amer. Potato J. 50:248-53.

Gibson, R.W. 1971. Glandular hairs providing resistance to aphids in certain wild potato species. Ann. Appl. Biol. 68:113-9.

Gibson, R.W. 1974. Aphid-trapping glandular hairs on hybrids of Solanum tuberosum and S. berthaultii. Potato Res. 17:152-4.

Gibson, R.W. 1976. Glandular hairs on Solanum polyadenium lessen damage by the Colorado beetle. Ann. Appl. Biol. 82:147-50.

Gibson, R.W. 1978. Resistance in glandular-haired wild potatoes to flea beetles. Amer. Potato J. 55:595-8.

Gibson, R.W. 1979. The geographical distribution, inheritance, and pest-resisting properties of sticky-tipped foliar hairs on potato species. Potato Res. 22:233-6.

Gibson, R.W. and J.A. Pickett. 1983. Wild potato repels aphids by release of aphid alarm pheromone. Nature 302:608-9.

Gibson, R.W. and R.H. Turner. 1977. Insect-trapping hairs on potato plants. P.A.N.S. 22:272-7.

Gregory, P. 1984. Glycoalkaloid composition of potatoes: diversity and biological implications. Amer. Potato J. 61:115-22.

Gregory, P., S.L. Sinden, S.F. Osman, W.M. Tingey and D.A. Chessin. 1981. Glycoalkaloids of some wild potato tuber-bearing Solanum species. J. Agric. Food Chem. 29:1212-15.

Gunenc, Y. and R.W. Gibson. 1980. Effects of glandular foliar hairs on the spread of potato virus Y. Potato Res. 23:345-51.

Koch, H.A. 1960. Untersuchungen uber die Wirkung von Insektiziden und von Pflanzenalkaloiden auf dem Darmtraktus des Kartoffelkafers und seiner Larven. Entomol. Exp. Appl. 3:103-13.

Kuc, J. 1984. Steroid glycoalkaloids and related compounds as potato quality factors. Amer. Potato J. 61:123-39.

Kuhn, R. and I. Low. 1961. The structure of leptines. Chem. Ber. 94:1088-95.

Lapointe, S.L. 1983. Potato glandular trichomes: effect on feeding behavior and potato virus Y transmission by Myzus persicae (Sulzer). M.S. Thesis, Cornell University. 76 p.

Lapointe, S.L. and W.M. Tingey. 1984. Feeding response of the green peach aphid (Homoptera: Aphididae) to potato glandular trichomes. J. Econ. Entomol. 77: (In press).

McCollum, G.D. and S.L. Sinden. 1979. Inheritance study of tuber glycoalkaloids in a wild potato, Solanum chacoense Bitter. Amer. Potato J. 56:95-113.

Mehlenbacher, S.A. 1982. Potatoes with glandular trichomes: inheritance and heritability studies. Ph.D. Thesis. Cornell University. 96 p.

Mehlenbacher, S.A., R.L. Plaisted, and W.M. Tingey. 1983. Inheritance of glandular trichomes in crosses with Solanum berthaultii. Amer. Potato J. 60:699-708.

Obrycki, J.J. 1982. Biological control and insect resistance: greenhouse and field studies of their interaction on potatoes. Ph.D. Thesis. Cornell University. 90 p.

Obrycki, J.J., M.J. Tauber and W.M. Tingey. 1983. Predators and parasitoids interact with aphid-resistant potatoes to reduce aphid densities: a two year field study. J. Econ. Entomol. 76:456-62.

Obrycki, J.J. and M.J. Tauber. 1984. Natural enemy activity on glandular pubescent potato plants in the greenhouse: an unreliable predictor of effects in the field. (In press).

Raman, K.V., W.M. Tingey and P. Gregory. 1979. Potato glycoalkaloids: effect on survival and feeding behavior of the potato leafhopper. J. Econ. Entomol. 72:337-41.

Ross, H. 1966. The use of wild Solanum species in German potato breeding of the past and today. Amer. Potato J. 43:63-80.

Schreiber, K. 1957. Naturally occurring plant resistance factors against the Colorado potato beetle (Leptinotarsa decemlineata) and their possible mode of action. Zuchter 27:289-99.

Sinden, S.L. 1984. Genetic and environmental control of potato glycoalkaloids. Amer. Potato J. 61:141-56.

Sinden, S.L., L.L. Sanford and S.F. Osman. 1980. Glycoalkaloids and resistance to the Colorado potato beetle in SOlanum chacoense Bitt. Amer. Potato J. 57:331-43.

Sturckow, B. and I. Low. 1961. The effects of some Solanum glycoalkaloids on the potato beetle. Entomol. Exp. Appl. 4:133-42.

Tingey, W.M. 1981. Potential for plant resistance in management of arthropod pests. p. 201-45 in Advances in Potato Pest Management (ed. J. Laschomb and R.A. Casagrande). Hutchinson Ross (Academic Press). 304 p.

Tingey, W.M. 1984. Glycoalkaloids as pest resistance factors. Amer. Potato J. 61:157-67.

Tingey, W.M. and R.W. Gibson. 1978. Feeding and mobility of the potato leafhopper impaired by glandular trichomes of Solanum berthaultii and S. polyadenium. J. Econ. Entomol. 71:856-8.

Tingey, W.M. and J.E. Laubengayer. 1981. Defense against the green peach aphid and potato leafhopper by glandular trichomes of Solanum berthaultii. J. Econ. Entomol. 74:721-5.

Tingey, W.M., J.D. Mackenzie, and P. Gregory. 1978. Total foliar glycoalkaloids and resistance of wild potato species to Empoasca fabae (Harris). Amer. Potato J. 55:577-85.

Tingey, W.M., R.L. Plaisted, J.E. Laubengayer, and S.A. Mehlenbacher. 1982. Green peach aphid resistance by glandular trichomes in Solanum tuberosum and S. berthaultii hybrids. Amer. Potato J. 59:241-51.

Tingey, W.M. and S.L. Sinden. 1982. Glandular pubescence, glycoalkaloid composition, and resistance to the green peach aphid, potato leafhopper, and potato fleabeetle in Solanum berthaultii. Amer. Potato J. 59:95-106.

Willimot, S.C. 1933. An investigation of solanine poisoning. Analyst 58:431-9.

Wright, R.H., W.M. Tingey, and R.L. Plaisted. 1984. Colorado potato beetle (Coleoptera: Chrysomelidae): expression of resistance in Solanum berthaultii and interspecific potato hybrids. (In press).

# Research Progress: Glandular Trichome Biochemistry and Potato Resistance to Insects

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## 1.0 INTRODUCTION

The potato breeding program at Cornell University has made considerable progress in the exploitation of Solanum berthaultii Hawkes for its resistance to several arthropod pests (Tingey, et al 1984). The resistance of this wild, tuber-bearing Bolivian species is conferred by glandular trichomes on the foliage (Gibson, 1971). Two types of glandular trichomes are involved. Type A is a short trichome with a four-lobed membrane-bound gland at its apex. Type B is a longer, simple trichome with an ovoid gland at its tip which continuously exudes a clear viscous exudate.

Although transfer of Solanum berthaultii Type A and B trichomes and good levels of associated resistance has already been achieved, further selection and breeding is needed to develop commercially acceptable resistant cultivars. As effectiveness of glandular trichomes is highly dependent upon biochemical as well as physical factors, knowledge of the essential biochemistry of trichome-mediated defense is directly relevant, in an applied sense, to the breeding program at Cornell University and elsewhere. This defensive phenomenon, because of its elegance and simplicity, also offers an exciting opportunity to explore fundamental aspects of resistance which can be masked in other more complex systems. In this report we highlight some of our recent data and demonstrate its relevance to breeding for improved potato resistance to insects.

## 2.0 ENZYMIC BROWNING BY TYPE A TRICHOMES

Upon insect attack, the four-lobed heads of Type A trichomes are ruptured and a clear exudate is released onto the insects' legs and mouthparts. This exudate becomes brown and hard. The insects are immobolized and feeding is disrupted (Gibson and Turner, 1977; Tingey and Gibson, 1978).

## 2.1 Polyphenoloxidase, Peroxidase and Phenolics

Polyphenoloxidase (PPO) and peroxidase (PO) activities have been demonstrated in the glandular trichomes of *S. berthaultii* (Gregory and Tingey, 1981; Ryan *et al*, 1982). Preliminary indications of phenolic oxidase activity in these trichomes was first reported by Gibson (1971). PPO and PO can oxidize endogenous phenolic substrates to quinones which are highly active and can polymerize to form brown polymers such as melanin or can react with protein and other cellular components. Various potential phenolic substrates for PPO and/or PO were extracted from the trichomes and identified by a combination of high-pressure liquid chromatography and thin-layer chromatography (Gregory, unpublished). The major phenolic component was chlorogenic acid.

## 2.2 Role of Polyphenoloxidase and the Importance of Browning

Treatment of *S. berthaultii* foliage with cysteine strongly inhibited the browning reaction (Ryan, unpublished data). As cysteine is an inhibitor of PPO (Mayer and Harel, 1979) this result strongly suggested that the browning reaction is indeed the result of PPO activity.

Cysteine treatment also resulted in greatly increased survival of the green peach aphid, *Myzus persicae* (Sulzer), and to lowered levels of encasement of legs and mouthparts by trichome exudate (Ryan, unpublished data). Cysteine had little or no direct effect on the green peach aphid, as shown by controls involving aphid survival measurements of cysteine-treated *S. tuberosum* foliage. The data also showed that, while extremely important, browning is not the only component of resistance in *S. berthaultii* as complete inhibition of browning did not completely eliminate resistance.

## 2.3 Biochemical Screening for Browning

Knowledge that (1) the browning reaction is an important component of resistance and (2) browning is probably a result of PPO activity, led to experiments in which PPO activity was determined in *S. tuberosum* x *S. berthaultii* $F_3$ hybrid clones exhibiting differential resistance to the green peach aphid (Ryan *et al*, 1983). Within this population of segregating clones, aphid infestation levels varied by 8-fold, while a 5-fold difference in glandular trichome PPO activity was observed. PPO

activity and aphid resistance were highly correlated. PO activity was not well correlated with resistance (Ryan, unpublished). Based on this finding, a new screening method for resistance, the total browning potential (TBP) test, was developed (Ryan et al, 1983). This test is a modification of the PPO assay and it is a measure not only of PPO but also of endogenous phenolic substrates. It is rapid, inexpensive, and even more effective than the PPO assay in identifying aphid resistant clones.

### 2.4 Further Enzymological Aspects

Detailed enzymological studies (Bouthyette, unpublished data) resulted in the discovery of two forms (Form A and Form B) of PPO in the trichomes. These PPO forms can be separated on acrylamide/agarose gels. Form A and B have approximate molecular weights of 55,000 and 550,000 respectively. Form B is bound to chlorogenic acid. Both forms exhibit similar affinities (Km values) for endogenous phenolic substrates but the specific activity of Form B was several-fold higher than that of Form A. The relationship between the two forms is not yet understood. At first we hypothesized that upon disruption of Type A trichomes by insects, Form B might be rapidly produced by interaction of Form A with substrate (chlorogenic acid) in a manner analagous to that described for hemoglobin and oxygen. This would provide the plant with a rapidly-induced highly effective response to insect attack. This hypothesis is not yet proven and an alternative possibility that the two forms of PPO exist as independent entities, possibly serving different functions in defense, is also plausible.

Use of isoelectric focusing demonstrated that Form A is a unique enzyme, differing in mobility from PPO enzymes in the cytosol and in chloroplasts (Bouthyette, unpublished data).

### 2.5 Histochemical Aspects

Various phenol-specific reagents were used in the localization of phenolics in S. berthaultii trichomes (Ryan, unpublished data). The reagents indicated the presence of phenols in the heads and stalks of Type A trichomes. Droplets and stalks of Type B trichomes did not appear to contain phenols.

PPO localization, as determined by microcapillary application of the highly reactive phenols L-dopa and catechol,

was intense in Type A stalks with lower activity in Type A heads and Type B stalks. No activity was observed in Type B droplets.

Intracellular localization of enzymes and substrates has not been studied.

## 3.0 TYPE B TRICHOME EXUDATE

Type B trichomes play an important role in the overall resistance mechanism (Tingey and Sinden, 1982; Tingey *et al*, 1984). The presence of Type B exudate on the insect results in enhanced entrapment by Type A trichomes by accelerating discharge of the latter (Tingey and Laubengayer, 1981). More recent work in our laboratory has demonstrated that the latter phenomenon is not only a function of the adhesive properties of Type B exudate.

### 3.1 Sesquiterpenoid Composition

Avé (unpublished data) has developed a procedure for collection of large quantities of Type B exudate. Three major volatile components of Type B exudate were resolved in 2 unrelated clones of *S. berthaultii*. The components were tentatively identified by gas chromatography-mass spectroscopy as the sesquiterpenes β-caryophyllene, β-cubebene and Δ-cadinene. Minor quantities of other sesquiterpenes such as E-β-farnesene (aphid alarm pheromone), α-humulene and α-copaene, also appeared to be present.

### 3.2 Unsettling Effect on the Green Peach Aphid

The sesquiterpenoid fraction from *S. berthaultii* (PI265858) Type B exudate was preparatively isolated by silica gel column chromatography, incorporated into controlled release media and assayed for biological activity against the green peach aphid at concentrations corresponding to Type B trichome densities of 30-42/mm$^2$ (Avé, unpublished data). In dual-choice assays, the sesquiterpenoid fraction promoted aphid irritability and reduced acceptance and settling on diet substrate.

### 3.3 Aphid Alarm Pheromone

Gibson and Pickett (1983) reported the presence of E-β-farnesene, the aphid alarm pheromone, as a major component in Type B exudate from *S. berthaultii* (PI265858). In contrast,

we have found only trace amounts of E-β-farnesene in Type B exudates of our accessions. However there are large quantities of E-β-farnesene in the foliage of S. tuberosum ( Avé unpublished data). Presumably these large amounts do not interface with the aphids.

The effects of our sesquiterpene fractions on aphids in dual-choice assays is very different from the effects we would expect if E-β-farnesene had been present in substantial amounts. The response to aphid alarm pheromone of falling or rapidly walking from the treated area was not observed in our assay with Type B sesquiterpene fractions. The latter appeared to exhibit a more generalized disturbance effect. This is not surprising, as the response to aphid alarm pheromone seems to be restricted to sesquiterpenes with structural features extremely similar to E-β-farnesene (Bowers et al, 1977). Transfer through breeding of elevated levels of E-β-farnesene from S. tuberosum to the glandular trichomes of S. tuberosum x S. berthaultii hybrids would greatly enhance present levels of resistance.

## 4.0 OVERVIEW OF THE TRICHOME-MEDIATED RESISTANCE MECHANISM

Our present understanding of the resistance mechanism can be summarized as follows: (1) the insect lands upon the foliage and encounters Type B trichomes, (2) Type B trichome exudate leads to stickiness and, due to sesquiterpenoid action, agitation of the insect, (3) due to the insect struggling in an agitated way, Type A heads are disrupted, (4) reaction of PPO with phenolic substrate (chlorogenic acid) occurs and oxidative processes are initiated. At this point, Form A of PPO might be transformed into the more highly active Form B, (5) as a result of phenolic oxidation to quinones (the browning reaction) the insect becomes immobilized,stops feeding and dies. Whether or not the insect is simply glued in place by quinone-based brown polymers or whether other quinone-related activities occur is unclear. For example, quinones might interact directly with the insect's surface, thus chemically binding the insect to the plant.

## 5.0 OUTLOOK

Screening for total browning potential will be continued as this has already been shown to be effective in identification of clones with resistance to green peach aphid. As the mechanistic story unfolds and we learn , for example, which of the sesquiterpenes is (or are) responsible for the

unsettling behavior of the green peach aphid, we may be able to develop additional rapid biochemical screening tests for assessment of resistance. In addition, we will screen a large number of S. tuberosum x S. berthaultii hybrids for the presence of aphid alarm pheromone. The transfer of this compound from S. tuberosum foliage into the glandular trichomes of the hybrids might greatly enhance resistance levels. Finally, as more emphasis in our breeding is being placed on the development of resistance to Colorado potato beetle, Leptinotarsa decemlineata (Say), we will attempt to elucidate the essential biochemistry of glandular trichomes-mediated defense against this pest and, as in the case of our green peach aphid work, apply our newly-gained knowledge to the development of more resistant potatoes.

## 6.0 LITERATURE CITED


Bowers, W. S., C. Nishino, M. E. Montgomery and L. R. Nault. 1977. Structure-activity relationships of analogs of the aphid alarm pheromone, E-β-farnesene. J. Insect. Physiol. 23:697-701.

Gibson, R. W. 1971. Glandular hairs providing resistance to aphids in certain wild potato species. Ann. Appl. Biol. 68:113-9.

Gibson, R. W. and J. A. Pickett. 1983. Wild potato repels aphids by release of aphid alarm pheromone. Nature 302:608-9.

Gibson, R. W. and R. H. Turner. 1977. Insect-trapping hairs on potato plants. P.A.N.S. 22:272-7.

Gregory, P. and W. M. Tingey. 1981. Chemical mechanisms of potato resistance to the potato leafhopper. In "Breeding for Resistance to Insects and Mites", Proc. 2nd Eucarpia/IOBC Meeting of the Working Group Breeding for Resistance to Insects and Mites. Canterbury, England, pages 95-99.

Mayer, A. M. and E. Harel. 1979. Polyphenoloxidases in plants. Phytochem. 18:193-215.

Ryan, J. D., P. Gregory and W. M. Tingey. 1982. Phenolic oxidase activities in the glandular trichomes of Solanum berthaultii (Hawkes). Phytochem. 21:1885-87.

Ryan, J. D., P. Gregory and W. M. Tingey. 1983. Glandular trichomes: enzymic browning assays for improved selection of resistance to the green peach aphid. Amer. Potato J. 60:861-8.

Tingey, W. M. and R. W. Gibson. 1978. Feeding and mobility of the potato leafhopper impaired by glandular trichomes of Solanum berthaulti and Solanum polyadenium. J. Econ. Entomol. 71:856-8.

Tingey, W. M., P. Gregory, R. L. Plaisted, and M. J. Tauber. 1984. Research Progress: Potato glandular trichomes and steroid glycoalkaloids. This issue.

Tingey, W. M. and J. E. Laubengayer. 1981. Defense against the green peach aphid and potato leafhopper by glandular trichomes of Solanum berthaultii. J. Econ. Entomol. 74:721-5.

Tingey, W. M. and S. L. Sinden. 1982. Glandular pubescence, glycoalkaloid composition, and resistance to the green peach aphid, potato leafhopper, and potato fleabeetle in Solanum berthaultii. Amer. Potato J. 59:95-106.

# Progress in Utilization of Aphid Resistance

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## Introduction

Worldwide, aphids, especially green peach aphid, Myzus persicae (Sulzer), are the most important insect pests of potato. This importance is primarily due to their role in the transmission of such virus diseases as potato leaf roll virus and potato virus Y. Screening of named potato cultivars for possible aphid resistance was initiated by entomologists more than 50 years ago (Radcliffe et al. 1981). However, little evidence of useful levels of aphid resistance has been found in any cultivated potato species. Between cultivars of S. tuberosum, differences in aphid infestations are relatively minor and appear more dependent upon temporal physiological conditions than host genotype. But, much greater differences in aphid resistance have been found among the wild potato species and many possible sources of usable resistance have now been identified. It is surprising, given the genetic diversity that exists in this crop and that aphids are recognized as being particularly amendable to control by means of host plant resistance, that this approach has not received more attention in potato breeding.

## Identification of Sources of Aphid Resistance

Extensive field screening trials have been conducted at the University of Minnesota using the United States Potato Collection to identify sources of resistance to green peach aphid and potato aphid, Macrosiphum euphorbiae (Thomas) (Radcliffe et al., 1981). In total, 1607 accessions representing approximately 100 potato species, have been screened for green peach aphid resistance and 1222 accessions have been screened for potato aphid resistance.

The materials tested were obtained as true seed. Seedlings were grown in the greenhouse and transplanted into the field 8-10 weeks later. Green peach aphids were introduced into the field on infested plants, but we relied on natural infestations for potato aphid. Aphid populations were enhanced by the application of sprays of insecticides

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to which the aphids are resistant, i.e., carbaryl or azinphosmethyl. Evaluations are by means of 45-sec/plant counts. Mean aphid numbers by species on each test accession were expressed as a ratio relative to the mean number of aphids on 9 highly resistant accessions that were common to virtually all experiments and counting dates. Means for accessions were computed across counting dates and years discarding test results that deviated by more than 3 standard deviations from the mean to produce a single index value for each accession. The accessions were then categorized on a 1-5 scale, class 1 (highly resistant) mean ratio < 0.5, class 2 resistant) mean ratio 0.5-0.999, class 3 (intermediate) mean ratio 1.000-1.999, class 4 (susceptible) 2.000-3.999, and class 5 (highly susceptible) >4.0. In total more than 125,000 single plant evaluations were made.

Aphid resistance was found to be of common occurrence in the tuber-bearing solanums. Resistance to green peach aphid resistance (Appendix, Tables 1A and 2A) was greatest in S. bulbocastanum and various species of the series Pinnatisecta, especially S. trifidum. But green peach aphid resistance occurs in many species across the various taxonomic series of potato, e.g., certain accessions of S. stoloniferum and S. sanctae-rosae are highly resistant. In the Series Tuberosa, high levels of resistance were found in certain accessions of S. marinasense, S. canasense, and S. multidissectum. Resistance to potato aphid (Appendix, Tables 3A and 4A) was characteristic of S. bulbocastanum and most species of the series Longipedicellata. In the Tuberosa, high levels of potato aphid resistance was evidenced by some accessions of S. canasense, S. multidissectum, and S. verrucosum. Some accessions of S. stoloniferum were highly resistant to both aphid species. Green peach aphid resistance and potato aphid resistance were significantly, but not closely, correlated across all evaluations (r = 0.149, 1221 d.f.).

## Crossability and Inheritance of Resistance to Green Peach Aphid

Two objectives of the Minnesota program have been to study the breeding behavior of resistance to green peach aphid in the Solanum species and to establish a pool of S. tuberosum containing germplasm with a broad genetic base and a high level of resistance to green peach aphid.

Quisumbing (1971) demonstrated that green peach aphid resistance in the wild Solanum species was transferable to the resulting progeny when resistant wild species were hybridized with S. tuberosum or S. tuberosum-phureja hybrids.

Sams et al (1976) investigated breeding behavior for green peach aphid resistance in 57 tuber-bearing Solanum progenies. Included in his

experiments were 36 species accessions, representing 17 species possessing green peach aphid-resistance, 19 derivatives of hybrids between S. tuberosum and resistant wild species, and 2 interspecific hybrids of wild parentage. The remaining 21 progenies were hybrid derivatives maintained through open pollination. Resistance was measured by the excised leaflet technique. Aphids confined on leaflets of the hybrids produced 1.5-6.6 progeny per female whereas those confined on susceptible S. tuberosum produced 8-16.

Sams studied 19 progenies of resistant hybrids x susceptible S tuberosum-phureja derivatives and showed that all were more resistant than the susceptible parent and that 14 of the 19 were more resistant than the mid-parental value. This suggested that resistance is partially dominant and that rapid progress could be made in a backcrossing program. Further selection and intermating maintained most of the selection differential. Two of the crosses had progeny means considerably below that of either parent suggesting that resistance genes from different sources may be additive in effect.

Lee (1981) studied segregation for green peach aphid resistance in 47 progenies derived by crossing resistant (R) and susceptible (S) female selections of Solanum sanctae-rosae-tuberosum, S. polytrichon-tuberosum, and S. stoloniferum-tuberosum hybrid progenies with bulk pollen of resistant and susceptible selections of S. sanctae-rosae-tuberosum or with pollen of green peach aphid susceptible S. phureja. The materials used in these experiments were open-pollinated progenies of $F_1$ hybrids between green peach aphid resistant wild species as one parent and green peach aphid susceptible S. tuberosum as the other (Table 1). These were chosen as parental sources on the basis of the following characteristics of their wild parents: green peach aphid resistance, crossability with S. tuberosum and other wild species, and geographic origin. Used as additional pollen sources were S. tuberosum: cv. 'Norland' and cv. 'Chieftain', MN 81614 (DH); and S. phureja, MN 148.17.

Table 1.--Wild parentages of Solanum interspecific hybrid derivatives.

| | | Wild Species | | |
|---|---|---|---|---|
| Code | Hybrid derivatives | Series | Ploidy | Origin |
| 2 | (S. multidissectum, PI 210051 X S. tuberosum (DH)) OP[a] | Tuberosa | 2x | Peru |

Table 1.--(Continued).

| Code | Hybrid derivatives | Wild Species | | |
|---|---|---|---|---|
| | | Series | Ploidy | Origin |
| 3 | (*S. sanctae-rosae*, PI 230464 X *S. tuberosum* OP | Megistacroloba | 2x | Argentina |
| 5 | (*S. polytrichon*, PI 184770 X *S. tuberosum* (DH)(DH))[b] OP | Longipedicellata | 4x | Mexico |
| 7 | (*S. stoloniferum*, PI 275246 X *S. tuberosum* (DH)(DH) OP | Longipedicellata | 4x | Mexico |

[a] Open-pollination (OP)

[b] (DH)(DH) denotes a reestablished tetraploid which has undergone chromosome doubling of haploid *S. tuberosum* (DH).

Twenty-nine to 30 clones of each hybrid progenies were grown from true seeds in 8-cm plastic pots in a growth chamber programmed for 16L:8D at 21°C:16°C. At eight to nine weeks after planting, the clones were evaluated for green peach aphid resistance using the excised leaf technique. Fully expanded leaves from the upper portion of each plant were prepared so that only the three terminal leaflets were retained. Excised leaves were maintained by immersing the petiole in tap water. A barrier to aphid movement was set by applying a strip of Tack-Trap[R] around the vial. First instar nymphs were obtained by transferring adult aphids from the laboratory culture maintained on Chinese cabbage, *Brassica pekinensis* cv. 'Michihli', to excised leaves of the susceptible cultivar Norland. Tests were initiated by placing five first nymphs on the upper surface of each excised leaf. On the seventh day, surviving female aphids, now mature, were transferred to a new excised leaf. On the ninth day, resulting progeny and surviving females were counted. Mean number of nymphs per green peach aphid adult were calculated by dividing the total number of nymphs produced between days seven and nine by the mean number of live adults on days seven and nine.

From each hybrid progeny population, five to six of the most resistant clones and five to six of the most susceptible clones were selected on the basis of progeny production per green peach aphid female in the first excised leaf test. Selected clones were transplanted to 15-cm

clay pots and six weeks later a second excised leaf test was conducted. Results of the two excised leaf tests were combined to rank the parental selection as to relative green peach aphid resistance. On the basis of the combined results of the two excised leaf tests, three to five of the most resistant and four to six of the most susceptible clones were selected as female parents. Pollen sources were selected as resistant or susceptible on the basis of the first excised leaf test. green peach aphid resistance of four additional pollen sources was based on three excised leaf tests for eight-week-old plants. When available, pollen was collected from each of the hybrid progenies and the additional pollen sources and stored in gelatin capsules at -20°C. Resistant and susceptible bulk pollen derived from five clones each were prepared once a week for pollinations.

All combinations of crosses were made between resistant (R) and susceptible (S) groups within hybrid progenies, between hybrid progenies, and between these hybrid progenies as female parents and Norland, Chieftain, MN 81614 (DH), and MN 148.17 (S. phureja) pollen. Most of the crosses either failed to set fruit or failed to produce enough seeds to allow the study of inheritance in resulting progenies.

Segregation for green peach aphid resistance was studied in 47 of the resulting progenies: 17 progenies from S. sanctae-rosae-tuberosum R and S females X S. sanctae-rosae-tuberosum R and S bulk pollen and S. phureja pollen; 16 from S. polytrichon-tuberosum R and S females X S. sanctae-rosae-tuberosum R and S bulk pollen and S. phureja pollen; and 14 from S. stoloniferum-tuberosum R and S females X S. sanctae-rosae-tuberosum R and S bulk pollen and susceptible S. phureja (phu) pollen. With respect to parental resistance levels of these progenies, ten were from R X R crosses, eleven from R X S, nine from S X X, nine from R X S(phu), and eight from S X S (phu).

Green peach aphid resistance of these progenies was measured when the plants were eight to nine weeks old by means of the excised leaf test. Four to 30 clones were evaluated from each progeny. Individual clones yielding 0.0-1.9 nymphs/GPA adult were rated highly resistant, 2.0-5.9 resistant, and 6.0 or more susceptible. Heritability estimates were computed by regressing mean number of nymphs produced per adult aphid of the progeny on the mean number of progeny per adult aphid of the maternal parent. Separate heritability estimates were made for progenies having S. sanctae-rosae-tuberosum as the pollen parent and for progenies having S. phureja as the pollen parent.

Resistance of parental source populations, as measured by nymphal production per green peach aphid adult between days seven and nine in excised leaf tests averaged 5.0 for S. polytrichon-tuberosum, 5.5 for S.

sanctae-rosae-tuberosum, and 7.8 for S. stoloniferum-tuberosum (Table 2). Overall the mean was 6.1. GPA confined on MN 81614 (DH), Norland, Chieftain, and MN 148.17 (S. phureja) averaged 10.3, 10.7, 12.0, and 10.0 nymphs per adult, respectively. Resistant parents averaged 1.4 nymphs per adult, respectively. Resistant parents average 1.4 nymphs per adult for S. sanctae-rosae-tuberosum, 1.8 for S. polytrichon-tuberosum, 2.5 for S. stoloniferum-tuberosum, and 1.9 across all three sources. Susceptible parents averaged 9.0 for S. sanctae-rosae-tuberosum, 6.7 for S. polytrichon-tuberosum, 9.3 for S. stoloniferum-tuberosum, and 8.2 across the three sources.

Table 2.--Green peach aphid resistance of Solanum interspecific hybrid progenies derived from intermatings between hybrid progenies and between hybrid progenies and S. phureja.

| Parent | | | | | Progeny | |
|---|---|---|---|---|---|---|
| Female | | | Male | | | |
| Source[a] | Clone | GPA-resistance[b] | Source[c] | GPA-resistance[b] | Clones tested | GPA-resistance[b] ± std. dev. |
| sct-tbr | 3-5 | 0.0 | sct-tbr | 2.1 | 7 | 1.7 ± 1.7 |
| | 3-16 | 0.0 | | " | 8 | 3.1 ± 3.1 |
| | 2-21 | 1.3 | | " | 6 | 0.9 ± 1.5 |
| | 3-14 | 4.4 | | " | 8 | 2.0 ± 3.0 |
| | 3-30 | 8.2 | | " | 8 | 4.4 ± 3.4 |
| | 3-29 | 8.7 | | " | 8 | 6.0 ± 3.4 |
| | 3-22 | 9.3 | | " | 6 | 2.0 ± 2.3 |
| | 3-19 | 9.8 | | " | 8 | 4.1 ± 2.3 |
| | 3-29 | 8.7 | | 8.4 | 10 | 5.7 ± 3.6 |
| | 3-22 | 9.3 | | " | 10 | 5.1 ± 3.2 |
| | 3-19 | 9.8 | | " | 10 | 4.2 ± 3.7 |
| | 3-5 | 0.0 | phu | 10.0 | 5 | 0.0 ± 0.0 |
| | 3-21 | 1.3 | | " | 10 | 2.2 ± 2.3 |
| | 3-14 | 4.4 | | " | 10 | 1.8 ± 2.0 |
| | 3-30 | 8.2 | | " | 10 | 4.7 ± 3.6 |
| | 3-29 | 8.7 | | " | 9 | 5.2 ± 3.8 |
| | 3-19 | 9.8 | | " | 10 | 3.7 ± 3.7 |
| plt-tbr | 5-25 | 0.2 | sct-tbr | 2.1 | 5 | 1.4 ± 1.5 |
| | 5-30 | 0.7 | | " | 6 | 3.5 ± 2.4 |

Table 2.--(Continued).

| Parent | | | | | Progeny | |
|---|---|---|---|---|---|---|
| Female | | | Male | | | |
| Source[a] | Clone | GPA-resistance[b] | Source[c] | GPA-resistance[b] | Clones tested | GPA-resistance[b] ± std. dev. |
| | 5-6 | 2.7 | | " | 6 | 2.0 ± 2.4 |
| | 5-26 | 6.5 | | " | 5 | 7.3 ± 3.5 |
| | 5-17 | 6.8 | | " | 4 | 4.1 ± 2.8 |
| | 5-25 | 0.2 | | 8.4 | 8 | 2.3 ± 2.3 |
| | 5-30 | 0.7 | | " | 8 | 2.4 ± 2.4 |
| | 5-8 | 3.8 | | " | 10 | 4.6 ± 2.9 |
| | 5-1 | 6.3 | | " | 10 | 5.9 ± 3.6 |
| | 5-26 | 6.5 | | " | 6 | 2.2 ± 2.6 |
| | 5-17 | 6.8 | | " | 7 | 4.1 ± 2.0 |
| | 5-4 | 7.0 | | " | 10 | 3.3 ± 1.8 |
| | 5-25 | 0.2 | phu | 10.0 | 10 | 4.4 ± 3.5 |
| | 5-30 | 0.7 | | " | 9 | 2.3 ± 2.0 |
| | 5-8 | 3.8 | | " | 5 | 5.6 ± 4.2 |
| | 5-17 | 6.8 | | " | 10 | 6.0 ± 2.8 |
| sto-tbr | 7-27 | 0.3 | sct-tbr | 2.1 | 8 | 4.7 ± 3.9 |
| | 7-7 | 2.7 | | " | 4 | 1.0 ± 2.0 |
| | 7-18 | 4.4 | | " | 6 | 3.6 ± 3.0 |
| | 7-5 | 6.4 | | " | 8 | 3.6 ± 3.6 |
| | 7-18 | 4.4 | | 8.4 | 30 | 6.9 ± 3.6 |
| | 7-2 | 11.7 | | " | 15 | 6.1 ± 3.6 |
| | 7-24 | 12.5 | | " | 15 | 7.3 ± 2.7 |
| | 7-27 | 0.3 | phu | 10.0 | 6 | 3.8 ± 3.3 |
| | 7-7 | 2.7 | | " | 6 | 6.4 ± 1.7 |
| | 7-18 | 4.4 | | " | 6 | 7.4 ± 2.8 |
| | 7-9 | 6.2 | | " | 9 | 5.0 ± 2.3 |
| | 7-5 | 6.4 | | " | 6 | 5.7 ± 1.9 |
| | 7-2 | 11.7 | | " | 6 | 8.1 ± 4.0 |
| | 7-24 | 12.5 | | " | 10 | 4.8 ± 3.2 |

[a] Abbreviations of species names follows Simmonds (1963), i.e., *S. phureja* (*phu*), *S. polytrichon* (*plt*), *S. sanctae-rosae* (*sct*), *S. stoloniferum* (*sto*), and *S. tuberosum* (*tbr*).

[b] Mean nymphal production per female on excised leaves.

[c] GPA-resistance of pollen parent of S. sanctae-rosae-tuberosum is an average of five clones in a bulk pollen.

Of the 47 resulting progenies evaluated for green peach aphid resistance most were more resistant (40 instances) than were the maternal parent sources. green peach aphid resistance of the 397 clones representing the 47 progenies ranged from 0.0 to 13.0 nymphs per adult, with a mean of 4.4. On 260 Of the 397 clones evaluated (65%), nymphal production was less than 6.0 per green peacg aphid adult, even though 333 (84%) of the clones had one or more susceptible parents. Our data support the suggestion of Quisumbing (1971) and Sams et al. (1976) that transfer of green peach aphid resistance from wild Solanum species to S. tuberosum should be possible.

Of progenies having S. sanctae-rosae-tuberosum as the female parent, six of 17 were highly resistant and eleven resistant. Corresponding results for progenies having S. polytrichon-tuberosum (16) or S. stoloniferum-tuberosum (14) as the female were, respectively, one each highly resistant, 13 and seven resistant, and two and six susceptible. All eight progenies rated susceptible were from S X S or S X S (phu). Mean green peach aphid resistance of progenies appeared to be associated with parental resistance level as well as the parental source involved in the cross.

Among progenies of S. sanctae-rosae-tuberosum X S. sanctae-rosae-tuberosum and S. polytrichon-tuberosum X S. sanctae-rosae-tuberosum, R X R yielded the greatest proportion of resistant clones and the highest percentage of highly resistant clones (Table 3). Among progenies of S. stoloniferum-tuberosum X S. sanctae-rosae-tuberosum, R X R and S X R crosses did not differ in proportion of resistant clones; however, R X R had a greater percentage of highly resistant clones. R X S and S X S crosses apparently did not differ in both proportion of resistant clones or in percentage of highly resistant clones.

Resistant clones occurred more frequently among progenies of susceptible (S) selections of S. sanctae-rosae-tuberosum and S. stoloniferum-tuberosum crossed with S. phureja than among progenies of those same maternal parents crossed with susceptible (S) pollen of S. sanctae-rosae-tuberosum. However, the pattern was the reverse for susceptible (S) female selections of S. polytrichon-tuberosum.

Among the three interspecific hybrid progenies, differences in segregation ratio of R and S selections within female sources was

greatest in S. sanctae-rosae-tuberosum when crossed with S. phureja, suggesting that response to selection may differ among parental sources. There were also differences in occurrence of highly resistant clones among progenies of the three female sources, S. sanctae-rosae-tuberosum having the highest percentage. Therefore, with the materials used in this study, we could not predict the breeding value of a resistant clone by referring only to clonal resistance level.

Regardless of the source of the maternal parent, S. sanctae-rosae-tuberosum, S. polytrichon-tuberosum, of S. stoloniferum-tuberosum, all mating schemes, R X R, R X S, S X S, R X S(phu), and S X S(phu), yielded a similar pattern or inheritance of green peach aphid resistance (Table 4). Although mean resistance levels' in the progeny of R X R crosses exhibited a tendency of regression toward susceptibility, 32 clones of 64 from R X R crosses were rated highly resistant and 25 resistant. Thus, as reported by Sams et al. (1976), selection for resistance and intermating would make it possible to maintain selection differential.

Few progenies of R X S and R X S(phu) crosses had greater resistance than that of the resistant (R) parent. Most progenies were intermediate in resistance between R parent and the mid-parental resistance level. The mating schemes of R X S and R X S(phu) in this study were similar to those reported by Sams et al. (1976).

Selection for resistance followed by intermating or backcrossing to S. tuberosum was not the only way to obtain highly resistant clones. All 17 progenies of S X S and S X S(phu) crosses were more resistant than either parent. Among 94 clones of S X S or S X S(phu), 31 clones were highly resistant and 18 were resistant. Since potato is a clonally propagated crop, regression toward resistance beyond the parental resistance level in S X S and S X S(phu) crosses may prove useful in development of green peach aphid resistant cultivars. Many crosses yield progenies having greater resistance than that of either parent, suggesting green peach aphid resistance in the Solanum involves two or more genes.

Inheritance patterns of mean progeny resistance level relative to the parents in different interspecific hybrid progenies may or may not differ from species to species. However, response to selection can differ from species to species. Therefore, breeding value of a clone should be examined in regard to its resistance level as well as its background of resistance source. Possible presence of different genes for green peach aphid resistance in Solanum species could be combined to enhance resistance level in S. tuberosum. Further studies are necessary to effectively use green peach aphid resistance genes present in a wide range of wild species.

Heritability estimates for the population having S. sanctae-rosae-tuberosum as the pollen parent was 57 ± 7% and that for the population having S. phureja as the pollen parent was 52 ± 11%. These moderately high heritabilities were consistent with those previously reported by Sams et al. (1976).

Crossability of derivatives selected for resistance or susceptibility to green peach aphid was studied in the same 4 interspecific hybrid progenies (Table 1) of Sams et al. (1976). Theses were open-pollinated progenies of $F_1$ hybrids between green peach aphid susceptible S. tuberosum and green peach aphid resistant wild species including S. multidissectum, S. sanctae-rosae, S. polytrichon, and S. stoloniferum. Since the various $F_1$ populations were not isolated, the derivatives could contain interprogeny (3-species) hybrids as well as intraprogeny $F_2$ hybrids. In addition, four green peach aphid susceptible clones were included as pollen parents: cv. 'Norland', cv. 'Chieftain', S. phureja-haploid S. tuberosum, MN 81614 (DH), and S. phureja, MN 148.17. The S. phureja clone delivers both n and 2n pollen.

Twenty-nine to 30 clones of each progeny were grown from true seeds in 8-cm plastic pots in a growth chamber programmed for 16L:8D at 21°C. At eight to nine weeks after planting, the clones were evaluated for green peach aphid resistance using the excised leaflet technique. From each interspecific hybrid progeny, five to six of the most resistant clones and five to six of the most susceptible clones were selected on the basis of progeny production per GPA female on excised leaves. Selected clones were transplanted to 15-cm clay pots and six weeks later a second excised leaf test was conducted.

Results of the two excised leaf tests were combined to rank the parental selections for relative green peach aphid resistance. On the basis of the combined results of the two excised leaf tests, three to five of the most resistant and four to six of the most susceptible clones were selected as female parents. Pollen sources were selected as resistant or susceptible on the basis of the first excised leaf test. When available, pollen was collected from each of the parental clones and stored in gelatin capsules at -20°C. Resistant and susceptible bulk pollen derived from five clones were prepared once a week for pollination.

All combinations of crosses were made between resistant (R) and susceptible (S) groups within hybrid progenies and between the progenies as well as between these interspecific hybrid progenies and 'Norland', 'Chieftain', MN 81614 (DH), and MN 148.17. Flowers were pollinated by dipping the stigmas into the pollen containing capsules. Fruit were harvested five to six weeks after pollination. Pollen fertility was

assayed with aceto-carmine. Pollen tube growth for crosses within progenies was examined using blue light fluorescence microscopy.

Previous crosses between 2-species hybrids (S. polytrichon-tuberosum and S. stoloniferum-tuberosum as female parents and S. sanctae-rosae-tuberosum as pollen parent) resulted in 3-species hybrid progenies. These 3-species hybrids were compared with their female parents (2-species hybrids) with regard to interspecific crossability. In addition to these two groups of 3-species hybrids, progenies resulting from the crosses within S. sanctae-rosae-tuberosum were also compared with the parents for interspecific crossability. Pollen sources in this experiment were: three 2-species hybrid progenies, S. sanctae-rosae-tuberosum, S. polytrichon-tuberosum, and S. stoloniferum; and three green peach aphid susceptible clones, cv. Norland, MN 81614, and MN 148.17.

Tubers were harvested from the original parental selections of S. sanctae-rosae-tuberosum, S. polytrichon-tuberosum, and S. polytrichon-tuberosum, and S. stoloniferum-tuberosum. The tubers were planted in 15-cm clay pots in the greenhouse. Many tubers did not sprout, especially the S. polytrichon-tuberosum of which only two clones were regrown. Ten to eleven clones were grown from true seeds of progenies from S. sanctae-rosae-tuberosum X S. sanctae-rosae-tuberosum, S. polytrichon-tuberosum X S. sanctae-rosae-tuberosum, and S. stoloniferum-tuberosum X S. sanctae-rosae-tuberosum. Bulk pollen from the original female parents was used in these experiments. This was derived from ten clones, irrespective of resistance level. Four to five flowers per clone were pollinated. Fruit were harvested five to six weeks after pollinations.

Some crosses were successful within the S. sanctae-rosae-tuberosum and within the S. polytrichon-tuberosum progenies (Table 2). However, crosses within the S. multidissectum-tuberosum and the S. stoloniferum-tuberosum progenies all failed to set fruit. Failure of crosses within S. multidissectum-tuberosum progeny appeared primarily due to a lack of fertile pollen since pollen stainability averaged only 9% (Table 3). The S. stoloniferum-tuberosum progeny, however, exhibited pollen stainability of 61% and normal pollen tube growth (Tables 3 and 4).

Both S. sanctae-rosae-tuberosum and S. polytrichon-tuberosum progenies showed a low rate of fruit set, but the fruit contained a considerable number of seeds (Table 2). In the S. sanctae-rosae-tuberosum progeny higher fruit set resulted from crosses between resistant selections, while in S. polytrichon-tuberosum progeny higher fruit set resulted from crosses between susceptible selections. There was no difference in pollen stainability and pollen tube growth between resistant and

susceptible selections within a hybrid progeny.

Table 3.--Resistant (R):Susceptible (S) segregation and percentages of highly resistant clones in progenies of Solanum interspecific hybrids.

| Female[a] source | | Male Source[a] | | | | | |
|---|---|---|---|---|---|---|---|
| | | sct-tbr | | | | | |
| | | R | | S | | phu | |
| | | R:S[b] | % HR[c] | R:S[b] | % HR[c] | R:S[b] | % HR[c] |
| sct-tbr | R | 27:2 | 63 | - | - | 24:1 | 67 |
| | S | 21:9 | 29 | 15:15 | 47 | 19:10 | 47 |
| plt-tbr | R | 16:1 | 44 | 23:3 | 30 | 18:6 | 44 |
| | S | 4:5 | 25 | 24:9 | 38 | 5:5 | 0 |
| sto-tbr | R | 14:4 | 57 | 12:18 | 25 | 9:9 | 22 |
| | S | 6:2 | 33 | 10:20 | 20 | 16:15 | 25 |

[a]Abbreviations of species names follows Simmonds (1963), i.e., S. phureja (phu), S. polytrichon (plt), S. sanctae-rosae (sct), S. stoloniferum (sto), and S. tuberosum (tbr).

[b]Resistant (R):susceptible (S) clones in the cross; lower than 6.0 nymphs per female (R).

[c]Percentages of highly resistant (HR) clones in R clones; lower than 2.0 nymphs per green peach aphid female (HR).

All four interspecific hybrid progenies produced seeds with S. tuberosum cv. Norland and S. phureja. Among the four hybrid progenies, S. stoloniferum-tuberosum showed the greatest crossability in terms of fruit set and seed production. Among the four green peach aphid susceptible pollen parents, S. phureja resulted in the highest seed production across the female parental sources. Low seed production resulted when MN 81614, Norland, and Chieftain were used as male parents despite a high fruit set.

Table 4.--Green peach aphid resistance levels in Solanum interspecific hybrid progenies relative to that of the parents.

| Cross[a] | Female X male | No. of progenies: Resistance relative to parents[b] ++ | + | - | -- |
|---|---|---|---|---|---|
| R X R | sct-tbr X sct-tbr | 2 | | 1 | 1 |
| | plt-tbr X sct-tbr | 1 | | 1 | 1 |
| | sto-tbr X sct-tbr | 1 | | 1 | 1 |
| | | (4) | | (3) | (3) |
| R X S | sct-tbr X sct-tbr | 1 | 2 | 1 | |
| | plt-tbr X sct-tbr | | 4 | | 1 |
| | sto-tbr X sct-tbr | | 1 | 1 | |
| | | (1) | (7) | (2) | (1) |
| S X S | sct-tbr X sct-tbr | 3 | | | |
| | plt-tbr X sct-tbr | 4 | | | |
| | sto-tbr X sct-tbr | 2 | | | |
| | | (9) | | | |
| R X phu | sct-tbr X sct-tbr | 1 | | | |
| | plt-tbr X sct-tbr | | 3 | | |
| | sto-tbr X sct-tbr | | 1 | 2 | |
| | | (1) | (6) | (2) | |
| S X phu | sct-tbr X phu | 3 | | | |
| | plt-tbr X phu | 1 | | | |
| | sto-tbr X phu | 4 | | | |
| | | (8) | | | |

[a] Abbreviations of species names follow Simmonds (1963), i.e., S. phureja (phu), S. polytrichon (plt), S. sanctae-rosae (sct), S. stoloniferum (sto), and S. tuberosum (tbr).

[b] Resistance levels based on excised leaf tests on 4-30 clones per progeny.

++ Progeny are more resistant than either parent.
+ Progeny intermediate, but greater than mid-parent.
- Progeny intermediate, but less than mid-parent.

-- Progeny are less resistant than either parent.

Resistant selections of S. sanctae-rosae-tuberosum progeny had a higher crossability with the three S. tuberosum pollen sources than did susceptible selections. With the S. stoloniferum-tuberosum progeny, however, susceptible selections produced higher fruit set across the S. tuberosum and S. phureja pollen sources although seed yield was the same as from resistant selections. In the S. polytrichon-tuberosum progeny, resistant selections showed higher crossability with 'Norland' while susceptible selections showed higher crossability with MN 81614 (DH). In the S. multidissectum-tuberosum progeny, there was no difference in seed production between selections when the progeny were crossed with three S. tuberosum pollen sources.

Non-reciprocal crosses between different interspecific hybrid progenies resulted in varying degrees of fruit set and seed production. Crossability between the hybrid progenies each involving different wild species was generally higher than that within the progenies. In the crosses having S. stoloniferum-tuberosum as the female parents, fruit set and seed production was greater in the wide crosses with S. sanctae-rosae-tuberosum as male parent than in the crosses with the more related S. polytrichon-tuberosum. In the crosses having S. multidissectum-tuberosum progeny as the female parent, fruit set and seed production were slightly higher in wide crosses with S. polytrichon-tuberosum or with S. stoloniferum-tuberosum as male parents than in the crosses with the more closely related S. sanctae-rosae-tuberosum. Higher crossability was observed when either parent was susceptible in crosses of S. multidissectum-tuberosum X other hybrid progenies and in S. stoloniferum X S. polytrichon-tuberosum.

When S. multidissectum-tuberosum progeny was used as the female parent successful crosses occurred in a nonrandom manner. A clone showing fruit set or seed production with one pollen source usually had a tendency to cross successfully with other pollen sources.

The more related the parents of the multi-species hybrids were, the greater the depression of fruit set and seed production. Individuals resulting from crossing within the S. sanctae-rosae-tuberosum progeny produced fewer seed across pollen parents than the original parents. In addition, this 3-species hybrid progeny showed lower seed production when backcrossed with the male parent S. sanctae-rosae-tuberosum. However, two of the 3-species hybrid progenies (S. polytrichon-sanctae-rosae-tuberosum and S. stoloniferum-sanctae-rosae-tuberosum) showed higher crossability when crossed with pollen of S. polytrichon-tuberosum and haploid S. tuberosum than did the female parents (S.

polytrichon-tuberosum and S. stoloniferum-tuberosum). A multi-species hybrid progeny having three green peach aphid resistant wild Solanum species and S. tuberosum in its background was obtained.

There was no evidence of a relationship between green peach aphid resistance and crossability in any of the mating schemes considered, within hybrid progenies, between hybrid progenies and S. tuberosum and S. phureja, and between interspecific hybrid progenies. Hermsen et al. (1977) reported that $F_1$ plants from interdihaploid matings of S. tuberosum when pollinated with S. verrucosum, segregated as to acceptance, non-acceptance, and pseudo-acceptance. A gene-for-gene relationship between dominant barrier genes of S. tuberosum and recessive penetration genes of S. verrucosum was proposed. The nonrandom pattern of successful crossing observed in this experiment may be explained by segregation into high or lower barrier capacity among the clones.

A cultivated species, S. phureja, surpassed S. tuberosum cultivars and a diplohaploid clone in seed production with the four hybrid progenies. Levin (1976) suggested that selection, inbreeding, and isolation played an important role in development of reproductive barriers between cultivars and between cultivars and wild species in Phlox drummondii. Plant populations subjected to different and very stringent selections or which have experienced severe inbreeding and/or genetic bottlenecks are more likely to show partial incongruity than those which have retained large populations and were not subjected to intense selection pressure. Therefore, the crossing success with S. phureja may reflect a history of less stringent selection.

Crosses between interspecific hybrid progenies showed, in general, better crossability, especially with respect to seed production, than crosses within progenies or between the hybrid progenies and S. tuberosum and S. phureja. Higher crossability occurred in the wide crosses of S. stoloniferum-tuberosum X S. sanctae-rosae-tuberosum and S. multidissectum-tuberosum X S. polytrichon-tuberosum or S. stoloniferum-tuberosum than in the other crosses in which the same female parents were involved. Conversely, lower crossability occurred in the related crosses of S. stoloniferum-tuberosum X S. polytrichon-tuberosum and S. multidissectum-tuberosum X S. sanctae-rosae-tuberosum. By the same token, the more related the parents of the multi-species hybrids were, the greater depression in fruit set and seed production.

Possible presence of different genes for green peach aphid resistance in wild Solanum species was suggested by Sams et al. (1976). In breeding for green peach aphid resistant potato cultivars, intermatings of different hybrid progenies may circumvent the barrier to cross-

compatibility with S. stoloniferum-tuberosum and S. multidissectum-ttuberosum and also combine different resistant genes.

## References


Hermsen, J. G. Th., I. Govart, S. Hoekstra, C. van Loon, and C. Neefjes. 1977. Analysis of the effect of parental genotype on crossability of diploid Solanum tuberosum with S. verrucosum. A gene-for-gene relationship? In: Interspecific Hybridization in Plant Breeding, eds. E. Sanchez-Monge and F. Garcia-Olmendo, pp. 305-312. Proc. 8th EUCARPIA Congr., Madrid.

Lee, M. H. 1981. Identification, crossability, and inheritance of resistance to green peach aphid in potato (Solanum) species. Ph.D. Thesis, Univ. Minn. 89 pp.

Levin, D. A. 1976. Consequences of long-term artificial selection, inbreeding, and isolation in Phlox: I. The evolution of cross-incompatibility. Evolution 30: 335-348.

Quisumbing, A. R. 1971. Resistance to Green Peach Aphid, Myzus persicae (Sulzer), and Potato Aphid, Macrosiphum euphorbiae Thomas, in Hybrids from Wild Tuber-bearing Solanum Species. M.S. Thesis, Univ. Minn. 50 pp.

Radcliffe, E. B., F. I. Lauer, M. H. Lee, and D. P. Robinson. 1981. Evaluation of the United States Potato Collection for Resistance to Green Peach Aphid and Potato Aphid. Univ. Minn. Agr. Exp. Sta. Tech. Bull. 331, 44 pp.

Sams, D. W., F. I. Lauer, and E. B. Radcliffe. 1976. Breeding behavior of resistance to green peach aphid in tuber-bearing Solanum germplasm. Amer. Potato J. 53: 23-29.

Simmonds, N. W. 1963. Abbreviations of potato names. Eur. Potato J. 6: 186-190.

## Appendix

Table 1A--Relative resistance of tuber-bearing *Solanum* accessions to green peach aphid. Minnesota, 1966-83.

| Series, species | Distribution of entries By resistance class 1 | 2 | 3 | 4 | 5 | Mean Resistance rating, no. entries |
|---|---|---|---|---|---|---|
| Series Juglandifolia | | | | | | |
| lycopersicoides | - | - | - | 1 | - | 4.00 (1) |
| ochranthum | - | - | - | - | 1 | 5.00 (1) |
| Series Etuberosa | | | | | | |
| etuberosum | - | 2 | 1 | - | - | 2.33 (3) |
| brevidens | - | - | 1 | 1 | - | 3.50 (2) |
| fernandezianum | - | - | - | - | 1 | 5.00 (1) |
| Series Morelliformia | | | | | | |
| morelliforme | 1 | - | - | - | - | 1.00 (1) |
| Series Bulbocastana | | | | | | |
| clarum | - | 2 | - | - | - | 2.00 (2) |
| bulbocastanum | 11 | 6 | 15 | 2 | - | 2.24 (34) |
| Series Pinnatisecta | | | | | | |
| trifidum | 5 | 5 | - | 1 | - | 1.73 (11) |
| trifidum x pinnatisectum | - | - | - | - | 1 | 5.00 (1) |
| brachistotrichum | - | 3 | - | - | - | 2.00 (3) |
| stenophyllidium | 1 | 1 | 2 | - | - | 2.25 (4) |
| cardiophyllum | - | 6 | 8 | 5 | 1 | 3.05 (20) |
| jamesii | - | 2 | 8 | 3 | 1 | 3.21 (14) |
| pinnatisectum | - | - | 1 | 8 | 5 | 4.07 (14) |
| x sambucinum | - | - | - | 1 | 1 | 4.50 (2) |
| Series Commersoniana | | | | | | |
| tarijense | - | 13 | 12 | 6 | 6 | 3.14 (37) |
| commersonii | - | - | 7 | 6 | 5 | 3.88 (18) |
| chacoense | - | - | - | 22 | 47 | 4.68 (69) |
| chacoense x multidissectum | - | - | 2 | - | - | 3.00 (2) |

Table 1A.--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| Series Circaeifolia | | | | | | |
| capsicibaccatum | 1 | - | 1 | - | - | 2.00 (2) |
| Series Conicibaccata | | | | | | |
| limbaniense | - | 1 | - | - | - | 2.00 (1) |
| chomatophilum | - | 8 | 1 | 1 | 2 | 2.75 (12) |
| santolallae | - | - | 1 | - | - | 3.00 (1) |
| oxycarpum | - | - | 2 | 2 | 1 | 3.80 (5) |
| colombianum | - | - | - | 2 | 2 | 4.50 (4) |
| paucijugum | - | - | - | 1 | 1 | 4.50 (2) |
| violaceimarmoratum | - | - | - | 2 | 3 | 4.60 (5) |
| agrimonifolium | - | - | - | - | 6 | 5.00 (6) |
| laxissimum | - | - | - | - | 1 | 5.00 (1) |
| moscopanum | - | - | - | - | 2 | 5.00 (2) |
| Series Piurana | | | | | | |
| acroglossum | 1 | - | - | - | - | 1.00 (1) |
| tuquerrense | - | 1 | - | - | - | 2.00 (1) |
| pascoense | - | - | 1 | - | - | 3.00 (1) |
| piurae | - | - | 1 | 2 | - | 3.67 (3) |
| paucissectum | - | - | 1 | - | 1 | 4.00 (2) |
| chancayense | - | - | 1 | - | 2 | 4.33 (3) |
| immite | - | - | - | 2 | 1 | 4.33 (3) |
| huancabambense | - | - | 1 | - | 3 | 4.50 (4) |
| Series Acaule | | | | | | |
| acaule | - | - | 6 | 45 | 45 | 4.41 (96) |
| acaule albicans | - | - | - | 2 | 1 | 4.33 (3) |
| Series Demissa | | | | | | |
| hougasii | 1 | - | - | 3 | 3 | 4.00 (7) |
| iopetalum | - | - | - | 2 | - | 4.00 (2) |
| guerreroense | - | - | - | 1 | 1 | 4.50 (2) |
| demissum | - | - | 1 | 19 | 35 | 4.62 (55) |
| brachycarpum | - | - | - | 1 | 5 | 4.83 (6) |

Table 1A.--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| Series Longipedicellata | | | | | | |
| x vallis-mexici | - | 1 | - | - | - | 2.00 (1) |
| hjertingii | - | - | 6 | - | - | 3.00 (6) |
| stoloniferum | - | 3 | 25 | 16 | 4 | 3.43 (48) |
| polytrichon | 1 | - | 6 | 4 | 8 | 3.95 (19) |
| fendleri | - | - | 5 | 7 | 6 | 4.06 (18) |
| papita | - | - | 1 | 4 | 4 | 4.33 (9) |
| Series Polyadenia | | | | | | |
| polyadenium | - | - | 4 | 5 | 5 | 4.07 (14) |
| lesteri | - | - | - | - | 1 | 5.00 (1) |
| Series Cuneoalata | | | | | | |
| infundibuliforme | - | 6 | 33 | 12 | 2 | 3.19 (53) |
| Series Megistacroloba | | | | | | |
| sanctae-rosae | 2 | 2 | 5 | 1 | 1 | 2.73 (11) |
| megistacrolobum | - | 2 | 23 | 17 | 7 | 2.98 (49) |
| toralapanum | - | 1 | 2 | 2 | - | 3.20 (5) |
| boliviense | 1 | - | 11 | 3 | 1 | 3.40 (15) |
| raphanifolium | - | - | 2 | 14 | 15 | 4.81 (31) |
| sogarandinum | - | - | - | - | 1 | 5.00 (1) |
| Series Tuberosa | | | | | | |
| wild species | | | | | | |
| lignicaule | 1 | - | 1 | 1 | - | 2.67 (3) |
| marinasense | 1 | 4 | 4 | 1 | 1 | 2.73 (11) |
| chiquidenum | 1 | 1 | 2 | 2 | - | 2.83 (6) |
| amabile | - | - | 1 | - | - | 3.00 (1) |
| cajamarcense | - | 1 | - | 1 | - | 3.00 (2) |
| canasense | 4 | 6 | 20 | 6 | 4 | 3.00 (40) |
| weberbaueri | - | - | 1 | - | - | 3.00 (1) |
| multidissectum | - | 4 | 11 | 6 | - | 3.10 (21) |
| verrucosum | - | 1 | 11 | 5 | - | 3.24 (17) |
| brevicaule | - | - | 1 | 1 | - | 3.50 (2) |
| multiinterruptum | - | 1 | 1 | 4 | - | 3.50 (6) |

Table 1A.--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| medians | 1 | - | 3 | 4 | 2 | 3.60 (10) |
| gourlayi | - | 1 | 16 | 28 | 5 | 3.74 (50) |
| spegazzinii | - | - | 12 | 7 | 10 | 3.93 (29) |
| spegazzinii | - | - | - | 1 | - | 4.00 (1) |
| abancayense | - | - | - | 3 | - | 4.00 (3) |
| acroscopicum | - | - | 1 | - | 1 | 4.00 (2) |
| ambosinum | - | - | - | 3 | - | 4.00 (3) |
| andreanum | - | - | - | 1 | - | 4.00 (1) |
| berthaultii | - | 1 | 5 | 7 | 7 | 4.00 (20) |
| pampasense | - | - | 1 | 3 | 1 | 4.00 (5) |
| leptophyes | - | - | 1 | 1 | 2 | 4.25 (4) |
| venturii | - | - | - | 9 | 3 | 4.25 (12) |
| oplocense | - | - | 1 | 13 | 12 | 4.42 (26) |
| maglia | - | - | - | 1 | 1 | 4.50 (2) |
| microdontum | - | - | 1 | 20 | 28 | 4.55 (49) |
| kurtzianum | - | - | 2 | 15 | 29 | 4.59 (46) |
| kurtzianum x multidissectum | - | - | - | 1 | 1 | 4.00 (1) |
| sucrense | - | - | - | 4 | 13 | 4.65 (17) |
| sparsipilum | - | - | - | 7 | 29 | 4.81 (36) |
| vernei | - | - | - | 3 | 15 | 4.83 (18) |
| gandarillasii | - | - | - | - | 3 | 5.00 (3) |
| mochicense | - | - | - | - | 3 | 5.00 (3) |
| Series Tuberosa | | | | | | |
| cultivated species | | | | | | |
| phureja | - | 1 | 15 | 36 | 15 | 3.97 (67) |
| phureja x tuberosum | - | - | - | 5 | - | 4.00 (5) |
| stenotomum | - | - | 1 | 11 | 12 | 4.46 (24) |
| stenotomum x tuberosum | - | - | - | 1 | 1 | 4.50 (2) |
| ajanhuiri | - | - | - | 1 | 2 | 4.67 (3) |
| tuberosum andigena | - | - | 2 | 56 | 156 | 4.72 (214) |
| tuberosum tuberosum | - | - | - | 12 | 38 | 4.76 (50) |
| t. tuberosum x canasense | 1 | - | - | - | - | 1.00 (1) |
| t. tuberosum x phureja | - | - | - | 1 | - | 4.00 (1) |
| t. tuberosum x stenotomum1 | - | - | - | 3 | 4.00 (4) | |
| t. tuberosum x chacoense | - | - | - | - | 1 | 5.00 (1) |
| t. tuberosum x megistacrolobum | - | - | - | - | 1 | 5.00 (1) |

Table 1A.--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| t. tuberosum x multidissectum | - | - | - | - | 1 | 5.00 (1) |
| x chaucha | - | - | - | - | 1 | 5.00 (1) |
| x curtilobum | - | - | - | - | 5 | 5.00 (5) |
| Unclassified | | | | | | |
| sp. nov. | - | - | 1 | 1 | - | 3.50 (2) |
| spp. undetermined | - | 2 | 1 | 9 | 2 | ---- (14) |
| Totals | 35 | 88 | 313 | 525 | 646 | |

Table 2A.--Accessions rated highly resistant (class 1 resistance) to green peach aphid (3 or more evaluations). Minnesota, 1966-83.

| Code | Species | Mean score | No. of tests |
|---|---|---|---|
| PI 365313 | acroglossum | 0.429 | 14 |
| Hof 1729 | boliviense | 0.415 | 9 |
| WRF 1729 | bulbocastanum | 0.145 | 4 |
| PI 275200 | bulbocastanum | 0.147 | 31 |
| WRF 1565 | bulbocastanum | 0.148 | 47 |
| PI 275194 | bulbocastanum | 0.207 | 43 |
| PI 275189 | bulbocastanum | 0.212 | 30 |
| PI 255516 | bulbocastanum | 0.338 | 22 |
| PI 255518 | bulbocastanum | 0.362 | 4 |
| PI 347757 | bulbocastanum | 0.383 | 5 |
| PI 275197 | bulbocastanum | 0.414 | 18 |
| PI 275195 | bulbocastanum | 0.417 | 7 |
| HHC 5107 | canasense | 0.444 | 21 |
| PI 210035 | canasense | 0.469 | 26 |
| PI 283074 | canasense | 0.483 | 35 |
| HHC 5087 | canasense | 0.498 | 28 |
| PI 205560 | capsicibaccatum | 0.150 | 28 |
| PI 310942 | chiquidenum | 0.463 | 13 |
| HHC 5113 | lignicaule | 0.409 | 5 |
| PI 365332 | marinasense | 0.276 | 14 |

Table 2A.--(Continued).

| Code | Species | Mean score | No. of tests |
|---|---|---|---|
| PI 275221 | morelliforme | 0.000 | 3 |
| PI 205397 | sanctae-rosae | 0.486 | 34 |
| PI 218221 | sanctae-rosae | 0.492 | 48 |
| PI 255530 | stenophyllidium | 0.455 | 7 |
| PI 255539 | trifidum | 0.074 | 6 |
| PI 283104 | trifidum | 0.119 | 11 |
| PI 255542 | trifidum | 0.251 | 25 |
| PI 255540 | trifidum | 0.286 | 24 |
| PI 255536 | trifidum | 0.493 | 4 |

Table 3A--Relative resistance of tuber-bearing Solanum accessions to potato aphid. Minnesota, 1966-83.

| Series, species | Distribution of entries by resistance class | | | | | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| Series Juglandifolia | | | | | | |
| lycopersicoides | - | - | 1 | - | - | 3.00 (1) |
| ochranthum | - | - | 1 | - | - | 3.00 (1) |
| Series Etuberosa | | | | | | |
| etuberosum | - | - | 1 | 2 | - | 3.67 (3) |
| brevidens | - | - | - | 2 | - | 4.00 (2) |
| fernandezianum | - | - | - | - | 1 | 5.00 (1) |
| Series Morelliformia | | | | | | |
| morelliforme | - | - | - | 1 | - | 4.00 (1) |
| Series Bulbocastana | | | | | | |
| clarum | 2 | - | - | - | - | 1.00 (2) |
| bulbocastanum | 11 | 9 | 11 | 2 | - | 2.12 (33) |
| Series Pinnatisecta | | | | | | |
| x sambucinum | - | 1 | - | 1 | - | 3.00 (2) |

Table 3A--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| trifidum | - | 1 | 5 | 1 | 2 | 3.44 (9) |
| trifidum x pinnatisectum | - | - | - | 1 | - | 4.00 (1) |
| cardiophyllum | - | 3 | 7 | 7 | 2 | 3.42 (19) |
| brachistotrichum | - | - | 1 | 2 | - | 3.67 (3) |
| stenophyllidium | - | - | 1 | 3 | - | 3.75 (4) |
| jamesii | - | - | 4 | 5 | 5 | 4.07 (12) |
| pinnatisectum | - | 1 | - | 8 | 4 | 4.15 (13) |
| Series Commersoniana | | | | | | |
| commersonii | 1 | - | 6 | 5 | 3 | 3.60 (15) |
| tarijense | 2 | - | - | 1 | 11 | 4.35 (14) |
| chacoense | 1 | - | 4 | 12 | 28 | 4.47 (48) |
| chacoense x multidissectum | - | 1 | 1 | - | - | 2.50 (2) |
| Series Circaeifolia | | | | | | |
| capsicibaccatum | - | - | 1 | 1 | - | 3.50 (2) |
| Series Conicibaccata | | | | | | |
| chomatophilum | 2 | 5 | 4 | 1 | - | 2.33 (12) |
| oxycarpum | - | 3 | 2 | - | - | 2.40 (5) |
| violaceimarmoratum | 1 | - | 1 | 1 | - | 2.67 (3) |
| colombianum | - | - | 3 | - | 1 | 3.50 (4) |
| moscopanum | - | - | 1 | 1 | - | 3.50 (2) |
| laxissimum | - | - | - | 1 | - | 4.00 (1) |
| paucijugum | - | - | - | 1 | - | 4.00 (1) |
| agrimonifolium | - | - | - | 5 | 1 | 4.83 (6) |
| santolallae | - | - | - | - | 1 | 5.00 (1) |
| Series Piurana | | | | | | |
| chancayense | 1 | 1 | - | - | - | 1.50 (2) |
| pascoense | - | 1 | - | - | - | 2.00 (1) |
| tuquerrense | - | - | 1 | - | - | 3.00 (1) |
| piurae | - | - | 1 | 1 | - | 3.50 (2) |
| immite | - | - | 1 | 1 | - | 3.50 (2) |
| huancabambense | - | - | 1 | 2 | - | 3.67 (3) |
| acroglossum | - | - | - | - | 1 | 5.00 (1) |

Table 3A--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| Series Acaule | | | | | | |
| acaule | 7 | 10 | 29 | 20 | 3 | 3.02 (69) |
| acaule albicans | 2 | - | - | - | - | 2.00 (2) |
| Series Demissa | | | | | | |
| hougasii | - | 5 | 1 | - | - | 2.17 (6) |
| iopetalum | - | 1 | 1 | - | - | 2.50 (2) |
| guerreroense | - | 1 | 1 | - | - | 2.50 (2) |
| demissum | 6 | 9 | 16 | 13 | 2 | 2.91 (46) |
| brachycarpum | - | 2 | 1 | 3 | - | 3.17 (6) |
| Series Longipedicellata | | | | | | |
| x vallis-mexici | - | 1 | - | - | - | 2.00 (1) |
| hjertingii | 2 | 3 | 2 | - | - | 2.00 (7) |
| stoloniferum | 5 | 21 | 16 | 5 | - | 2.53 (46) |
| polytrichon | 1 | 4 | 10 | 5 | - | 2.95 (20) |
| papita | - | - | 3 | 5 | 1 | 3.77 (9) |
| fendleri | 1 | 2 | 2 | 6 | 6 | 3.82 (17) |
| Series Polyadenia | | | | | | |
| lesteri | - | - | 1 | - | - | 3.00 (1) |
| polyadenium | - | - | 2 | 4 | 4 | 4.20 (10) |
| Series Cuneoalata | | | | | | |
| infundibuliforme | 2 | 3 | 8 | 6 | - | 2.85 (20) |
| Series Megistacroloba | | | | | | |
| toralapanum | 1 | - | 3 | 1 | - | 2.80 (5) |
| boliviense | - | - | 5 | 7 | - | 3.58 (12) |
| megistacrolobum | - | 1 | 5 | 10 | 2 | 3.72 (18) |
| raphanifolium | - | 1 | 9 | 9 | 6 | 3.80 (25) |
| sanctae-rosae | - | - | 2 | 5 | 1 | 3.88 (8) |
| sogarandinum | - | - | - | 1 | - | 4.00 (1) |
| Series Tuberosa | | | | | | |
| wild species | | | | | | |
| amabile | - | 1 | - | - | - | 2.00 (1) |

Table 3A--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| lignicaule | 1 | 1 | 1 | - | - | 2.00 (3) |
| multidissectum | 3 | 9 | 5 | 2 | - | 2.32 (19) |
| verrucosum | 2 | 5 | 9 | - | - | 2.44 (16) |
| medians | 2 | 1 | 3 | 2 | 1 | 2.78 (9) |
| canasense | 1 | 12 | 16 | 5 | 2 | 2.86 (36) |
| ambosinum | - | 1 | 1 | 1 | - | 3.00 (3) |
| gandarillasii | - | 1 | 1 | 1 | - | 3.00 (3) |
| weberbaueri | - | - | 1 | - | - | 3.00 (1) |
| gourlayi | 1 | 4 | 6 | 3 | 3 | 3.17 (17) |
| multiinterruptum | - | - | 2 | 2 | - | 3.50 (4) |
| marinasense | 1 | - | 1 | 6 | 2 | 3.80 (10) |
| oplocense | - | - | 1 | 6 | - | 3.85 (7) |
| spegazzinii | 1 | - | - | 13 | 3 | 3.94 (17) |
| spegazzinii | - | - | 1 | 1 | - | 3.50 (2) |
| abancayense | - | - | - | 2 | - | 4.00 (2) |
| andreanum | - | - | 2 | - | - | 4.00 (1) |
| brevicaule | - | - | - | 2 | - | 4.00 (2) |
| cajamarcense | - | - | - | 2 | - | 4.00 (2) |
| chiquidenum | - | - | 2 | 1 | 2 | 4.00 (5) |
| pampasense | - | - | 1 | 1 | 1 | 4.00 (3) |
| berthaultii | 1 | 1 | 2 | 3 | 11 | 4.22 (18) |
| sparsipilum | - | 1 | 3 | 7 | 10 | 4.23 (21) |
| sucrense | - | - | 1 | 7 | 4 | 4.25 (12) |
| microdontum | - | - | 6 | 7 | 14 | 4.29 (27) |
| kurtzianum | - | - | 2 | 4 | 8 | 4.42 (14) |
| kurtzianum x multidissectum | - | - | 1 | - | - | 3.00 (1) |
| vernei | - | - | - | 5 | 4 | 4.44 (9) |
| acroscopicum | - | - | - | 1 | 1 | 4.50 (2) |
| mochicense | - | - | - | 1 | 2 | 4.67 (3) |
| leptophyes | - | - | - | 1 | 3 | 4.75 (4) |
| venturii | - | - | - | 1 | 6 | 4.85 (7) |
| maglia | - | - | - | - | 2 | 5.00 (2) |
| Series Tuberosa | | | | | | |
| cultivated species | | | | | | |
| x curtilobum | - | 1 | 2 | 2 | - | 3.20 (5) |
| stenotomum | 2 | 2 | 10 | 7 | 3 | 3.29 (24) |

Table 3A--(Continued).

| Series, species | Distribution of entries by resistance class 1 | 2 | 3 | 4 | 5 | Mean resistance rating, no. entries |
|---|---|---|---|---|---|---|
| stenotomum x tuberosum | - | - | - | 2 | - | 4.00 (2) |
| tuberosum andigena | 3 | 16 | 77 | 79 | 26 | 3.55 (200) |
| ajanhuiri | - | - | 1 | 2 | - | 3.67 (3) |
| phureja | 1 | 1 | 16 | 31 | 8 | 3.77 (57) |
| phureja x tuberosum | 1 | - | 1 | 3 | - | 3.20 (5) |
| x chaucha | - | - | - | 1 | - | 4.00 (1) |
| tuberosum tuberosum | - | 1 | 9 | 28 | 11 | 4.00 (49) |
| t. tuberosum x canasense | - | - | 1 | - | - | 3.00 (1) |
| t. tuberosum x phureja | - | - | 1 | - | - | 3.00 (1) |
| t. tuberosum x stenotomum | - | - | 1 | 2 | 1 | 4.00 (4) |
| t. tuberosum x chacoense | - | - | - | - | 1 | 5.00 (1) |
| t. tuberosum x megistacrolobum | - | - | - | 1 | - | 4.00 (1) |
| t. tuberosum x multidissectum | - | - | 1 | - | - | 3.00 (1) |
| Unclassified | | | | | | |
| sp. nov. | 1 | - | 1 | - | - | 2.00 (2) |
| spp. undetermined | 3 | 3 | 2 | 4 | 1 | ---- (13) |
| Totals | 72 | 151 | 368 | 416 | 215 | |

Table 4A.--Accessions rated highly resistant (class 1 resistance) to potato aphid (3 or more evaluations). Minnesota, 1966-83.

| Code | Species | Mean score | No. of tests |
|---|---|---|---|
| PI 365312 | acaule | 0.493 | 6 |
| PI 365376 | acaule albicans | 0.368 | 5 |
| PI 347758 | bulbocastanum | 0.120 | 3 |
| PI 255516 | bulbocastanum | 0.195 | 20 |
| PI 275196 | bulbocastanum | 0.204 | 4 |
| WRF 1729 | bulbocastanum | 0.252 | 4 |
| PI 275194 | bulbocastanum | 0.299 | 35 |
| PI 275189 | bulbocastanum | 0.389 | 25 |
| PI 275195 | bulbocastanum | 0.421 | 8 |

Table 4A.--(Continued.

| Code | Species | Mean score | No. of tests |
|---|---|---|---|
| PI 275188 | bulbocastanum | 0.429 | 8 |
| PI 255518 | bulbocastanum | 0.443 | 4 |
| PI 243513 | bulbocastanum | 0.462 | 4 |
| WRF 1565 | bulbocastanum | 0.468 | 37 |
| PI 338615 | chancayense | 0.378 | 12 |
| PI 243355 | clarum | 0.139 | 3 |
| PI 275202 | clarum | 0.401 | 13 |
| PI 320267 | commersonii | 0.379 | 4 |
| PI 230592 | demissum | 0.365 | 9 |
| PI 230589 | demissum | 0.426 | 9 |
| PI 347761 | demissum | 0.489 | 3 |
| PI 251063 | hjertingii | 0.290 | 42 |
| PI 186560 | hjertingii | 0.332 | 8 |
| Oka 3960 | infundibuliforme | 0.317 | 3 |
| HHC 5082 | multidissectum | 0.203 | 4 |
| HHC 5226 | multidissectum | 0.359 | 3 |
| HHC 5444 | multidissectum | 0.434 | 3 |
| PI 184770 | polytrichon | 0.416 | 42 |
| PI 160226 | stoloniferum | 0.300 | 42 |
| PI 161178 | stoloniferum | 0.361 | 12 |
| PI 310980 | stoloniferum | 0.411 | 9 |
| PI 275249 | stoloniferum | 0.432 | 41 |
| PI 280907 | tuberosum andigena | 0.274 | 3 |
| PI 365351 | spp. undetermined | 0.281 | 7 |
| PI 195171 | verrucosum | 0.358 | 3 |
| PI 310966 | verrucosum | 0.478 | 9 |
| PI 258856 | violaceimarmoratum | 0.321 | 8 |

# MECHANISMS OF RESISTANCE TO POTATO MOTH OVIPOSITION ON FOLIAGE

L. Valencia*

## INTRODUCTION

Oviposition by the potato moth has long been one of the most controversial aspects of its life history. There are reports that the foliage of potato plants is the preferred site for oviposition (Graf, 1917; Hofmaster, 1949; Meisner et al., 1974) while other reports mention that the main place for oviposition is the soil around the plant base (Atherton, 1936; Hofmaster, 1949; Reed, 1971; Traynier, 1975). The oviposition site by any insect pest is very important because it indicates the beginning of the insecthost plant association. Exact knowledge might facilitate control and a better understanding of the insect pesthost plant association in the context of plant resistant.

Although factors such as colour, texture, height, thickness of stem, infection by fungi or micro-organisms, and so on often plays an important part in the choice of plants on which to lay, there is little doubt that the odour and/or taste of the plant are usually of much greater significance in triggering oviposition behaviour than any other factors. In a few instances, the chemical substances responsible have been identified (Hinton, 1981).

Preferences for oviposition by the potato moth on tubers and foliage of some commercial potato cultivars has been reported from New Zealand (Fenemore, 1980). It was found that using pieces of foliage as oviposition substrate, the potato cultivar Pentland Dell received significantly less eggs than the cultivar Ilam Hardy, which was used for comparison. Fenemore did not investigate the cause of that preference.

In the case of the potato plant, in addition to any chemical factor which may influence the oviposition by the potato

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moth there are also physical barriers. For example, the leaf surface of certain potato cultivars have two types of glandular trichomes (Bancher and Holzl, 1959; Lyshede, 1980); one with a globular head and the other with a club-shaped head. The first one is more common on the abaxial (bottom) surface, and the second one is more common on the adaxial surface of the leaves.

The possible role of these trichomes as a plant defense mechanisms to insect pests was suggested by Gibson (1971, 1974, and 1976) who worked with the wild potato species Solanum berthaultii Hawkes, S. polyadenium Greenm., and S. Tarijense Hawkes. He found that these species have high densities of four-lobed hairs, Type A (globular head trichomes of Bancher and Holzl, 1959; Lyshede, 1980); S. berthaultii and S. tarijense have in addition a second kind, Type B, which are longer and have a sticky droplet at the tip.

Under laboratory conditions it has been demonstrated that female moths prefer surface depressions just large enough to accommodate eggs (0.2-0.5 mm ); but, in addition, hairy substrates were much more attractive than smooth (Fenemore, 1978). If the effect of any chemical on oviposition is carried out then the resultant will be an additive effect of the physical or mechanical stimulus plus the chemical one.

Of chemicals isolated from potato plants glutamic acid was reported to be an oviposition localizer (Meisner et al., 1974), and mixtures of the glycoalkaloids -chaconine and -solanine did not show any effect at all (Raman et al., 1981). Traynier (1975; 1983) has reported to have a good localizer effect on the oviposition by the potato moth when leaf extracts were used. The volatiles from the foliage of potatoes were reported by Visser et al., (1979) as a mixture of: trans-2-hexen-1-ol; 1-hexanol; cis-3-hexen-1-ol; trans-2-hexenal; and linalool.

Although the main oviposition site by the potato moth is the soil around the plant base, there is still some oviposition on the foliage and therefore any study in this direction may give some insight into the host selection mechanisms of this species. Preferences for oviposition on the foliage of ten rooted commercial potato cultivars are reported. Observations on the main morphological characteristics of each cultivars involved in the comparisons was noted, and the effect of some chemicals produced by the foliage of the potato plant on the oviposition was also studied.

## MATERIALS AND METHODS

Seed tubers of Red la Soda, Sebago, Katahdin, Up-to-Date, Red Pontiac, Tasman, Kennebec, Coliban, Sequoia, and Exton cultivars were obtained from the Potato Research Station of the Department of Agriculture, Victoria. Tubers of the named cultivars were planted approximately 10 cm deep in 24 cm diameter black plastic pots, containing a 1:1 mixture of bedding sand and peat moss. The medium was first sterilized with hot steam to kill pathogenic micro-organisms and weed seeds.

When plants were approximately 10 cm high, they were excised from a tuber with a sterilized knife and transplanted individually to plastic pots of 20 cm diameter. When the transplanted cuttings were approximately 20 cm high, they were used in the oviposition experiments. The transplanted cuttings received supplementary nutrients in the form of 50 ml per pot of a 0.1 percent Aquasol (Hortico Ltd.) solution once every fortnight.

Two different techniques were used to study the oviposition preferences by the potato moth on the commercial potato cultivars, under glasshouse and controlled environment conditions (26 ±2° C; 60 5% RH; and 12-hour photoperiod). In the first one, plants of each of the named potato cultivars propagated by the cutting technique were randomly placed in each of four rows in a 5.50 x 3 x 2.40 m cage in a glasshouse. The cage was covered with green plastic screen.

Two days later, 100 pairs of two-day old moths were released into the cage. During the test period, temperature varied between 22-28 ° C and humidity varied between 35-75% RH. After two days, the number of eggs laid on each plant was recorded and data were transformed by the square root of the function (x + 1) before statistical analysis.

In the second technique, the Sebago cv, which is the most extensively cultivated in South Queensland, was compared in paired tests with each of the eight other cultivars in controlled environment. Six to ten plants of the Sebago cv were compared with the same number of plants belonging to each of the other cultivars. These comparisons were made in 2 x 0.8 x 1 m cage covered with white nylon gauze. Each comparison was run overnight and the following day the number of eggs was counted and the leaf area of each plant was measured in a Patton electronic leaf area meter. In

each comparison approximately 50 pairs of two-day old moths were used. Data were transformed by the log of the ratio V1/V2; where V1 and V2 are the number of eggs laid on the foliage of the cultivar pairs being compaired. The transformed data were tested for significant difference from zero using Student 't' test. Without the use of the log transformation the ratio V1/V2 does not follow a normal distribution.

## Laboratory Experiments

Adult moths were obtained from a culture maintained in the Department of Entomology, University of Queensland. The culture was maintained by techniques similar to those reported by Platner and Oatman (1968). Newly emerged adults were kept together during the first 24 hours in order to ensure mating, and adults aged 48 hours were used in all experiments. Moths were anesthetized with ether for 3 minutes to facilitate their handling. All the laboratory experiments were made in a constant temperature room at 26±2°C and 60±5% RH with a photoperiod of 12 hours.

## Choice Chambers for Oviposition

Choice chambers were made from plastic containers 125 mm in diameter and 75 mm depth (Fig. 1). A piece of plastic sponge was inserted through a small hole in the side of the container and a 50 mm diameter hole in the lid was covered by black cloth with mesh of approximately 0.5 mm. The area covered by the cloth was divided into two equal areas by a strip of masking tape 5 mm wide. One of these semi-circular areas was treated with the chemical to be tested and the other half was treated with solvent only and thus acted as a control. A 10% sugar solution in the sponge provided food for the moths. Unless otherwise stated, all the choice chamber experiments were run for 48 hours.

## Study of the Density of Globular Head Trichomes Among Potato Cultivars.

The number of trichomes of the apical leaflet of the third youngest compound leaf of ten different plants per cultivar was counted. This was accomplished by means of an eye piece (circle of cardboard with a round hole made by an office paper perforator) attached to one of the arms of a Leitz stereo microscope. Using this eye piece at an appropriate magnification, trichomes in a field of 1.77 mm2 area were

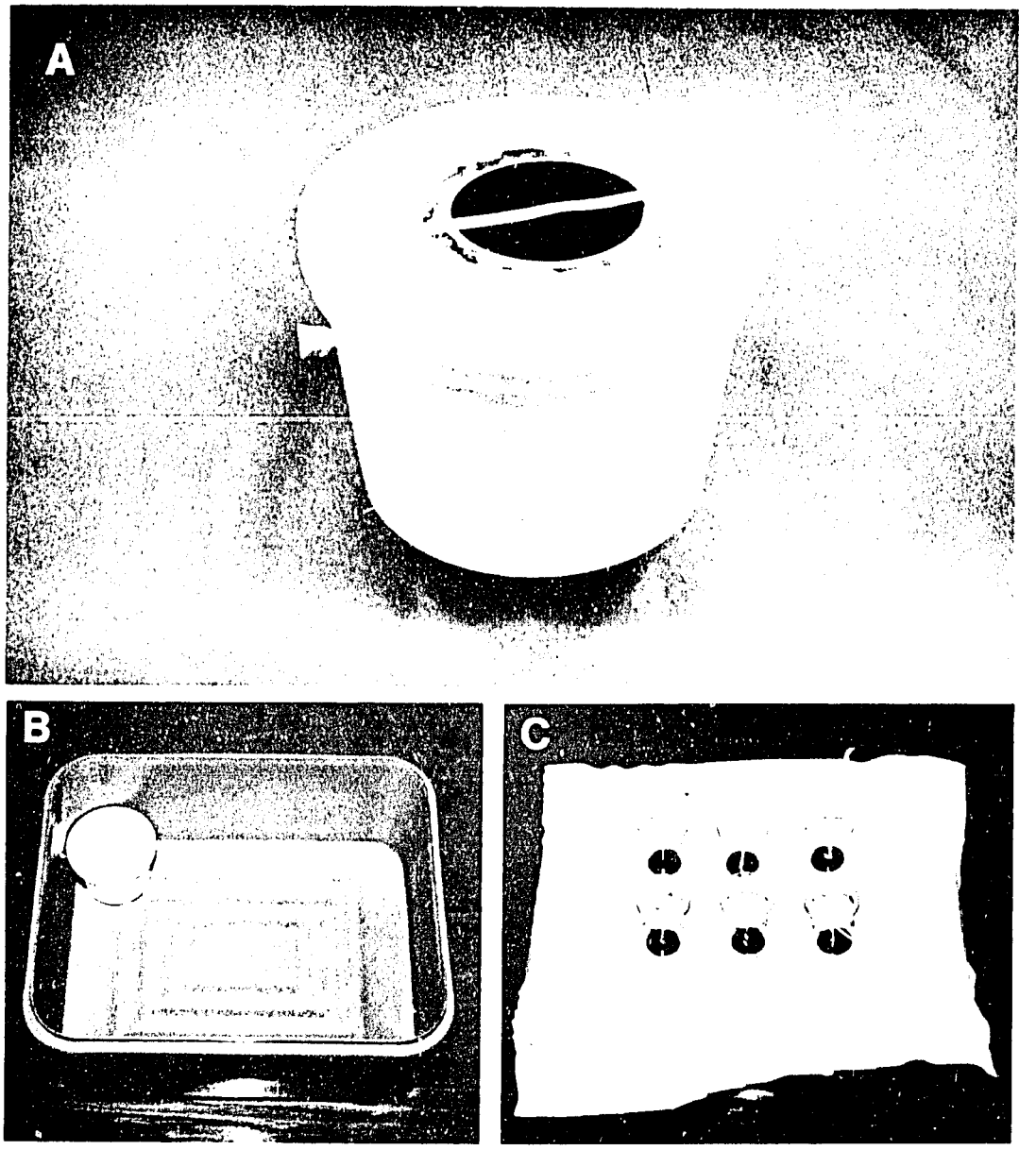


Figure 1.- Chambers used for the study of the oviposition behaviour of the potato moth. A.- Choice chamber. B.- Multichoice chamber showing food cup to provide a 10% sugar solution. C.- Multichoice chamber showing arrangement of the treated pieces of black filter paper backed by small plastic cups.

counted. The abaxial surface of the leaflets, which usually has the highest trichomes densities, was examined. Data were transformed by the log of X before statistical analysis.

Preliminary Experiment

In the choice chambers the degree of preference (+) or rejection (-) was described by the Discrimination Coefficient (DC), (A-B)/(A+B), in which A and B are the number of eggs laid on the 2 areas of the ovipositional substrate. This coefficient was first used by David and van Harrewage (1970) for *Drosophila melanogaster* Meigen and subsequently, Jermy and Szentesi (1978) for *Acanthoscelides obtectus* Say. The main advantage of this approach is that the coefficient is independent of the number of eggs laid which can vary between replicates. For each comparison a standard error of this function was calculated, together with the "t" statistic.

For this preliminary experiment a 0.1% tomatine solution was prepared and used in the following combinations:

Treatment (a).- The 0.1% tomatine solution dissolved in hot methanol was applied with a fine brush to the cloth. No filter paper backed the cloth.

Treatment (b).- The 0.1% tomatine solution applied to the cloth and to the filter paper backing the cloth.

Treatment (c).- The 0.1% tomatine solution applied to the filter paper only, nothing applied to the cloth, and

Treatment (d).- The 0.1% tomatine solution applied to the cloth but this time the treated and untreated areas were backed by untreated filter paper.

There were 7 replications per treatment and the data were analysed using the Generalised Linear Modeling Program (GLIM) 3.10.

## Experiment with Leaf Extract (Soxhlet extracted)

Once the appropriate technique for the study of chemicals on oviposition was reached, the effect of different concentrations of a leaf extract on oviposition was carried out. Leaves of Sebago cv plants were dried for 3 days in an oven at 45°C and then ground with a mortar and pestle. The powder was soxhlet extracted overnight with pure methanol and then evaporated to dryness in the rotavapor at 70°C under vacuum. The material obtained was weighed and dissolved in warm 95% aqueous ethanol. From this stock solution, concentrations of (a) 0.1%, (b) 0.5%, (c) 1%, (d) 2.5%, (e) 5%, (f) 10% were prepared and tested in the choice chambers.

## Test with Pure Non-Volatile Chemicals

Pure α-solanine, α-chaconine, tomatine, zeatin, zeatin riboside were obtained from Sigma Chemical Company, St. Louis, Mo., USA; chlorogenic acid was bought from Aldrich Chemical Company Inc., USA. The chemicals used and their concentration, together with the number of replication for each chemical and concentration are set out in Table 1. α-solanine and α-chaconine were dissolved in boiling ethanol and made up to the appropriate volume with 70% aqueous ethanol in order to make the highest concentration. In all cases, the highest concentrations of each chemical was made first and the other concentrations were prepared by dilution. Tomatine was dissolved in hot pure methanol; glutamic acid was dissolved with 70% ethanol; zeatin and zeatin riboside were dissolved in 0.5 ml of warm 0.05 M sodium hydroxide and dilute with distilled water; and chlorogenic acid was dissolved with warm 70% aqueous methanol.

## Test with Pure Volatile Chemicals

Plastic containers of 31 cm x 26 cm x 12 cm were used as experimental units (Fig. 2, B and C) for the study of volatile chemicals in a multichoice chamber. The lid of each plastic container was cut away and replaced by nylon gauze. A 10% sugar solution provided as food for the moths was placed in a small cup inside each container. A piece of sponge attached to its lid provided access to the food solution. The chemical candidates were applied to a disc of Whatman No. 29 black filter paper, and presented to the moths above the nylon gauze on the lid of the multichoice chamber. A small plastic cup was placed above each disc of

Table 1. Chemicals, concentrations, and number of replications used in the oviposition tests(*).

| CHEMICALS | NO. REPLICATES/ CONCENTRATION | CONCENTRATION TESTED IN PPM | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 0.0001 | 0.001 | 0.01 | 0.1 | 1 | 10 | 100 | 1000 | 2000 |
| Glutamic acid | 10 | | | | | a | b | c | d | |
| α-chaconine | 10 | a | b | c | d | e | f | g | h | i |
| α-solanine | 10 | | | | a | b | c | d | e | f |
| Chlorogenic acid | 5 | | | a | b | c | d | e | f | g |
| Tomatine | 5 | | a | b | c | d | e | f | g | |
| Zeatin riboside | 10 | | | a | b | c | d | e | f | |
| Zeatin | 7 | | | a | b | c | d | e | f | |

(*) Letters indicate the appropriate concentration for each chemical.

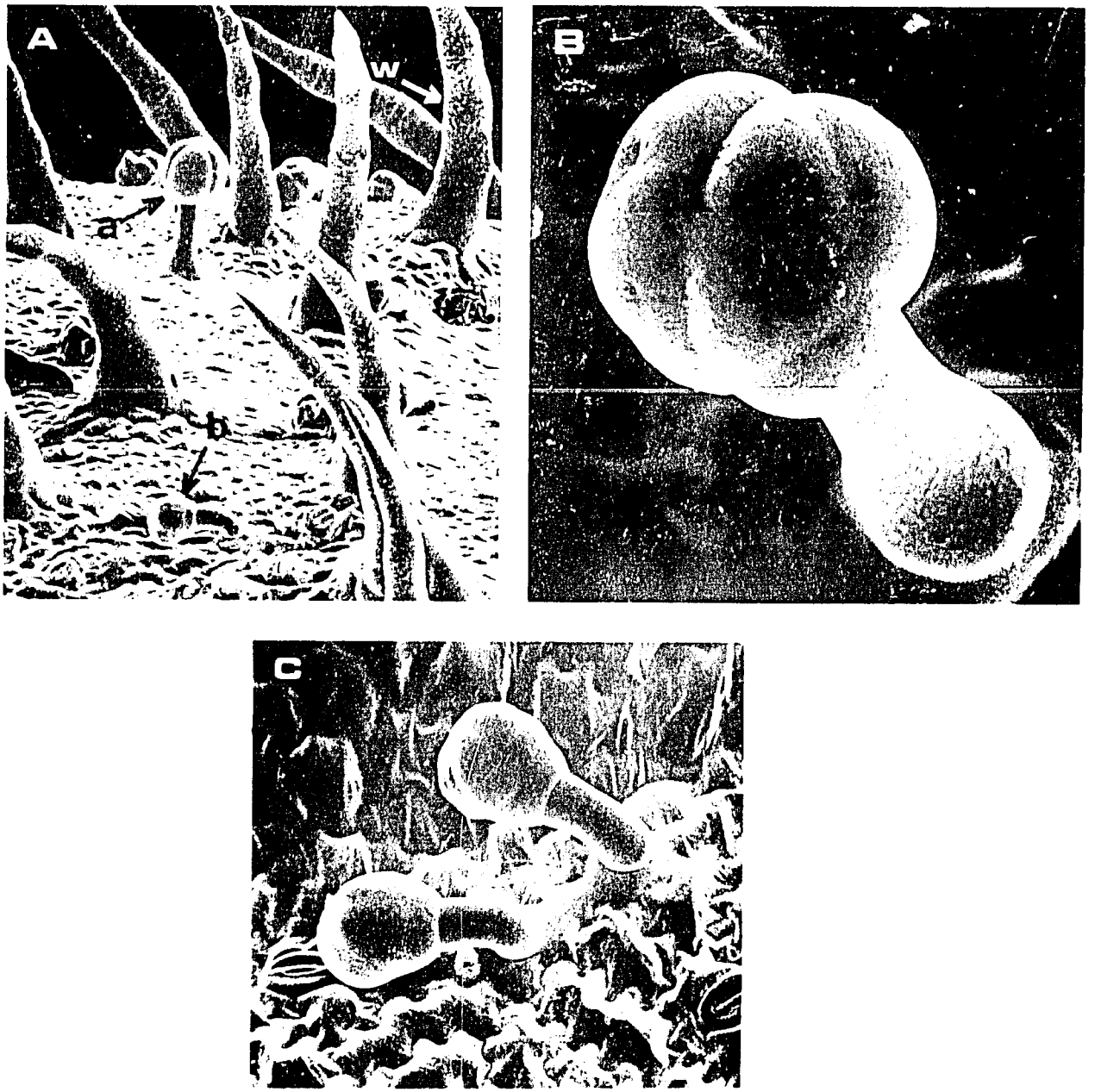


Figure 2.- Scanning electron micrographs of leaves of Red La Soda cv. A.- Abaxial surface of the leaf showing a, glandular trichome with a globular head; b, glandular trichome with a club shaped head; w, wax deposites on the wall of a single trichome. B.- Glandular trichome with a globular head. C.- Glandular trichomes with a club shaped head.

black filter paper to enhance the contact between the nylon gauze and the disc of filter paper.

Pure 1-hexanol, trans-2-hexen-1-ol, and linalool were obtained from Fluka A.G., chemische Fabrik, Buchs S. G., Switzerland; cis-3-hexen-1-ol was bought from Aldrich Chemical Company; and trans-2-hexenal was obtained from Sigma Chemical Company.

Influence of Pure Volatile Chemicals on the Total Number of Eggs Laid.

0.2 ml of a concentration of 3.3% of pure trans-2-hexen-1-ol, cis-3-hexen-1-ol, 1-hexanol, trans-2-hexenal, and linalool in diethyl ether, were applied to half discs of black filter paper (disc of 45 mm diameter). After the application of the chemical (treatments) to the filter paper, the diethyl ether was allowed to evaporate for 30 minutes and the paper offered to insects in the choice chamber. As a control, another piece of filter paper was treated with diethyl ether only. Six replications per chemical were used, and the experiment was run for 12 hours. Data were analysed by the Kruskal-Wallis test (Conover, 1980).

Effect of Pure Volatile Chemicals on the Attraction or Repellancy for Oviposition.

As in the previous experiment, pure chemicals were made up to the concentration of 3.33 % in diethyl ether, and applied to disc of black filter paper 27 mm in diameter. The diluted chemicals were applied in the volume of 0.1 ml per disc and the diethyl ether allowed to evaporate for 30 minutes. The control had diethyl ether applied only. The discs were then randomly distributed on the nylon gauze of the multichoice chamber such that each disc was the same distance from the next in order to avoid neighboring effects.

The experiment was run for 12 hours. Six replications were used and the data were analysed by the Kruskal-Wallis test.

RESULTS

Female moths showed significant preference for oviposition on some cultivars (Table 2). The most preferred cultivar for oviposition was Exton, and the least preferred was Red la Soda.

Table 2 .- Oviposition by the potato moth on the haulm of nine potato cultivars in the glasshouse.

| CULTIVAR | MEAN NUMBER EGGS/PLANT* |
|---|---|
| Red la Soda | 0.00 a |
| Sebago | 1.25 a b |
| Katahdin | 1.75 a b c |
| Coliban | 2.25 a b c |
| Sequoia | 4.25 a b c |
| Red Pontiac | 5.75 a b c |
| Kennebec | 6.75 a b c |
| Up-to-Date | 8.75 b c |
| Exton | 16.00 c |

* Means followed by the same letter are not significantly different with Duncan's multiple range test at P = 0.05.

In the other experiment, where the Sebago cv was compared against each of the other cultivars, Tasman, Up-to-Date, and Red Pontiac were preferred for oviposition by the potato moth (Table 3). There was no statistical difference between the leaf areas of potato cultivars involved in each comparison.

Table 3.- Mean number of eggs laid by the potato moth in a choice situation between two cultivars.

| COMPARISON | MEAN NUMBER OF EGGS/ CULTIVAR | | DIFERENCES* |
|---|---|---|---|
| Sebago vs. Red la Soda | 25.88 | 20.38 | 5.5 NS |
| Sebago vs. Katahdin | 24.00 | 18.50 | 5.5 NS |
| Sebago vs. Kennebec | 6.67 | 13.50 | -6.83 NS |
| Sebago vs. Sequoia | 11.56 | 18.56 | -7.00 NS |
| Sebago vs. Exton | 9.90 | 16.90 | -7.00 NS |
| Sebago vs. Tasman | 6.67 | 17.50 | -10.83* |
| Sebago vs. Up-to-Date | 14.63 | 43.88 | -29.25** |
| Sebago vs. Red Pontiac | 24.30 | 43.00 | -18.70** |

NS = Non-Significant
* = Difference Significant at P = 0.05 level
** = Difference Significant at P.= 0.01 level

## Density of Globular Head Trichomes Among Potato Cultivars.

There was a significant difference among potato cultivars with regard to the number of trichomes with globular head per unit of area. Results (Table 4) and trichomes of the cultivated potatoes in Fig. 3. Red la Soda had the highest density of trichomes, significantly greater than all except Katahdin of the other cultivars. The cultivars Coliban, Up-to-Date, and Red Pontiac had the lowest densities of trichomes.

Table 4.- Mean number of globular head (Type A sensu Gibson) Trichomes per square millimeter of the apical leaflet from the third youngest compound leaf of the potato cultivars.

| CULTIVAR | MEAN NUMBER OF TRICHOMES | | | | | | |
|---|---|---|---|---|---|---|---|
| Red la Soda | 8.87 | a | | | | | |
| Katahdin | 7.85 | a | b | | | | |
| Sebago | 7.10 | | b | c | | | |
| Exton | 7.03 | | b | c | | | |
| Kennebec | 6.90 | | b | c | | | |
| Sequoia | 6.28 | | | c | d | | |
| Tasman | 5.54 | | | | d | e | |
| Coliban | 4.18 | | | | | e | f |
| Up-to-Date | 3.89 | | | | | | f |
| Red Pontiac | 3.77 | | | | | | f |

* Means followed by the same letter are not significantly different with Duncan's multiple range test at P= 0.01.

## Preliminary Experiment

Results, Table 5, only treatment (a) (0.1% tomatine solution applied directly to the black cloth and no filter paper backing) showed a significant statistical differences although fewer eggs were laid in this treatment than in the other 3 treatments. The use of the 0.1% tomatine solution as indicated in treatment (a), avoided the clustering of eggs by the female moths, Fig. 4 . This clustering usually happens when filter paper backs the cloth. An unwanted consequence of the clustering is that for a given number of

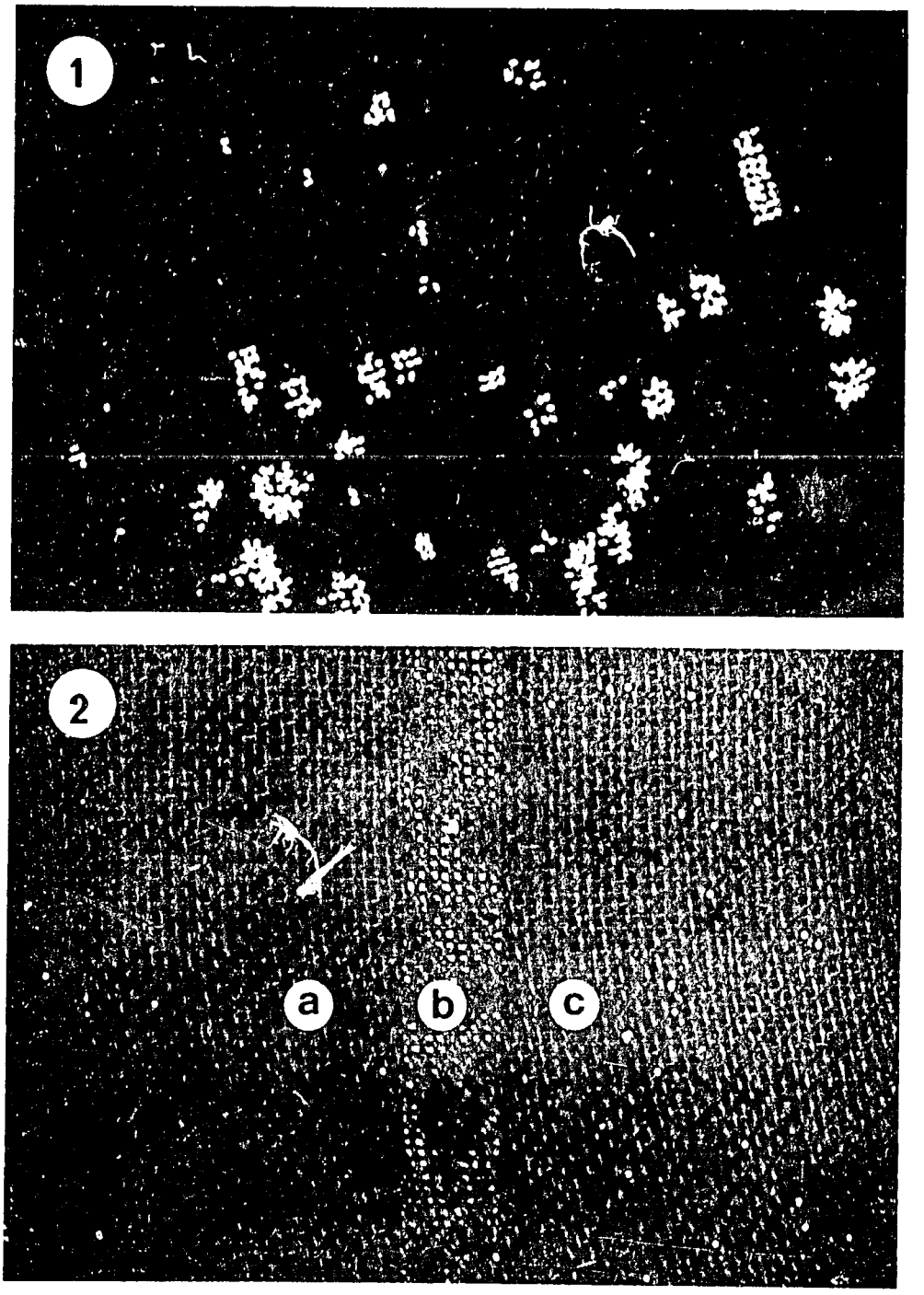


Figure 3.- (1), egg clusters laid when filter paper is backing the cloth. (2) a, control area treated with solvent only; b, sticky tape strip separating the control and treated areas, and c, egg distribution on cloth treated with 0.1% tomatine solution and no filter paper backing.

eggs laid standard errors are greatly increased. Eggs in treatment (a) were laid individually. When the total number of eggs laid per treatment was analysed (Table 5) treatments where the cloth was backed by filter paper (treatments b, c and d) had significantly greater number of eggs than treatments (a) which was without filter paper. This highly significant difference in the total number of eggs, between treatments with and without filter paper, is the difference that is assumed to be provided by the mechanical stimuli, and results obtained with treatments (b), (c) and (d), are assumed to be the result of the addition of the mechanical plus the chemical stimuli.

Table 5.- Mean number of eggs laid per treatment by the potato moth in the preliminary experiment.

| TREATMENT (1) | MEAN NO. OF EGGS(*) | | |
|---|---|---|---|
| b | 216.86 | a | |
| c | 208.43 | a | b |
| d | 159.43 | a | b |
| a | 96.29 | | c |

(*) Mean followed by the same letter are not significantly different with the Kruskal-Wallis test at P = 0.01.

(1) Treatments:

(a) 0.1% tomatine solution on the cloth.
(b) 0.1% tomatine solution applied to the cloth and to the filter paper.
(c) 0.1% tomatine solution applied to the filter paper only.
(d) 0.1% tomatine solution on the cloth but this time the treated and untreated areas backed by untreated filter paper.

## Experiment with Leaf Extract (soxhlet extracted)

From the six different concentrations bioassayed, the 10% concentration showed a highly deterrent effect. As the concentration decreased the deterrent effect changed to a significant localizer effect for oviposition at the 1% concentration, and to a highly significant localizer effect at the 0.5% and 0.1% concentrations (Fig. 4 ).

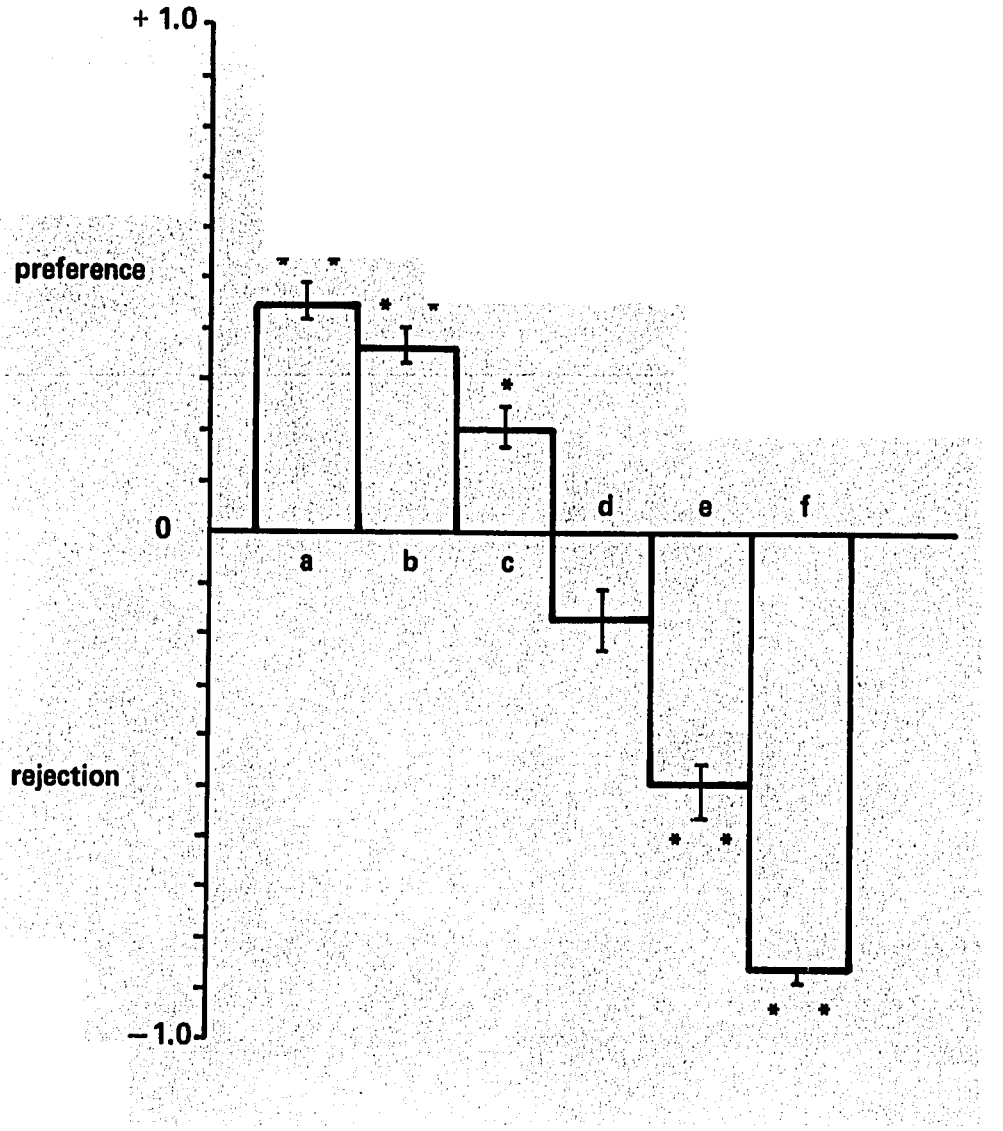


Figure 4,- Discrimination coefficient for the different concentrations from soxhlet extract: a, 0.1%; b, 0.5%; c, 1%; d, 2.5%; e, 5%; f, 10%. Bars mean the standard error for each comparison.

* Difference dignificant at P = 0.05 level.
** Difference significant at P = 0.01 level.

## Test with Pure Non-Volatile Chemicals

Results obtained with pure non-volatile chemicals are shown in Fig. 5. All of them except zeatin, at certain concentrations were oviposition localizers for the potato moth.

When concentrations producing the oviposition localizer effect of all the chemicals tested were bioassayed to determine their influence on the total number of eggs produced in 48 hours, the results presented in Table 6 were obtained. When the criteria of number of eggs laid on the cloth was used, glutamic acid and tomatine gave a significant smaller number of eggs regarding the other treatments.

Table 6.- Effect of pure non-volatile chemicals on the mean number of eggs laid on the cloth.

| TREATMENTS | MEANS(*) | |
|---|---|---|
| α- solanine | 24.2 | a |
| zeatin riboside | 23.9 | a |
| α- chaconine | 23.8 | a |
| chlorogenic acid | 21.5 | a |
| control | 15.6 | a |
| glutamic acid | 9.4 | b |
| tomatine | 7.6 | b |

(*) Means followed by the same letter are not significantly different by the Kruskal-Wallis test at P = 0.01 level.

When the ratio of eggs laid on the plastic container: eggs laid on the cloth was analysed, results in Table 7 were obtained. Tomatine had the highest : value for this relationship followed by glutamic acid and the control. A high value for the ratio between eggs laid on the container: eggs laid on the cloth could be interpreted as a deterrent of oviposition while large number of eggs on the cloth would be interpreted as a stimulant effect.

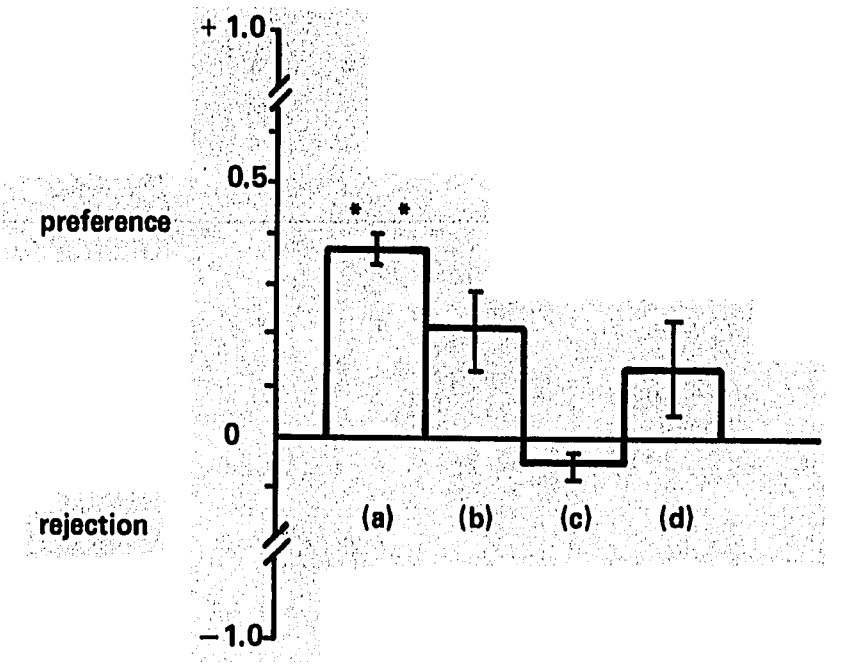


Figure 5.- Discrimination coefficient of treatments. (a) 0.1% tomatine on cloth, no filter paper; (b) 0.1% tomatine on cloth and on filter paper; (c) 0.1% tomatine on filter paper, nothing on cloth, and; (d) 0.1% tomatine on cloth, untreated filter paper backing the cloth.

** Difference significant at P = 0.01 level.

Table 7.- Effect of pure non-volatile chemicals on the total number of eggs laid, measured as the ratio between the number of eggs laid on the container and eggs laid on the cloth.

| TREATMENT | MEAN (*) |
|---|---|
| Tomatine | 29.0 a |
| Glutamic acid | 25.5 a b |
| Control | 20.3 a b c |
| Zeatin riboside | 18.6 b c |
| Chlorogenic acid | 12.8 c |
| α-chaconine | 12.7 c |
| α-solanine | 7.3 d |

(*) Means followed by the same letter are not significantly different by the Kruskal-Wallis test at P = 0.01 level.

Influence of Pure Volatile Chemicals on the Total Number of Eggs Laid.

Results obtained in this experiment are shown in Table 8. Based on the total number of eggs laid it can be seen that the chemicals 1-hexanol, trans-2-hexen-1-ol, and cis-3-hexen-1-ol, increased oviposition as compared with the control. However, there was no statistical difference. Both trans-2-hexenal and linalool reduced oviposition compared to the control an the results were highly significant.

Table 8. Influence of pure volatile chemicals on the total number of eggs laid during one night.

| TREATMENT | MEAN NO. OF EGGS (*) |
|---|---|
| 1-hexanol | 78.00 a |
| trans-2-hexen-1-ol | 70.83 a |
| cis-3-hexen-1-ol | 67.50 a |
| control | 51.50 a |
| trans-2-hexenal | 9.00 b |
| linalool | 0.17 b |

(*) Means followed by the same letter are not significantly different by the Kruskal-Wallis test at P = 0.01 level.

## Effect of Pure Volatile Chemicals on the Attraction or Repellency for Oviposition.

In a multichoice situation, the female moths laid more eggs on the control with all the other treatments being significantly different (Table 9). Trans-2-hexen-1-ol attracted the most eggs of the chemical treatments. Linalool was a highly significant ovipositional repellent but could not be distinguish statistically from trans-2-hexenal.

Table 9.- Effect of the pure volatile chemicals on the oviposition by the potato moth in a multichoice situation.

| TREATMENT | MEAN NO. OF EGGS (*) |
|---|---|
| control | 81.33 a |
| trans-2-hexen-1-ol | 22.83 b |
| 1-hexanol | 8.17 b c |
| cis-3-hexen-1-ol | 6.17 c d |
| trans-2-hexenal | 1.5 d e |
| linalool | 0 e |

(*) Means followed by the same letter are not significantly different by the Kruskal-Wallis test at P = 0.01 level.

## DISCUSSION

Although the main oviposition site for the potato moth is the soil around the plant base, it still lays some eggs on the foliage and, even more, it is able to show preferences for oviposition on some potato cultivars. The finding of selectivity for oviposition is important when considering plant resistance, because it indicates that among different potato cultivars there are some factors which may be exploited in order to develop resistant cultivars.

There is no report in the literature with regard to differences in the number of globular head trichomes among commercial potato cultivars.

It was interesting to note that potato cultivars with higher densities of globular head trichomes were found to be non-preferred for oviposition by the potato moth, and potato cultivars with the lower densities of trichomes were the preferred ones for oviposition. This association suggests that some chemical (or chemicals) stored in the trichomes or the mechanical effect provided by them may be responsible for deterring oviposition by the potato moth.

From the preliminary experiment it is clear that the oviposition behaviour of the potato moth is largely affected by the presence of chemical and physical stimuli and in a minor degree by the way in which the contact between the insect body and the chemical is produced. Table 5 shows that all treatments (b,c,and d) where the chemical and the physical stimuli (filter paper) were together, gave a higher number of eggs. On the other hand, when the perception of the chemical was made first by the tarsal receptors and later by the ovipositor chemoreceptors reported by Valencia and Rice, (1982), there was always a preference effect for oviposition. Meanwhile when the chemical perception is made only through the ovipositor on chemoreceptors, there was a small rejection effect but insignificant. Although this rejection effect was small it still indicates that female moths are able to recognize harmful chemicals through them. This fact reinforces the view that oviposition chemoreceptors are the last key to release the oviposition behaviour. Very recently, oviposition chemoreceptors have been reported from several lepidoptera species (Chadha and Roome, 1980; Valencia and Rice, 1982; Klijnstra, 1982) and the best accepted concept of host recognition for oviposition is that it is a sequencial phenomenon once the female has located a potential host the antennae, the tarsi and the ovipositor are all tuned by the chemical composition of the substrate in that sequence (Ichinose and Honda,1978; Calvert, 1974; Calvert and Hanson, 1983; Chadha and Roome,1980).

The main conclusion of this preliminary experiment is that by using the chemical candidates as in a treatment (a), applied directly to the cloth without any filter paper backing, it should be possible to detect which chemicals are able to influence oviposition by the potato moth.

Test with different concentrations of leaf extract (soxhlet extracted) showed that the localizer effect for oviposition by the potato moth was concentration dependant. If the concentration is too high, it results in a deterrent effect. A similar effect was observed on oviposition by the diamond-

back moth, Plutella xylostella (L), when the concentration of allyl isothiocyanate was changed (Gupta and Thorsteinson, 1960).

With the leaf extract the study of most of the foliage components was carried out. Then some pure chemicals which have already been reported as components of the foliage of the potato plant were studied.

Of the chemicals tested, glutamic acid was found to be an oviposition localizer by Meisner et al. (1974).

The potato glycoalkaloids α-solanine and α-choconine were tested for their effects on oviposition by the potato moth by Raman et al. (1981). They used pure extracts of 35% solanine and 64% chaconine at 5, 10, 50 and 250 mg/100 ml of water without any effect on oviposition. However, the characteristics of the bioassay used were not specified and, in any case, the glycoalkaloids are little soluble in water. The present experiments using several concentrations for each chemical separately and under the conditions described showed that both are oviposition localizers for the potato moth.

Chlorogenic acid was also an oviposition localizer for the potato moth, but the effect was not as great as shown by the potato glycoalkaloids. This chemical has been reported as a feeding stimulant for the Colorado potato beetle Leptinotarsa decemlineata (Say) (Hsiao and Fraenkel, 1968) and as a growth stimulant for the silkworm (Bombyx mori L.) (Kato, 1978). Most recently, it has been reported as a growth inhibitory compound for Heliothis zea (Boddie) (Elliger et al., 1981; Waiss et al., 1981); it is also a trace component of the glandular trichomes of tomato and it contributes significantly to the antibiotic effect of the leaf against H. zea as measured by reduction in larval growth (Duffey and Isman, 1981). Chlorogenic acid and rutin, are major phenolic constituents of tomato foliage and both inhibit early larval growth of H. zea (Isman and Duffey, 1982). Tomatine, the main glycoalkaloid of the tomato plant, has also been reported occurring in several species of wild potatoes (see Roddick, 1974 p. 14). It was found to be on oviposition localizer for the potato moth in the present study. A substance that stimulates oviposition by adult moths of the tomato pin worm, Keiferia lycopersicella (Walsingham), occurs on the surface of tomato plants (Burton and Schuster, 1981). This substance was extractable in water or ethanol and seems equally distributed on the upper and lower sur-

faces of leaves. This finding opens up the possibility that some of the chemicals of the tomato foliage, or which tomatine is one of the most abundant, may be involved. Zeatin riboside was also an oviposition localizer.

The influence of the non-valatile chemicals on the total number of eggs laid indicates that α-solanine is the best stimulant and glutamic acid and tomatine were the least stimulants for oviposition. However, if the ratios presented in Table 7 reflect deterrent effects, tomatine was again the most deterrent chemical.

It is not uncommon that highly toxic substances are feeding and oviposition cues and stimulants for specialized insect.

It is of interest to mention here that although some chemicals (glutamic acid and tomatine ) may be used as cues for localization of oviposition by the potato moth, they may still be noxious for the insect. This finding is not new, since very recently, Brattsten et al., (1983) have shown that all instars of the southern armyworm (Spodoptera eridania Cramer) larvae grow as well or better when cyanide was present in their diet as when it was absent. Concentrations up to 0.5% stimulated feeding in first to fourth instar larvae. Concentrations from 0.1% to 1.0% stimulated feeding in fifth and sixth instar larvae. A 1.0% dietary KCN exposure during the sixth instar reduces ecdysis to 17% adult emergence and completely inhibits ovipositon.

Results reported here for tomatine follow very closely the pattern described for cyanide with the southern armyworm. Meisner et al. (1974) reported that preferred oviposition sites of the potato moth were in the order: potato leaves (51.3%), eggplant (43.6%), tobacco (2.5%), tomato (2.3%), and pepper (0.35). Study of the influence of the food consumed during the larval stages on the oviposition preferences of resulting adults showed that consumption of tomato (the richest source of tomatine in nature) resulted in a drop of over 50% in the average of total number of eggs laid per female (12.2) as compared to those reared on potato leaves (31.2). Gomaa et al., (1978) reported that larvae of leaves and tuber (53.40 eggs per female against 173.50 eggs per female).

Regarding the volatile chemicals, it is clear that 1-hexanol, trans-2-hexen-1-ol, cis-3-hexen-1-ol, trans-2-hexenal, and linalool influenced oviposition by the female moth.

The leaf aldehyde trans-2-hexenal, and linalool were highly significant ovipositional inhibitor. It is of interest to mention here that Bancher and Holzl (1959) reported that the glandular trichome with a globular head has a intercell space fill with oil. In the experiments on oviposition preferences among potato cultivars it was found that potato cultivars with the higher densities of this type of trichomes were the least preferred for oviposition. If trans-2-hexenal and linalool are some of the components of the trichomes oil, then this may be the explanation of the cited preference showed by the potato moth.

When the volatile chemicals were offered to the moths in a multichoice situation, the control was the preferred oviposition site. This behaviour may indicate that these chemicals by themselves do not elicit any oviposition attraction response. As Visser et al. (1979) have suggested for the Colorado beetle, the appropriate mixture of all the components may be the stimulus the potato moth uses to localize the oviposition site. From these results it is clear that trans-2-hexenal and linalool should be investigated as possible methods of control of potato moth. In the pink bollworm, P. gossypiella, (Saunders), another member of the family Gelechiidae to which the potato moth belongs, phenylacetaldehyde, a volatile chemical was found to be an oviposition inhibitor (Flint et al., 1977). These authors reported that the inhibition apparently results from direct contact with the treated plant since the odour of the compound did not keep females from ovipositing on closely adjacent plants in treated plots, and males freely responded to pheromonebaited traps in treated plots.

Finally it is interesting to mention here that the use of some aromatic weed plants such as Lantana sp. Mintostachis sp., Eucalyptus sp. are providing good results as protectant of potato tubers under storage conditions (Anonimous, 1983). The mechanism involved in this interaction seems to be a repellant type which match pretty well with the basic research reported here.

## REFERENCES


Anonymous, 1979. CIP Anual Report, International Potato Center, Lima, Peru.

Atherton, D. O., 1936. Leafminer and stem borer of tabacco in North Queensland. Qd Agric. J. 45: 12-31.

Bancher, E. and J. Holzl, 1959. Uber die drusenhaare vor Solanum tuberosum sorte "Sieglinde". Protoplasma 50: 356-369.

Brattsten, L. B., J. H. Samuelian, K. Y. Long, S. A. Kincaid and C. K. Evans, 1983. Cyanide as a feeding stimulant for the southern army-worm, Spodoptera eridania. Ecol. Entomol 8: 125-132.

Burton, R. L. and D. J. Schuster, 1981. Oviposition stimulants for tomato pinworms from surfaces of tomato plants. Ann. Entomol. Soc. Am. 74: 512-515.

Calvert, W. H., 1974. The external morphology of foretarsal receptors involved with host discrimination by the nynphalid butterfly, Chlosyne lacinia. Ann. Entomol. Soc. Am. 67: 853-856.

Calvert, W. H. and F. E. Hanson, 1983. The role of sensory structures and preoviposition behavior in oviposition by the patch butterfly. Chlosyne lacinia. Entomol. Exp. Appl. 33: 179-187.

Chadha, G. K. and R. E. Roome. 1980. Oviposition behavior and the sensilla of the ovipositor of Chilo partellus and Spodoptera littoralis (Lepidoptera: Noctuidae). J. Zool. Lond. 192: 160-178.

Conover, W. J., 1980. Practical Nonparametric Statistics. John Wiley & Sons, New York.

David, J. and J. van Herrewege, 1970. Choix d'un site de ponte chez Drosophila melanogaster: Technique d' etude et variabilite Rev. Comp. Animal, T.4: 82-84.

Duffey, S. S. and M. B. Isman, 1981. Inhibition of insect larval growth by phenolics in glandular trichomes of tomato leaves. Experientia 37: 574-576.

Elliger, W. Y., B. G. Chan, and A. C. Waiss, 1981. Growth inhibitors in tomato(Lycopersicon) to tomato fruitworm (Heliothis zea). J.Chem.Ecol.7: 753-758.

Fenemore, P., 1978. Oviposition of potato tuber moth, Phthorimaea operculella Zell. (Lepidoptera: Gelechiidae); the physical nature of the oviposition substrate. N. Z. J. Zool. 5: 591-599.

Fenemore, P. 1980. Some aspects of the host plant relationships of potato tuber moth. Phthorimaea operculella Zell. (Lepidoptera: Gelechiidae). Ph. D. thesis, Massey Univ. New Zealand.

Flint, H. M., R. L. Smith, J. G. Pomonis, D. E. Forey, and B. R. Horn, 1977. Phenylacetaldehyde: Oviposition inhibitor for the pink bollworm. J. Econ. Entomol. 70: 547-548.

Gibson, R. N., 1971. Glandular hairs providing resistance to aphids in certain wild potato species. Ann. Appl. Biol. 68: 113-119.

Gibson, R. W., 1974. Aphid-trapping glandular hairs on hybrids of Solanum tuberosum and S. berthaultii. Potato Res. 17: 152-154.

Gibson, R. G., 1976. Glandular hairs of Solanum polyadenium lessen damage by the Colorado beetle. Ann. Appl. Biol. 82: 147-150.

Gomaa, A. A., S. El-Sherif, and I. A. Hemeida, 1978. On the biology of potato tuberworm Phthorimaea operculella Zeller (Lepidoptera, Gelechiidae) I. Effect of larval diet. Z. Angew Entomol. 86: 290-294.

Graf, J. E., 1917. The potato tuber moth. United State Dep. of Agric. Bull. No. 427.

Gupta, P. D. and A. J. Thorsteinson, 1960. Food plant relationships of the diamond-back moth [Plutella maculipennis (Curt.)] II. Sensory regulation of oviposition of the adult female. Entomol. Exp. Appl. 3: 305-314.

Hinton, H. E., 1981. Biology of insect eggs. Vol. 1 Pergamon Press, Oxford.

Hofmaster, R. N., 1949. Biology and control of the potato tuberworm with special references to eastern Virginia. Virginia Truck Exp. Sta. Bull. No. III.

Hsiao, T. H. and G. Fraenkel, 1968. The role of secondary plant substances in the food specificity of the Colorado potato beetle. Ann. Entomol. Soc. Am. 61: 485-493.

Ichinose, T. and H. Honda, 1978. Ovipositional behavior of Papilio protenor demetrius Cramer and the factors involved in its host plants. Appl. Entomol. Zool. 13: 103-114.

Isman, M. B. and S. S. Duffey, 1982. Toxicity of tomato phenolic compounds to the fruitworm, Heliothis zea. Entomol. Exp. Appl. 31: 370-376.

Jermy, T. and A. Szentesi, 1978. The role of inhibitory stimuli in the choice of oviposition site by phytophagous insects. Entomol. Exp. Appl. 24: 458-471.

Kato, M., 1978. Phenols as indispensible components of the synthetic diet of the silkworm, Bombyx mori. Entomol. Exp. Appl. 24: 285-290.

Klijnstra, J. W., 1982. Perception of the oviposition deterrent pheromone in Pieris brassicae. In Proc. 5th Int. Symp. Insect-Plant Relationships. J. H. Visser and A. K. Minks (Eds.) Pudoc, Wageningen.

Lyshede, O. B., 1980. The ultrastructure of the glandular trichomes of Solanum tuberosum. Ann. Bot. 46: 519-526.

Meisner, J., K. R. S. Ascher and D. Lavie, 1974. Factors influencing the attraction to oviposition of the potato tuber moth, Gnorimoschema operculella Zell. Z. Ang. Entomol. 77: 179-189.

Platner, G. R. and E. R. Oatman, 1968. An improved technique for producing potato tuberworm [Phthorimaea operculella (Zell.)] eggs for mass production of natural enemies. J. Econ. Entomol. 61: 1054-1057.

Raman, K. V., M. Iwanaga, M. Palacios and R. Egusquiza, 1981. Studies on identifying sources of resistance to potato tuberworm, Phthorimaea operculella (Zeller). Am.

Potato J. 58: 517.

Reed, E. M., 1971. Factors affecting the status of a virus as a control agent for the potato moth [Phthorimaea operculella (Zell.)] (Lep., Gelechiidae). Bull. Entomol. Res. 61: 207-222.

Roddick, J. G., 1974. The steroidal glycoalkaloid -tomatine. Phytochemistry 13: 9-25.

Traynier, R. M. M., 1975. Field and laboratory experiments on the site of oviposition by the potato moth Phthorimaea operculella (Zell.) (Lepidoptera, Gelechiidae). Bull. Entomol. Res. 65: 391-398.

Traynier, R. M. M., 1983. Influence of plants and adult food on the fecundity of the potato moth, Phthorimaea operculella. Entomol. Exp. Appl. 33: 145-154.

Valencia, L. and M. J. Rice, 1982. Contact chenoreceptors on the ovipositor of the potato moth, Phthorimaea operculella (Zell.) (Lepidoptera: Gelechiidae). Int. J. Insect Morphol. Embryol. 11: 121-128.

Visser, J. H., S. van Straten and H. Maarse, 1979. Isolation and identification of volatiles in the foliage of potato, Solanum tuberosum, a host plant of the Colorado beetle, Leptinotarsa decemlineata. J. Chem. Ecol. 5: 13-25.

Waiss, A. C. Jr., B. G. Chan, C. A. Elliger, D. L. Dreyer, R. G. Binder and R. C. Gueldner, 1981. Insect growth inhibitors in crops plants. Bull Entomol. Soc. Am. 27: 217-221.

# Biological Control in IPM

Fred D. Bennett

Biological control occurs when the action of parasites, predators, or pathogens temporarily controls or continually regulates pest populations below the level they would otherwise fluctuate (Huffaker and Smith, 1980). In the context of IPM, such control is of little importance to man, unless it results in benefits in the form of increased yields, reduced use of pesticides, etc. The majority of pest species are under some degree of naturally occurring biological control, and this is often under-estimated or ignored. Proof of its value has been most dramatically demonstrated when due to the misuse of pesticides, species previously considered to be non-pests have become major ones following destruction of their natural enemies.

Applied biological control infers man's intervention by manipulation of natural enemies, the pest population and/or some other component of the environment. The manipulation of natural enemies is usually by Introduction, Augmentation and/or Conservation. The greatest activity has been with Introduction i.e. the conduct of classical biological control which involves the introduction of an exotic biotic agent for the control of exotic or native pests. Predaceous and parasitic arthropods have predominated in such attempts, but attempts to exploit pathogens mainly viruses, bacteria and fungi and other groups such as the nematodes, are attracting increasing attention. The targets for classical biological control programmes have generally been insects, mites, and weeds, but the use of the myxomatosis virus for rabbit control and of dung beetles to bury manure thereby reducing fly breeding sites in Australia, demonstrates some of the potential of this approach.

The range of agents now also includes nematode trapping fungi, antagonistic fungi and viruses and the range of target organisms has been broadened to include bacteria, fungi, viruses, nematodes, etc.

Releases to increase the effectiveness of locally occurring natural enemies or of exotic ones which unaided do not provide adequate control range in sequence Inoculative $\longrightarrow$ Incremental $\longrightarrow$ Inundative as increasing numbers are made; all types have been used in IPM programmes. Conservation, the other important component of biological control, can also be practised in several ways eg. the use of cultivation practices

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such as strip cropping or cutting, mixed cropping, addition of habitat resources, alternative hosts, refuges, subsidiary foods and even at times the release of the target pest species.

Attempts have been made to categorize and rank the types of pests and of crops where biological control is most likely to succeed. Pests of annual crops are usually given a low ranking on the basis that there is not time for a favorable equilibrium between pests and control agents to become established, and because many annual crops have a high economic value, and hence, a low economic pest damage threshold. Nevertheless, there are several examples of successful or partial biological control of pests of high value annual crops. The utilization of natural enemies in commercial greenhouses has become big business as whitefly, spidermites and aphids can be controlled more effectively and cheaply than with chemical control.

As an example of how cultural practices can enhance naturally occurring biological control in an annual row crop, we can refer to soybeans. In Brazil, the fungus Nomuraea rileyi in many years provides a high level of infection of Anticarsia gemmatalis and other lepidopterous defoliators of soyabeans. However, naturally occurring epizootics of the fungus may occur too late to prevent economic damage. Closer between-row planting increases relative humidity which leads to the earlier apppearance of the fungus and satisfactory control. When control is inadequate in years of below average rainfall, applications of the virus Baculovirus anticarsi provide control. Farmers are trained to collect and store virus-infected caterpillars from year to year, and to apply crude virus suspensions in those years when natural control by the fungus is inadequate.

## The Importance of Key Pests

Frequently one or a few pest species dictate the need for control measures. The customary practice is to apply pesticides which in turn release other species from existing natural control. If the key species can be suppressed by a non-chemical method, the populations of the 'pesticide-induced' species usually revert to former levels.

In Peru, Ing. O. Beingolea after careful study, named the diaspine scale Selenaspidus articulatus and the woolly whitefly Aleurothrixus floccosus to be the key citrus pests which mandated heavy pesticide usage. The situation was remedied by the successful control of the former by the introduction of Aphytis roseni from East Africa and of the latter by the importation of the Chilean parasite Cales noacki (Pacora 1979).

## Potential of Biological Control in IPM of Potato Pests

Although potato is attacked by a broad range of pests, (Radcliffe 1981) many of these do not require control measures. Aphids, because of their role as primary pests as well as virus vectors, and potato tuber moth Phthorimaea operculella are the most important widespread pests. In parts of the Andean region other 'tuber moths' Scrobipalpula absoluta and Symmestrichema plaesiosema, have become increasingly important; the Andean potato weevils Premnotrypes spp. require soil application of pesticides; and the leafminer Liriomyza huidobrensis has become a dominant pest since the advent of chlorinated hydrocarbon insecticides. (Herrera 1963). Aphids, mealybugs and tuber moths are also serious pests in rustic storage houses.

### Aphids

Planting material traditionally consists of sections of tubers and hence, potato production depends on virus free planting material and avoidance of infection by aphids during the growing season and during storage.

We are often asked whether traditional or classical biological control is a valid tactic for the control of insect vectors. For a specialized natural enemy such as an aphid parasite to be self prepetuating, the host species must also survive to provide hosts for future generations. Radcliffe (1981) points out that parasitism levels of aphids in potato fields are usually low. Releases of parasites in potato fields are unlikely to act quickly enough to prevent aphid feeding and transmission of virus. and hence, different strategies within the IPM framework are required and will vary from area to area.

In the temperate regions aphids on their primary (overwintering) hosts are virus free, but pickup virus infection by feeding on infected weeds or volunteer potato plants. Similarily in the tropics, aphids migrate into potato fields from alternate plant hosts. Reduction of aphids on primary or wild hosts by increased parasitism or predation, removal of infected wild hosts, or a concentration of natural enemies on these to reduce the numbers of aphids available to migrate to potato fields are tactics to consider. The benefits of mixed cropping, strip cropping, etc. are well known and have been demonstrated by CIP personnel. Similarily, the encouragement of limited populations of weeds in and around potato fields which support non-vector species of aphids thereby, encouraging a build up of natural enemies, prior to the arrival of potato aphids could prove to be a useful tactic, but would require careful study, because of the potential adverse effects of the selected

weeds. Obviously, dense stands of certain weeds amongst the crop are detrimental to crop growth and can serve as reservoirs of insect pests, nematodes and plant pathogens. On the other hand, weeds and their fauna can provide a source of nectar, pollen, shelter, hosts or prey essential to ensure the retention of natural enemies in the field. Samways (1979) indicated the important role of natural enemies on vegetation on the periphery of cassava fields and Altieri and Whitcombe (1979) discussed the potential of the manipulation of insect populations through seasonal disturbance of weed communities.

The possibilities of classical biological control of most aphids have not been fully explored and it is probable that more effective parasites could be found for certain regions. For example, in Trinidad Lysiphlebus testaceipes is the only aphidiine aphid parasite known; undoubtedly, more efficient parasites of certain species could be introduced. Even if introduced natural enemies were not particularily effective within potato fields, their effect on aphid populations on other plants could reduce the number of infected aphids entering potato fields.

The impact that exotic aphids introduced without their natural enemies, and similarily the impact that their specialized natural enemies can have was dramatically illustrated following the arrival of European cereal aphids in South America. Following the spread of Sitobion avenae and Metopolophidium dirhodum wheat production was seriously threatened in all temperate regions; direct damage and the aphid transmitted virus B.Y.D.U. reduced yields by 30%. Heavy pesticide usage lead to the rapid increase of other pests including native aphids. From 2 to 6 applications of aphicide were applied to more than 3 million hectares of wheat. This situation was rectified by the introduction of 14 species of parasites from Europe. In Rio Grande do Sul, Brazil, where 100% of the wheat acreage required pesticide applications in 1977, less than 3% required treatment in 1981 and 1982. In contrast 95% of the crop required treatment in 1982 in the State of Parana where major parasite releases were not started until 1981 (Gassen & Tambase 1983). In addition to their action within the crop, the role of the parasites on aphid populations on wild hosts was highly significant. Accordingly, the potential of classical biological control in IPM programmes against potato aphids should not be ignored.

If aphids are of sufficient importance in diffused light, potato storage the release of coccinellid predators or trials of commercially available preparations of the fungus Verticillium lecanii developed for aphid control in greenhouses should be tried experimentally.

## Andean Potato Weevils (Premnotrypes spp.)

In some potato producing regions in Colombia, Peru, etc. treatment with carbofuran or other soil insecticide is considered essential to prevent economic damage by Premnotrypes spp. The potential for control by manipulation of arthropod parasites and predators appears to be limited, but there is scope for microbial control. Beauveria bassiana, the white muscardine fungus, and Metarrhizium anisopliae, the green muscardine fungus, are currently under study in Colombia. Another recent promising development is the discovery of a nematode, Neoaplectana sp. as a parasite of Premnotrypes in Colombia by A. López. Its potential as a control agent is being assessed (Ingeborg Zenner de Polania, pers. comm. 1984).

## Colorado Potato Beetle Leptinotarsa decemlineata

A North American species which transferred from the wild Solanum rostratum after the potato was introduced into North America in 1719 the Colorado potato beetle became and has remained the key pest of potato in the USA and Canada, and in those parts of Europe where it has gained a foothold. Although natural enemies occur, they are not effective on this host plant.

Due to the high levels of pesticide resistance, there has been increasing interest in the potential of biological control. Trials with Bacillus thuringiensis and Neoaplectina spp. have shown some promise. Exploration for natural enemies of other species of Leptinotarsa in South and Central America, has lead to the discovery of the parasite Edovum puttleri, in Colombia (Grissell 1981). The parasite although seasonally effective, does not overwinter in the main potato production areas of the USA and Canada. The potential of a strain of the parasite from colder areas is being assessed, and the feasibility of annual inoculative releases is also being examined. This technique has been very successful for the control of the Mexican bean beetle Epilachna varivestis in the southeastern USA where Pediobius foveolata a parasite of an allied epilachnid from India failed to overwinter. Relatively small inoculative releases each spring can provide excellent control (Stehr 1982).

## Agromyzid Potato Leafminer Liriomyza huidobrensis

In Peru Liriomyza huidobrensis became a serious pest following the regular use of chlorinated hydrocarbons (Herrera 1963). Although it is

now considered to be a key pest, it can also be classified as a pesticide induced pest. Early season applications of pesticides against the lepidopterous leaf and stem miner Scrobipalpula absoluta disrupt the natural biological control which existed.

As an example of an IPM programme for a leafminer, reference can be made to studies in progress in Colombia against Liriomyza trifolii, a pest of Chrysanthemum. The programme combines the use of yellow traps, both to monitor and reduce fly populations, the collection of leafminer rearing and release of parasites obtained from these. Equilibrium can be maintained throughout successive crops if other pests can be contained by microbial or selective pesticides, but it can be readily disrupted by an application of a broad spectrum pesticide. This reinforces the view that the L. huidobrensis problem is pesticide induced. Delgado and Aguilar (1980) reported a complex of 11 parasites of this leafminer in Peru. Raman and Redolfi (1984) report high levels of parasitism once spraying is terminated. They also report that the use of lead arsenate mixed with an attractant recommended for leafminer control in the coastal area of Peru adversely affects parasitism.

The Commonwealth Institute of Biological Control has recently conducted surveys of natural enemies of the allied leafminer L. trifolii and has arranged the introduction of several North American Caribbean and South American parasites into Senegal (Murphy 1984). Earlier introduction of several of these parasites into Hawaii has reduced the need for chemical control. Hence, the introduction of additional parasites for the control of L. huidobrensis should be considered as a component of future IPM programmes, if with the rational use of pesticides L. huidobrensis continues to be a problem.

## Potato Tuber Moth Phthorimaea operculella and Allied Species

A pest of South American origin Potato Tuber Moth (PTM) Phthorimaea operculella is now distributed through most of the tropical and subtropical regions where potatoes are grown. Several natural enemies have been reported from S. America and in other regions it has acquired additional local species which have transferred from native caterpillars. Certain of these species have been distributed by CIBC and other organizations, and five species Apanteles subandinus, Copidosoma koehleri, C. desantisi, Orgilus lepidus and Campoplex haywardi have become established in a few countries. The first two have provided economic benefits in Zimbabwe and Zambia and Cyprus; a more limited degree of control has been reported in Australia, Bermuda and the USA. In Zambia the benefits from this biological control campaign, costing only a few hundred pounds, projected to 1980 were £235.380 (Cruickshank and Ahmed 1973).

Investigations in Australia have lead to the patenting and commercialization of the PTM granulosis virus which may prove to be a useful component in IPM programmes in other countries. In Australia applications have proven as effective as those of chemical pesticides with the added benefit that it persists from year to year. However, for various reasons it has not provided consistently reliable economic control.

A tactic tried in Colombia for a related pest Scrobipalpula absoluta was the mass release of egg parasites Trichogramma spp. Although the eggs of this species are parasitised, they are probably too small to mature viable parasites, but repeated releases if economic could provide control.

Despite the earlier attempts at classical biological control, the full potential of this method has not been realized. Potato tuber moth parasites introductions, many of them very limited have been made in only 20 countries. After reviewing previous attempts, Sankaran and Girling (1980) recommended more extensive surveys for natural enemies in South America followed by the selection and trial of promising species in various countries. Similarily, parasites of allied genera could be considered ie. parasites of Scrobipalpula absoluta and S. melanocampa from S. America and of Scrobipalposis solanivora from Central America. A well coordinated adequately funded comparatively long term programme (3 to 5 years) is required rather than a series of short poorly financed expeditions which are all that can be accomplished on funding usually available from a single country.

In my view there is also scope for classical biological control of potato tuber moth in many parts of South America, because in any one area only part of the complex of natural enemies is operational. An exchange of parasites within the region should be attempted.

CIP, as the potato research centre for the world, situated in the region where the potato and PTM originated and in a country with a strong tradition for biological control, could serve as an excellent location where biological control activities of the pest could be centred and coordinated. A data base and probably a "bank" of natural enemies obtained from various ecological zones in S. America should be built up. Information supplied to various countries would stimulate interest in biological control programmes. Although it is unlikely that natural enemies will provide complete control, they could and should form the central component to which other components are added to build an ecologically sound IPM programme.

Other related tuber or stem moths Scrobipalpula and Symmetrischema are dealt with in the following paper (Raman and Redolfi 1984). These are locally of equal or greater importance to P. operculella both in the field and in storage. In storage the role of microbial agents eg. formulations of Bacillus thuringiensis, parasites and repellent plants is already under investigation. (Raman and Booth 1983).

## General

As several important pests of potato exist and as the complex varies from country to country, or from one ecological zone to another within the same country, the role of biological control as a component of IPM will vary. It is important to identify and control the key pests by non-disruptive methods whether this be by biological control, plant breeding, cultural control, the use of microbial or selective pesticides or other innovative methods. The potential for biological control should be recognized and IPM programmes built around it rather than turning to it as a last resort after other methods have failed.

## REFERENCES


Altieri, M.A. and W.H. Whitcombe. 1979. Manipulation of insect populations through seasonal disturbance of weed communities. Prot. Ecol. 1:185-202.

Cruickshank S., and F. Ahmed. 1973. Biological control of potato tuber moth Phthorimaea operculella (Zeller) (Lep: Gelichiidae) in Zambia. Commonw. Inst. Biol. Control Tech. Bul.. 16:147-162.

Delgado, J.J., and P.G. Aguilar. 1980. 'Control integrado en papa. Rev. Per. Ent. 23:102-104.

Gassen, D.M., and F.J. Tambase. 1983. Controle biologico dos pulgoes do trigo no Brazil. Informe Agropecuario 9(104) 49-51.

Grissell, E.E. 1981. Edovum puttleri n.g., n. sp. (Hymenoptera: Eulophidae), an egg parasite of the Colorado potato beetle (Chrysomelidae) Proc. Entomol. Soc. Washington 83:790-796.

Herrera A., J.M. 1963. Problemas insectiles del cultivo de la papa en el Valle de Cañete. Rev. Per. Ent. 6(1):1-10.

Huffaker, C.B., and R.F. Smith. 1980. Rationale, Organization and Development of a National Integrated Pest Management Project. pp 1-24 in New Technology of Pest Control, C.B. Huffaker (Editor) John Wiley and Sons Inc., New York 500 pp.

Murphy, S.T. 1984. Final report on surveys in the Neotropical/Nearctic region for natural enemies of Liriomyza trifolii and L. sativae (Diptera, Agromyzidae). CIBC unpubl. report 28 pp.

Pacora, R.J.F. 1979. El CICIU y los resultados de la investigación en apoyo a la producción agraria. Rev. Per. Ent. 22(1) 99-102.

Radcliffe, E.B. 1981. Insect Pests of Potato. Ann. Rev. Entomol. 27:173-204.

Raman, K.V., and R.H. Booth. 1973. Integrated control of potato moth in rustic stores. Proc. Sixth Symp. Int. Soc. Tropical Root Crops, International Potato Centre, Lima, Perú.

Raman, K.V., and I. Redolfi. 1984. Progress in biological control of major potato pests at CIP. in Report of the XXVII Planning Conference "Integrated Pest Management". International Potato Centre, Lima, Perú.

Samways, M.J. 1979. Practical pest management in Brazil. Outl. Agric. 10:78-84.

Sankaran, T., and D.J. Girling. 1980. The current status of biological control of the potato tuber moth. Biocontrol News and Information 1(3) 207-211.

Stehr, F.W. 1982. Parasitoids and Predators in Pest Management. pp 135-173. in Introduction to Pest Management. R.L. Metcalf, and W.H. Luckmann (Editors), John Wiley and Sons Inc. New York, 577 pp.

# PROGRESS IN BIOLOGICAL CONTROL OF MAJOR POTATO PESTS

K.V. Raman and I. Redolfi

## 1 JUSTIFICATION

The potato crop is subject to a wide range of pests and diseases, which reduce yield and quality of tubers. In Peru, at least 50 arthropod pests have been reported to damage the potato crop. Damage caused by insect pests is a major constraint to potato production in many parts of the developing world, and the indiscriminate use of insecticides is spreading rapidly. Throughout the world, more chemical pesticides are used on potatoes than on any other crop, except cotton. Complete dependance on chemical control is fraught with serious handicaps, including the development of resistance by insect pests to insecticides. In potatoes specific examples cited include Colorado potato beetle resistance to organochlorine, organophosphate, and carbamate insecticides (Harris and Svec, 1981); green peach aphid resistance to several insecticides (Radcliffe et al., 1979); potato leafminer fly resistance to synthetic pyrethroids (Collantes and Raman, 1982); and potato tuber moth resistance to organochlorine and synthetic pyrethroid insecticides (Haines, 1977; Collantes et al., 1983). Recent observations in the Mantaro Valley region of Peru indicate that the organochlorine insecticides in most areas are now ineffective in controlling the Andean potato weevil. Also of concern is the destruction of beneficial organisms; "pest resurgence" has been reported for several potato pests following destruction of natural enemies by indescriminate use of pesticides. Rapid resurgence of potato tuberworm has been reported by Shelton et al. (1981), and that of green peach aphid by Cancelado and Radcliffe (1979). Secondary pest outbreaks or development of new pests more important than the original ones has also been documented following indescriminate use of insecticides. In the coastal area of Peru potato leafminer fly, Liriomyza huidobrensis, became a major pest as a result of indiscriminate use of insecticides against Scrobipalpula absoluta (Cisneros, 1982).

Lastly, there have been public demands to reduce pesticide use in order to protect health and the environment. Due to these reasons, a major portion of the International Potato Center's (CIP's) research is aimed at identifying pest management techniques that allow farmers to improve

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control while reducing insecticide use. Biological control, therefore, is being investigated as one of the priority components in integrated pest management. CIP is collaborating with the Department of Biology, National Agrarian University, La Molina (Lima) and the national potato program of Peru in an effort to conserve and protect the natural control agents and complement their effect with other forms of control, including the selective use of chemicals.

## 2 BIOLOGICAL CONTROL OF MAJOR PESTS

Work in this area has been restricted to three major pests occurring in developing countries.

a Potato Tuber Moth (PTM) (*Phthorimaea operculella* and other gelechiid species). This pest is now spread throughout tropical and subtropical regions where potatoes are grown. Larvae feed on both foliage and tubers. Losses due to damage in the field and storage may exceed 50 percent in the absence of proper control measures. Other important gelechiid species found in South America are *Scrobipalpula absoluta* and *Symmetrischema plaesiosema*. Collectively these three species are highly destructive and can cause total crop loss under field and storage conditions at ambient temperatures. *S. absoluta* is primarily a foliage feeder while *S. plaesiosema* prefers tubers. Several parasitoid insects have been reported from Peru (Table 1) by Delgado and Aguilar (1980).

The relative importance and percent parasitism by these parasitoids needs further detailed field studies. Preliminary data obtained in 1982 on this aspect of biological control of PTM larvae causing foliage damage in untreated experimental plots at CIP, La Molina, are shown in Table 2. Percent larval parasitism varied from 29 to 52 percent. Major parasites encountered were two species of the genus *Apanteles* (Braconidae) and two underscribed species of the genus *Temulucha* (Ichneumonidae) identified by Dr. Henry Townes, American Entomological Institute, Michigan, U.S.A. *Copidasoma koehleri* (Encyrtidae) (Figure 1), a polyembryonic parasite of the egg and larval stages of PTM, was collected from a field in Huancayo (3,280 m), Peru, where 24 percent parasitism was recorded on larvae infesting tubers. The highest degree of parasitization among imported parasites in Cyprus was due to *C. koehleri* (Krambias, 1979). Good results were also reported from Zambia where the potato yield was raised by 22 to 25 percent (Anon., 1980).

Table 1 -- Major Parasitoids of Potato Tuber Moth

| Pest: *Phthorimaea operculella* | Pest: *Scrobipalpula absoluta* |
|---|---|
| Parasite | Parasite |
| Braconidae | Ichneumonidae |
| *Apanteles* sp. | *Cremastus* sp. |
| | *Pristomerus* sp. |
| Encyrtidae | |
| *Copidosoma koehleri* | Braconidae |
| | *Apanteles scutellaris* |
| Tachnidae | *Apanteles* sp. |
| *Incamyia cuzcensis* | |
| | Pteromalidae |
| | *Dibrachys cavus* |
| | Tachnidae |
| | *Schizactia* sp. |

Table 2 -- Biological Control of Potato Tuber Moth Larvae Causing Foliage Damage

| | | % Larvae Parsitised by | | |
|---|---|---|---|---|
| Days after planting | *Apanteles* spp. | *Temulucha* new species | *Chelonus* sp. | % Total parasitized |
| 64 | 37 | - | - | 37 |
| 71 | 27 | 2 | - | 29 |
| 78 | 23 | 19 | - | 42 |
| 86 | 26 | 22 | - | 38 |
| 93 | 22 | 30 | - | 52 |
| 100 | 32 | 7 | 2 | 41 |
| 105 | 29 | 6 | - | 35 |

An ectoparasite of the prepupal stage of Symmetrischema plaesiosema was collected in Huancayo. This species belongs to the family Pteromalidae and has been identified as Dibrachys cavus (Figure 2).

Also the biological insecticide Dipel containing active spores of Bacillus thuringiensis has been tested by both spray and dust application. Single pre-storage sprays at either 0.2 or 0.5 percent reduced both sprout damage and tuber rotting (Figure 5). Pre-storage dust formulation at 3 to 4 kg. per ton of potatoes also gave effective control (Raman and Booth, 1983).

b Leafminer Fly (Liriomyza huidobrensis). In Peru and Brazil, both adults and larvae of L. huidobrensis and two other leafminer species cause extensive yield losses. Eleven parasitoids have been reported from Peru (Table 3) by Delgado and Aguilar (1980). Percent parasitism and the relative importance of these parasites have been studied at La Molina. The most predominant species was Halticoptera patellana (Pteromalidae) (Figure 3), causing 21 percent parasitism. Table 4 shows the various parasites identified, the stage of pest parasitised, and the percent parasitism.

Insecticides Decis, Vydate, and lead arsenate have been tested for their selectivity, and all three significantly reduced pupal parasitism by leafminer fly parasitoids. In the coastal area of Peru lead arsenate mixed with an attractant like molasses is commonly used to control this pest. Our results indicate that mixing an attractant like 0.4 percent protein hydrolysate with lead arsenate affects percent pupal parasitism in the field (Figure 5). We have also observed that the populations of parasites of this pest increase to very high levels with an increase in temperature. Adjusting dates of planting to coincide with high parasite/predator activity provides successful biological control.

c Aphids (Myzus persicae and others). Aphids are distributed worldwide and are vectors of many virus diseases. M. persicae is the main vector of potato leafroll virus (PLRV) and potato virus Y (PVY). Apart from virus transmission, studies at CIP indicate that high populations of aphids can lead to a yield loss of 44 percent (Anon., 1983).

Three species of parasitoids and 12 species of predators have been reported from Peru (Delgado and Aguilar, 1980). In our studies, Aphidius sp. (Aphididae) (Figure 4) was the most predominant parasite observed at the experimental station of the National Agrarian

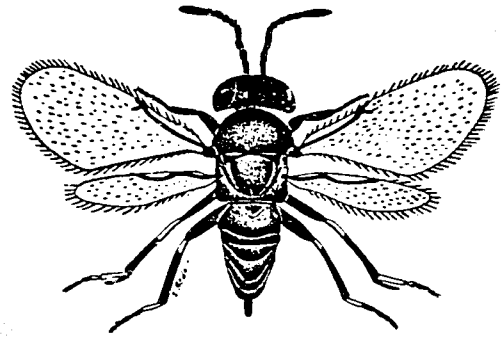

Fig. 1. *Copidosoma koehleri.*

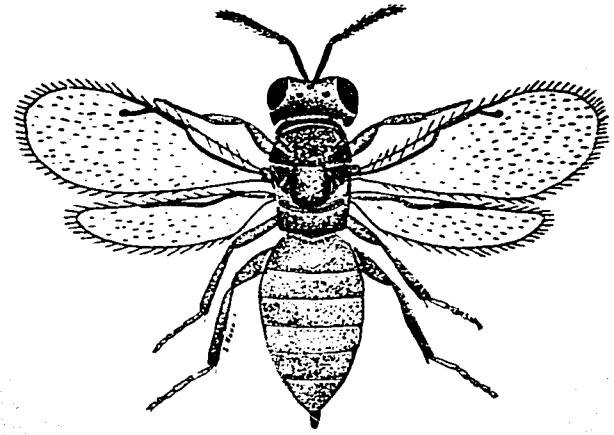

Fig. 2. *Dibrachys cavus.*

0,4 mm

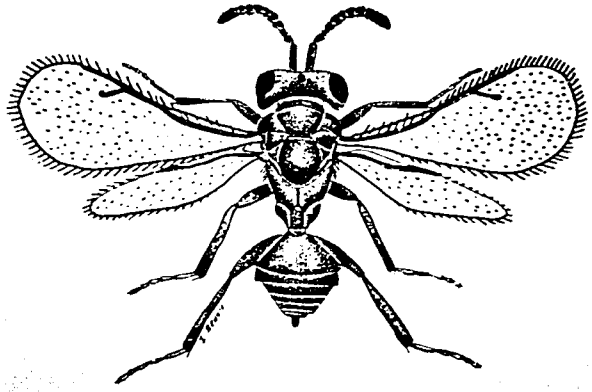

Fig. 3. *Halticoptera patellana.*

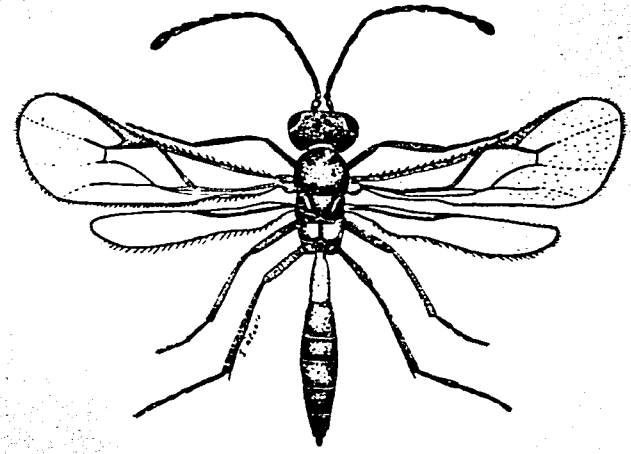

Fig. 4. *Aphidius* sp.

Table 3 -- Major Parasitoids of Leafminer Fly

| PARASITE | | |
|---|---|---|
| Eulophidae | Pteromalidae | Braconidae |
| *Solenotus websteri* | *Halticoptera patellana* | *Opius scabriventris* |
| *Chrysocharis aisliei* | *Halticoptera* sp. | |
| *Chrysocharis* sp. | | |
| *Euparacrias phytomyzae* | | |
| *Euparacrias* sp. | | |
| *Closterocerus* sp. | | |
| *Zagrammosoma* sp. | | |
| *Heteroschema* sp. | | |

Table 4 -- Percent Parasitism of Leafminer Fly in Field, La Molina

| Species identified | Family | Stage parasitised | % Parasitism |
|---|---|---|---|
| *Halticoptera patellana* (Dalman) | Pteromalidae | Larval, Pupal | 21.18 |
| *Chrysocharis phytomyzae* (Brethes) | Eulophidae | Larval, Pupal | 3.50 |
| *Diglyphus* sp. | Eulophidae | Larval | 5.71 |
| *Chrysocharis* sp. | Eulophidae | Larval, Pupal | 0.02 |
| *Opius* sp. | Braconidae | Larval, Pupal | 0.01 |

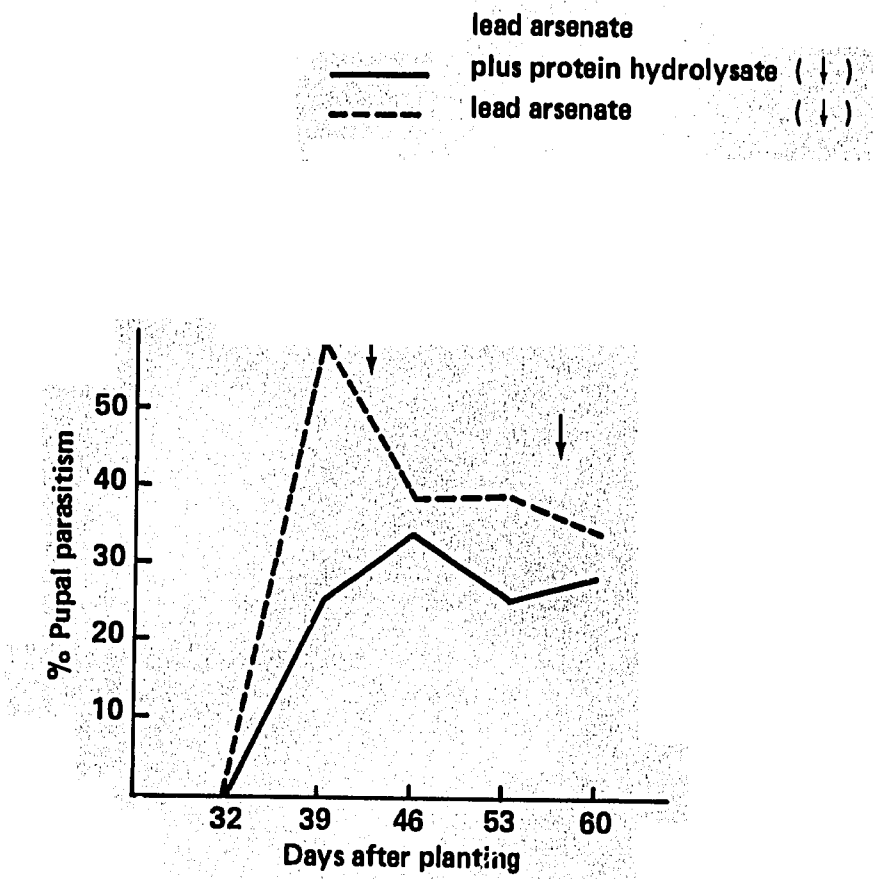


Figure 5. Effect of lead arsenate, and lead arsenate plus protein hydrolysate on parasites of leafminer fly.

University in La Molina, where 50 percent parasitism was observed. The female parasitoid wasp lays a single microscopic egg within the host aphid and, as the larva develops and feeds, the aphid body becomes mummified and only the skin remains.

## 3 DISCUSSION AND FUTURE STRATEGY

Several strategies are available for the bilogical control of pests; these include introduction, augmentation, inoculation, and conservation. Biological control by introduction is the best means of pest control, and for this reason, "classical biological control" has so far been the aim of most practitioners. Clear-cut results on the control of potato tuber moth through the introduction of parasites collected from South America has been obtained in Cyprus and Zambia by the Commonwealth Institute of Biological Control (Greathead and Waage, 1983). As a result of these successes, futher attempts should be made in other countries to use those parasitoids which have been proved effective.

Peru being the home of the potato is also the home of several pests and their natural enemies. CIP, therefore, aims at obtaining an inventory of natural enemies which may be of use in other countries. Where feasible, promising natural enemies will be selected for an in-depth study in the field and laboratory to provide information on their host specificity, safety, and culture method. This work will probably be a subject for graduate thesis research. In order to achieve importation, natural enemies need to be screened to eliminate disease and other unwanted contaminants, and shipped to the receiving country. CIP has no facilities to do this research, and collaboration should be established with other institutes such as the Commonwealth Institute of Biological Control (CIBC) and the University of California that are currently involved in this research. CIP can coordinate with national programs to monitor and obtain an assessment of the effects of the introduction on the pest and to allow adjustment of techniques to achieve the maximum benefit.

The other form of biological control involving augmentation, inoculation, and inundation of parasitoids or predators requires mass-culture of control agents. At present, CIP has no facilities to conduct this research, and it is hoped that the private sector will get involved in this activity. Microbial agents, notably the use of *Bacillus thuringiensis*, are an exception to this strategy as these agents are now produced in many developing countries.

The last form of biological control involves conservation which is an activity to protect and maintain the natural enemies of the pests. Selective control strategies include the use of host plant resistance, selective insecticides, judicious use of broad-spectrum insecticides, sex pheromones, mixed cropping, and cultural practices. These strategies will be emphasized because they are the least disruptive to the natural enemies occurring in the field.

## REFERENCES


Anonymous. 1980. Biological Control Service. 25 years of achievement, CIBC, Gordon St. Curepe, Trinidad, West Indies.

Anonymous. 1983. Annual Report. International Potato Center. Lima, Peru.

Cancelado, R. E. and E. B. Radcliffe. 1979. Action thresholds for green peach aphid on potatoes in Minnesota. J. Econ. Ent. Vol. 72, No. 4. 604-609.

Collantes, G. and K. V. Raman. 1982. Método práctico para determinar resistencia de los insectos a los insecticidas. XXV Convención Nacional de Entomología 3-7, October, 1982, Huaraz, Peru. p.45.

Collantes, G., K. V. Raman, and F. Cisneros. 1983. Determinación de la toxicidad relativa de dos piretroides sobre Phthorimaea operculella (Zeller). XXVI Convención Nacional de Entomología, 7-11 Agosto, 1983, Tingo María, Perú. p. 34.

Cisneros, F. H. 1983. Integrated pest control: New approaches to the priority components. "Research for the potato in the year 2000." International Potato Center. Lima, Peru. pp.34-37.

Delgado, J. J. and P. G. Aguilar. 1980. Control integrado en papa. Rev. Peruana de Entomología, Vol. 23 No. 1. pp. 102-104.

Greathead, D. J. and J. K. Waage. 1983. Opportunities for biological control of agricultural pests in developing countries. World Bank Tech. Paper 11. World Bank. Washington, D.C. U.S.A.

Haines, C. P. 1977. The potato tuber moth Phthorimaea operculella (Zeller) a bibliography of recent literature and review of its biology and control on potatoes in the field and in store. Report G. 112, Tropical Products Institute, London, 15 pp.

Harris, C.R. and H. H. Svec. 1981. Colorado potato beetle resistance to carbofuran and several other insecticides in Quebec. J. Econ. Ent. 74 421-424.

Krambias, A. 1979. The development of an integrated control programme for potato tuber moth in Cyprus. Ph.D. Thesis. University of Reading, Reading, England. 212 pp.

Radcliffe, E. B., R. E. Cancelado, and W. S. Cranshaw. 1979. Establishing action thresholds for insect pests. Proceedings IX Int. Congress of Plant Protection. Washington, D.C., U.S.A. Vol. 3: 477-480.

Raman, K. V. and R. H. Booth. 1983. Integrated control of potato moth in rustic stores. Sixth Symposium of the Int. Soc. for Tropical Root Crops. 20-25 Feb., 1983. International Potato Center. Lima, Peru.

# PHEROMONE USE IN DEVELOPING COUNTRIES AND NEW DEVELOPMENTS IN PEST CONTROL

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## Introduction

Chemical signals play important roles in governing insect behaviour, and research into the identification of these "semiochemicals" and determination of their functions is providing new tools for use in the management of insect pests.

Semiochemicals may act interspecifically (allelochemicals) or intraspecifically (pheromones). Allelochemicals include oviposition deterrents and attractants and compounds which guide predators and parasites to their hosts. These would have great potential in insect pest control, but to date there are relatively few examples of chemical identification and even fewer cases of their field use. The most significant advances have been in the identification and use of pheromones, particularly those of Lepidoptera and Coleoptera which are responsible for attracting males and females together for mating (sex pheromones) and for attracting both sexes together for feeding and mating (aggregation pheromones).

Pheromones have several characteristics making them particularly suitable for use in insect pest management. They are effective in extremely small amounts, and, unlike conventional insecticides, they are specific for the target insect. Generally they have no effect against non-target insect species, including predators and parasites, and are non-toxic to other animals and plants. Pheromones are thus totally compatible with pest management systems where biological control is being used.

Synthetic pheromones can be used in monitoring insect pests and in pest control by mass trapping or communication disruption. Their use in developing countries has been described by CAMPION & NESBITT (1981), HASKELL et al. (1981), HALL (1981), BEEVOR et al. (1983), CAMPION & NESBITT (1983) and CAMPION (1983). This review will outline more recent work, particularly that involving chemists and entomologists from the U.K. Overseas Development Administration's Tropical Development and Research Institute.

## Pheromone Identification

Sex pheromones of Lepidoptera are produced in minute, nanogram quantities by the insects, and their identification requires very specialised techniques (NESBITT, 1978). The chemical and stereo-chemical structure must be rigorously determined, and the pheromones often consist of two or more components in a narrowly-defined ratio. Pheromones have been identified for many pests of major economic importance on a range of tropical crops including cotton, rice, cereals, sugar, vegetables and citrus (CAMPION & NESBITT, 1981). Recently, the identification and field trials have been reported of the female sex pheromones of Cryptophlebia batrachopa, a borer pest of macadamia nuts in Malawi (HALL et al. 1984), and the yellow rice stem borer, Scirpophaga incertulas (CORK et al. 1984). The pheromone produced by female potato tuber moths, Scrobipalpopsis solanivora, has also been identified and shown to be highly attractive to male moths in Costa Rica and Guatemala (unpublished).

## Monitoring

Traps baited with synthetic pheromone provide a means of monitoring insect populations that is simple and cheap yet very sensitive and specific for the target insect. With most lepidopterous sex pheromones the traps attract male moths, and considerable work is often necessary to establish what correlation exists between trap catches of moths and subsequent larval populations. Nevertheless, pheromone traps are proving particularly useful in detecting the presence and movements of highly mobile pest insects.

Movements of the African armyworm moth, Spodoptera exempta, are being mapped by use of a network of pheromone traps in Kenya, Tanzania, Uganda, Ethiopa and the Yemen. In Malawi, a network of 63 pheromone traps for S. exempta is being operated by extension staff, and catches are reported to a central coordinating unit. Trap catches can now be interpreted in the light of over seven years' experience and outbreaks dealt with at an early stage (NYIRENDA, 1982).

A network of 49 pheromone traps to monitor Heliothis armigera has been set up in India, Pakistan, Bangladesh and Sri Lanka by ICRISAT. The catches are being correlated with climatic data to build up a picture of the dynamics of this pest in Asia with the eventual aim of being able to predict the size and timing of attacks in any area (ICRISAT, 1982; PAWAR, et al., 1983). The use of pheromone traps to monitor H. armigera at ICARDA in Syria has also been reported by TAHHAN & HARIRI (1982)

Traps baited with synthetic pheromone have been used to monitor populations of the rice leaf folder, Cnaphalocrocis medinalis in Sri Lanka. Peak crop damage was observed 10-20 days after peak moth count (KUDAGAMAGE, 1983). The use of pheromone traps to predict the timing and magnitude of attacks by the maize stalk borer, Busseola fusca, is

being investigated in Zimbabwe (THORNYCROFT, 1982).

The greater grain borer, Prostephanus truncatus, is a minor pest of stored grain in Central America, but the beetle has been introduced into Tanzania where it has spread rapidly in the absence of natural controls (HODGES et al., 1983a). Traps baited with one component of the aggregation pheromone of a related species, Rhyzopertha dominica, have been shown to attract both male and female P. truncatus in the field (HODGES et al., 1983b). A component of the aggregation pheromone of P. truncatus has now been identified and used to bait even more sensitive and specific traps for monitoring the spread of this pest and assessing the effectiveness of control measures (unpublished).

## Mass Trapping

It seems unlikely that mass trapping of male moths with pheromone traps will provide a generally applicable means of reducing insect populations, although this strategy may be effective in certain situations, such as in areas isolated by virtue of geography or the localisation of crop and pest, in warehouse situations or where the pest causes damage at extremely low population levels. Where attractants for the female insect have been identified, mass trapping has much greater potential.

Mass trapping of macadamia borers, Cryptophlebia batrachopa and C. leucotreta, in Malawi was shown to reduce the proportion of bored nuts significantly (unpublished). A pheromone trap was hung on every tree to give a density of over 100 traps per ha, so that any effect on moth populations may have been due to mating disruption rather than to trapping out, and this is being tested in further trials.

## Mating Disruption

The most promising method of using sex pheromones in control of insect pests is currently mating disruption in which a large number of point sources of synthetic pheromone is distributed over the crop. These may act on the male moths in one or more ways: the male moths may become habituated and unresponsive to the pheromone produced by female moths when exposed to a fog of synthetic pheromone; the male moths may be unable to detect the small amounts of pheromone produced by the female moths against a background of synthetic pheromone, or the male moths may be attracted to the individual point sources of synthetic pheromone and hence reduce the probability that they will find a female moth (BARTELL, 1982).

One of the major problems in using this technique has been that of developing formulations of synthetic pheromone which can be applied over large areas, which release the pheromone into the atmosphere in a controlled manner over a suitable period of time and which protect the pheromone from degradation by environmental factors such as heat and sunlight. Now three types of formulation are commercially

available - microcapsules (HALL et al., 1982), hollow fibres (ASHARE et al., 1982) and plastic laminate flakes (QUISUMBING & KYDONIEUS, 1982). The aqueous-based microencapsulated formulations can be applied to the crop with any conventional ground or aerial spraying equipment. The hollow fibre and plastic laminate flake formulations require a sticker and can be sprayed with specially developed apparatus or applied to the crop by hand.

The most extensive work on mating disruption in the developing countries has been carried out in Egypt on pink bollworm, Pectinophora gossypiella, a cotton pest of world-wide importance. During 1980, trials on small 0.01 ha plots showed that microencapsulated pheromone at application levels as low as 5 gm per ha prevented male moths from locating pheromone traps in the sprayed area (HALL et al., 1982). In 1981, two areas of 50 ha were treated with microencapsulated pheromone as the sole means of controlling P. gossypiella. Five applications at 10 gm per ha were made between May and August by fixed-wing aircraft. Damage caused by P. gossypiella was measured in terms of percentages of rosetted flowers and infested bolls, and the gross yields and quality of the seed cotton produced were determined. By all these criteria, there were no significant differences between plots treated with pheromone and similar plots where the recommended four sprays of conventional insecticides were used (CRITCHLEY et al., 1983).

In the 1982 season, two plots of 50 ha each were treated with five and six applications of microencapsulated pheromone, applied by helicopter at 7.5-10 gm per ha at approximately two week intervals. A similar plot was treated with six applications of a hollow fibre formulation of the pheromone: clumps of 4-5 fibres were deposited on the cotton plants every 4-5 $m^2$ to give an application rate of 3 gm per ha. A fourth plot was treated with six applications of a plastic laminate formulation of the pheromone at a density of 800 flakes per ha to give an application rate of 3 gm per ha. The latter two formulations were applied by hand using an appropriate sticker. This was carried out by teams of children who earlier in the season had been employed in collecting egg masses of the cotton leafworm, Spodoptera littoralis. One child could treat 1 ha in 2 days at a cost of 1.5 US $ compared with the cost of 8.10 US $ per ha for aerial application of the microencapsulated formulation. Hand application of hollow fibre, plastic laminate flake or microencapsulated pheromone formulations may thus be an appropriate technique where labour is readily available, a situation that may occur particularly in developing countries.

Extensive surveys of damage caused by P. gossypiella were carried out as well as determination of the yields and quality of the harvested cotton. No significant differences were found between the plots treated with the different pheromone formulations and three similar areas where P. gossypiella was controlled with the recommended three or four sprays of conventional insecticides. In addition, counts of

beneficial insects were made in the various plots, and, on average, three times as many were found in the plots treated with pheromone as were found in the plots treated with insecticide (unpublished).

In 1983, areas of up to 200 ha were treated with the three pheromone formulations in pre-registration trials. The data is still being assessed, but preliminary results are encouraging and match those of the previous years.

Trials with microencapsulated formulations of the P. gossypiella pheromone are also being carried out in Pakistan and Peru. The pheromones of many other insects can be microencapsulated, and trials are being carried out against Cryptophlebia batrachopa and C. leucotreta on macadamia in Malawi, against the sugar cane borer, Chilo sacchariphagus in Mauritius, and against the potato tuberworm moth, Phthorimaea operculella, in Peru. Mating disruption of Ephestia cautella has been demonstrated in warehouses in Brazil using one component of the pheromone formulated in polyethylene vials (HODGES et al., 1984), and it is anticipated that the microencapsulated pheromone formulations will also be suitable for use in storage situations.

## Conclusions

Agriculture is of great importance in the economies of the majority of developing countries, and insect pests often cause extensive crop losses. Semiochemicals in general, and pheromones in particular, provide important new tools for insect pest management with many advantages over conventional methods. Accurate forecasting with pheromone traps and use of pheromones in mass trapping and mating disruption can reduce the dependence of developing countries on insecticides and help to avoid the problems of environmental contamination, destruction of natural predators and parasites and the build up of insect resistance that overuse of insecticides can cause. However, no one method can provide a universal panacea, and each situation must be assessed separately in order to select the most appropriate combination of methods to reduce the damage caused by insect pests below economically acceptable levels.

## References

ASHARE, E., BROOKS, T.W. & SWENSON, D.W. (1982). Controlled release from hollow fibres. In: Insect Suppression with Controlled Release Pheromone Systems, Vol I. Eds. A.F. Kydonieus and M. Beroza. CRC Press Inc., Boca Raton, Florida. 237-244.

BARTELL, R.J. (1982). Mechanisms of communication disruption by pheromone in the control of Lepidoptera: a review. Physiological Entomology, 7, 353-364.

BEEVOR, P.S., HALL, D.R. & NESBITT, B.F. (1983). Pheromones and other recent developments in biochemical pest management. In: Chemistry and World Food Supplies: the New Frontiers. CHEMRAWN II. Ed. L.W. Shemilt. Pergamon Press, Oxford, England. 163-171.

CAMPION, D.G. (1983). Pheromones for control of insect pests in Mediterranean countries. Crop Protection, 2, 3-16.

CAMPION, D.G. & NESBITT, B.F. (1981). Lepidopteran sex pheromones and pest management in developing countries. Tropical Pest Management, 27, 53-61.

CAMPION, D.G. & NESBITT, B.F. (1983). The utilisation of sex pheromones for the control of stem borers. Insect Science and its Application, 4, 191-197.

CORK, A., BEEVOR, P.S., HALL, D.R., NESBITT, B.F., ARIDA, G.S. & MOCHIDA, O. (1984). Components of the female sex pheromone of the yellow stem borer, Scirpophaga incertulas. Entomologia experimentalis et applicata, submitted for publication.

CRITCHLEY, B.R., CAMPION, D.G., McVEIGH, L.J., HUNTER-JONES, P., HALL, D.R., CORK, A., NESBITT, B.F., MARRS, G.J., JUTSUM, A.R., HOSNY, M.M. & NASR, El-S.A. (1983). Control of pink bollworm, Pectinophora gossypiella (Saunders) (Lepidoptera: Gelechiidae), in Egypt by mating disruption using an aerially applied microencapsulated pheromone formulation. Bulletin of Entomological Research, 73, 289-299.

HALL, D.R. (1981). Insect pheromones - isolation and identification; Insect pheromones - use in pest control. Zimbabwe Science News, 15, 227-233.

HALL, D.R., NESBITT, B.F., MARRS, G.J., GREEN, A. St.J., CAMPION, D.G. & CRITCHLEY, B.R. (1982). Development of microencapsulated pheromone formulations. In: Insect Pheromone Technology: Chemistry and Applications. Eds. B.A. Leonhardt & M. Beroza. ACS Symposium Series 190, American Chemical Society, Washington D.C. 131-143.

HALL, D.R., BEEVOR, P.S., CORK, A., NESBITT, B.F. & LA CROIX, E.A.S. (1984). (Z)-8-Dodecenyl acetate: the major component of the female sex pheromone of Cryptophlebia batrachopa, a Tortricid pest of macadamia in Malawi. Entomologia experimentalis et applicata, 35, 33-36.

HASKELL, P.T., CAMPION, D.G. & NESBITT, B.F. (1981). Behaviour modifying chemicals in tropical pest management. Med. Fac. Landbouww. Rijksuniv. Gent, 46, 27-38.

HODGES, R.J., DUNSTAN, W.R., MAGAZINI, I. & GOLOB, P. (1983a). An outbreak of Prostephanus truncatus (Coleoptera: Bostrichidae) in East Africa. Protection Ecology, 5, 183-194.

HODGES, R.J., HALL, D.R., GOLOB, P. & MEIK, J. (1983b). Responses of Prostephanus truncatus to components of the aggregation pheromone of Rhyzopertha dominica in the laboratory and field. Entomologia experimentalis et applicata, 34, 266-272.

HODGES, R.J., BENTON, F.P., HALL, D.R. & dos SANTO SERODIO, R. (1984). Control of Ephestia cautella Walker (Lepidoptera: Phycitidae) by synthetic sex pheromones in the laboratory and the store. Journal of Stored Product Research, in press.

ICRISAT (1982). Annual Report.

KUDAGAMAGE, C. (1983). Leaffolder population monitoring using a sex pheromone. International Rice Research Newsletter, 8, 11.

NESBITT, B.F. (1978). A review of work on insect pheromones at the Tropical Products Institute. Tropical Science, 20, 1-10.

NYIRENDA, G.K.C. (1982). The armyworm (Spodoptera exempta Wlk.) pheromone trap network in Malawi. Paper presented at Armyworm and other Migrant Pest Workshop, Arusha, Tanzania, 5-9 July.

PAWAR, C.S., SRIVASTAVA, C.P. & REED, W. (1983). Pheromone trap network for Heliothis armigera in India. International Pigeonpea Newsletter, 2, 60-61.

QUISUMBING, A.R. & KYDONIEUS, A.F. (1982). Laminated structure dispensers. In: Insect Suppression with Controlled Release Pheromone Systems. Vol. I. Eds. A.F. Kydonieus & M. Beroza. CRC Press Inc., Boca Raton, Florida. 213-235.

TAHHAN, O. & HARIRI, G. (1982). Preliminary study of trapping Heliothis armigera (Hb) with pheromones at ICARDA, Syria. International Chick-pea Newsletter, 6, 19-20.

THORNYCROFT, C. (1982). Pheromone traps, pests and pesticides. The Farmer, 53, 9.

# PROGRESS IN PHEROMONE UTILIZATION AND OTHER NOVEL CONTROL PRACTICES

DR. K. V. RAMAN

## INTRODUCTION

Work on sex pheromones at the International Potato Center (CIP) started in 1979. This was at a time when the drawbacks of the conventional broad-spectrum insecticides were causing concern in many developing countries and arose from requests by national programs to identify alternatives to the use of chemical control. Close collaboration with Institute for Pesticide Research, Wageningen, The Netherlands, Tropical Development Research Institute, London, United Kingdom, and national programs of developing countries was established from the early stages of work. The use of sex pheromones in potato pest control has developed along three main pathways: monitoring of insect populations with pheromone-baited traps; control by mass trapping using large numbers of traps to reduce population levels, and control by mating disruption in which synthetic pheromone is used to permeate the atmosphere so that an insect will be unseccessful in finding a mate. For pests eg. Leafminer fly, *Liriomyza huidobrensis*, where pheromones have not yet been synthesised progress has been made on the use of novel control practices, which include the use of sticky green colored traps to monitor and mass trap this pest. This paper reviews briefly the work conducted at CIP on developing the use of pheromones and sticky traps for the control of certain insect pests prevalent in developing countries.

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## Identification and Synthesis of Pheromones

The female sex pheromones of Potato tuber moth: Phthorimaea opercu-lella, one of the most widespread pest affecting potato growth im many parts os the world, consist of two substances. The first was identified as trans-4, cis-7, trideca-dienyl acetate, having the formula $CH_3\ (CH_2)_4\ CH^c = CHCH_2\ CH^t = CH\ (CH_2)_3\ OCOCH_3$. The second active substance is trans-4, cis-7, cis-10 tridecatrienyl acetate having the formula $CH_3\ CH_2 \overset{c}{=} CHCH_2\ CH \overset{ch}{=} (CH_2)_3\ COCH_3$. Roelofs et. al. (1975) and Persoons et. al (1976). Recently in 1982, Dr. Brenda Nesbitt and her co-workers synthesised the pheromone of Scrobipalpopsis solanivora, a major PTM species ocurring in Central America (Unpublished data, B. Nesbitt, T.D. R.I., London, United Kingdom). Another PTM species reported to occur in Perú and Colombia is Symmetrischema plaesiosema. Synthetic pheromones have not yet been made available for this pest. The pheromones of two major cutworm species damaging potatoes are currently available commercially. The pheromone of Prodenia eridiana consists of Z, E-9, 12TDDA (500 ug): Z-9-TDA (500 ug) and that of Spodoptera exempta is Z, E-9, 12TDDA : Z-9-TDA. These two sex pheromones are available from Wolfson Unit of Chemical Entomology, University of Southampton, United Kingdom.

Other important potato pests for which pheromones are not yet synthesised include Leafminer fly, Liriomyza huidobrensis Andean potato weevils, Premnotrypes suturicallus and the potato leaf miner, Scrobipalpula absoluta. Some success has been achieved with S. absoluta and S. plaesiosema using virgin females. The attractivity of impure PTM1 and PTM2 (distilled and products) samples of Dr. S. Voerman, Institute for Pesticide Research, Wageningen, were not effective against S. absoluta.

## Field and Storage Application of Pheromones

Monitoring: When used as bait in traps to attract and capture male insects, pheromones provide the basis for a survey tool. Pheromones of *P. operculella* have been used extensively in monitoring PTM populations (Raman, 1982). Detailed studies on trapping techniques have been reported by Bacon et. al. (1976) with the highest moth catches obtained with a water trap. This trap through effective in monitoring, is unsuitable for use in mass trapping, because it needs frequent servicing with water thereby increasing the cost of maintenance and operation. The water trap was compared with a funnel trap to determine an alternative to the use of water trap. Results of trapping studies with the funnel trap at three different heights and the water pan trap are presented in Table 1. Throughout the 15 day trapping period, moth populations trapped remained high. No significant differences ($P > 0.05$) in trap captures were observed during the entire trapping period. Thus it appears the funnel trap compared favorably with the water trap. Comparing data from funnel traps at different elevations, the catches at ground level though slightly higher (mean = 8.67/day) were not significantly different ($P > 0.05$) from traps set at 40 and 80 cm height (Table 1). The 40 cm level is well suited to the usual height of the potato foliage. Details of this experiment are published in (Raman 1984). Current trap designs for evaluation by national programs include funnel, water and sticky traps (Raman and Booth, 1983a). During the later part of the season the pheromone traps provide a good correlation between oviposition by PTM on the foliage of potato plants and the pheromone trap data. This indicates that, when male moths are monitored, the data reflect the ovipositional activity of the female component of the population which is not

Table 1. Effect of trap design and height on capture of male potato tuberworm moths, Lima, 1982

| Trap type | $\bar{x}$ No. of moths per trap per day |
|---|---|
| Water pan trap | 9.14a |
| Funnel trap | |
| Ground level | 8.67a |
| 40 cm | 6.85a |
| 80 cm | 7.62a |

* Test conducted between 26 January and 16 February.

* Four replicates per treatment. Means followed by the same letter are not significantly different at the 5% level, by Duncan's multiple range test.

monitored (Valencia, 1981). Male PTM moth capture in potato fields is correlated positively with tuber damage at harvest r = 0.76 (Campos, 1983). Similar results were observed in Lima. Fields with low moth populations during winter plantings of 1980 did not sustain economic damage. When moth populations were high during summer planting of 1980, potato done DTO 33 sustained 42% tuber damage (Raman 1982).

Live virgin females of S. absoluta and S. Plaesiosema have been used in survey work when synthetic pheromones were not available. Females used as bait in these studies need to be reared in the laboratory. The trap capture varies with the number of virgin female moths used per trap. With S. plaesiosema 8 female moths per trap gave the highest capture in field (Fig. 1). A dual monitoring system wherein the pheromones of P. operculella and S. solanivora have been combined are presently used by the National potato program in Costa Rica (Murillo, R. unpublished data). Such an approach is feasible when synthetic pheromones for all the major pests are available. The effects on catch of P. operculella in relation to wind speed, relative humidity and temperature have been reported by (Krambias 1979), and (Sanchez, 1984). Increased wind speed in the range of 0.1 - 4.7 $ms^{-1}$, and temperatures in the range of 22-26° C promoted higher catches of male moths. The regression of catches on relative humidity was negative ($P < 0.01$ $r = -0.37$) indicating a reduction in mating success due to high humidity. Pheromone traps have also been used in monitoring PTM populations in storage areas (Raman & Booth, 1983).

## Mass Trapping

When insect populations are low, mass trapping may provide a means of

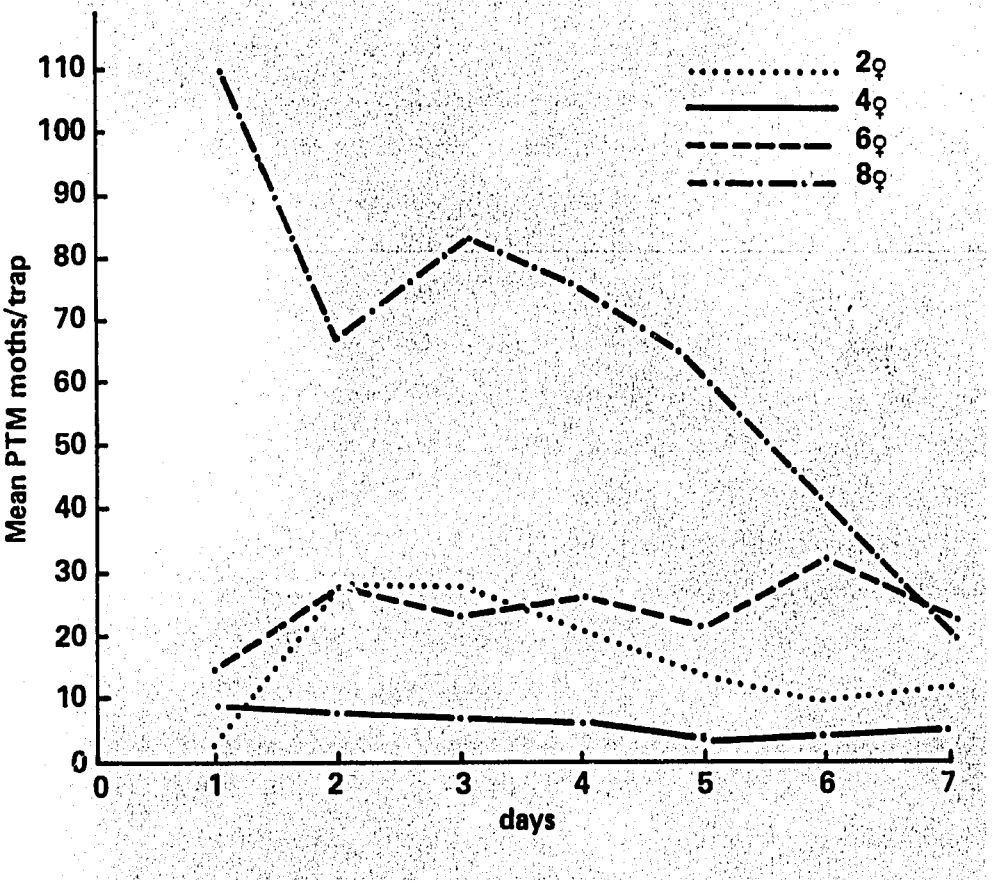


**Fig. 1. Effect of the number of virgin females (*S. plaesiosema*) per trap on male catches.**

control by slowing down population build-up to an acceptable level. In regions where labour is cheap, the deployment of a limited number of traps per unit area to catch selected target insects may offer a convenient and more economic method of control compared with spraying conventional insecticides. For effective mass trapping it is essential to have a cheap effective trap with minimum maintenance, a pheromone blend which would be attractive for a long period of time, and the cost of the pheromone should be low. Progress has been made with P. opercu-lella to overcome some of the above objectives. An effective funnel trap was identified and eight ratios of PTM1 to PTM2 at 0.1 to 1-mg loading per pheromone cap and virgin females were compared during 90 day field trapping studies using the funnel trap (Table 2). The mean capture for 90 days indicates that there were significant differences ($P > 0.05$) in male captures at traps baited with blend of PTM1 and PTM2 and virgin females. Significant differences were observed between traps baited with virgin females and blanks. However, all traps baited with synthetic sex pheromones captured significantly higher male PTM moths per trap. Highest capture (mean = 4.93 per trap) was obtained by using the pheromone blend at 9:1 ratio. The use of this blend would greatly reduce costs in preparation of pheromone caps for large-scale use in mass trapping. From studies of Krambias (1979) and Voerman and Rothschild (1978) the attractiveness of pheromone blend varies from one location to another and careful experimentation would be needed to identify the most attractive pheromone blend for use in mass trapping. The 9:1 pheromone ratio is attractive for a period of 90 days after which the attractivity drops. The 1:1.5 ratio remained attractive for 90 days and beyond (Table 3).

Laboratory techniques to impregnate the pheromone PTM1 + PTM2 in rub-ber stoppers have been developed. Work has also been conducted on re-

Table 2. Mean number of male potato tuberworm moths captured with various blends of PTM 1 and PTM 2, Lima, 1982.

| Ratio of PTM 1 to PTM 2 | Amt of PTM 1 and PTM 2 (mg) | PTM 1 (mg) | PTM 2 (mg) | $\bar{x}$ Catch/ trap per day |
|---|---|---|---|---|
| 9: 1.0 | 1.0 | 0.900 | 0.100 | 4.93a |
| 1: 1.5 | 1.0 | 0.400 | 0.600 | 4.52ab |
| 3: 1.0 | 1.0 | 0.750 | 0.250 | 4.41ab |
| 1: 1.0 | 1.0 | 0.500 | 0.500 | 4.15b |
| 1: 3.0 | 1.0 | 0.250 | 0.750 | 4.12b |
| 1: 0 | 1.0 | 1.000 | — | 3.61c |
| 1: 1.7 | 0.1 | 0.037 | 0.063 | 3.53c |
| 1: 9 | 1.0 | 0.100 | 0.900 | 3.30c |
| Virgin females | — | — | — | 1.59d |
| Blank | — | — | — | 1.08e |

* Test conducted between 15 April and 7 September

* Two replicates per treatment, means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. Mean number of male potato tuberworm moths captured with unused and field exposed blends of PTM 1 and PTM 2, Lima, 1982.

| Ratio of PTM 1 to PTM 2 | Treatments (pheromone condition) | $\bar{x}$ Catch/trap per day |
|---|---|---|
| 9:1 | Freshly prepared | 6.51a |
| 9:1 | Reused after 90-day field exposure | 4.62b |
| 1:1.5 | Freshly prepared | 5.99abc |
| 1:1.5 | Stored 6 mo at -5°C before use | 4.78bc |
| 1:1.5 | Stored 2 mo at -5°C before use | 6.18ab |
| 1:1.5 | Reused after 90-day field exposure | 5.51abc |
| Virgin females | | 1.87d |
| Blank | | 1.19d |

* Test conducted between 21 September and 12 November

* Four replicates per treatment; means followed by the same letter are not significantly different at the 5% level by Duncan's multiple range test.

ducing the cost of rubber stopper by using smaller size (9 mm diam) stoppers (Anon 1984). The cost of PTM1 + PTM2 pheromone would be significantly reduced if these could be used along with the impurities E-24, 7-13: OH and E-24, 10-13 OH. Unfortunately the presence of these impurities reduces trap catch dramatically ($P > 0.05$). Mass trapping studies, which involved placing one dry funnel trap/225 $mt^2$ over an area of 5000 $m^2$ were conducted at La Molina during the summer of 1982. One application of Tamaron was applied to the sex pheromone-treated plots was 19% compared to 42% percent in control plots that received normal insecticide apllications only. There was significantly lower larval infestation (6 vs 9.4 larvae/plant) in the foliage of plots treated with sex pheromones: a total of 92,000 male moths were captured in 112 days using 21 traps. In storage trials at San Ramón, two funnel traps placed inside each store at the same height as stacked crates caught a total of ca 22,000 male moths, reduced tuber and sprout damage significantly ($P > 0.05$). Fig.2 presents results of mass trapping in field with one trap per 70 square meter conducted in La Molina during 1981 (Anon. 1981). Synthetic pheromones placed in traps reduced the catch of male PTM's by 97% in traps baited with virgin females.

Campion and Nesbitt (1981) indicate that mass trapping would be effective if organized on an area wide basis and therefore farmer cooperation is a must, otherwise mated female moths may move into treated area from outside. We feel mass trapping would be relatively easy under storage conditions, the number of traps needed under such situations are very limited, and each store is relatively isolated, entry of mated female moths from outside is to a minimum. Such an approach would take full advantage of natural controlling agencies and may fit in well with existing farming practices.

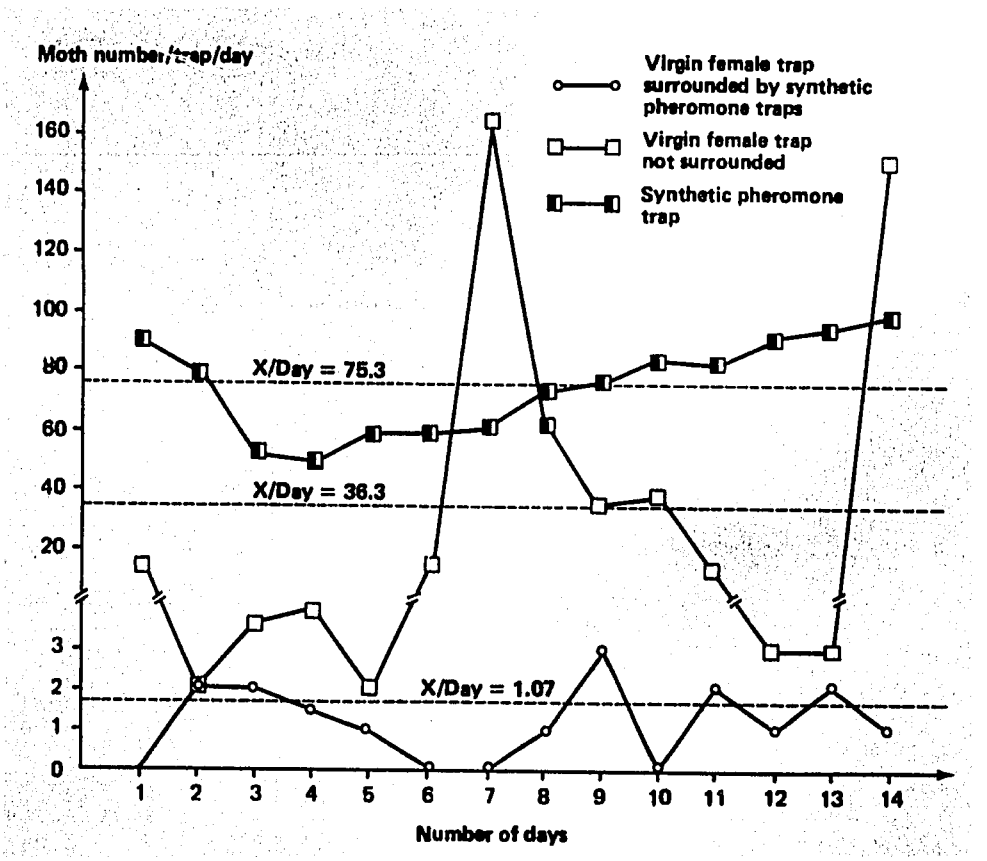


Figure 2. Mass trapping of potato tuber moth using pheromones.

## Mating Disruption

This method involves blanketing the treated area with synthetic pheromone so that males cannot detect the pheromone produced by female moths and mating does not occur, The exact mechanism of this process is not really known. It may be that the male moths adapt and become less responsive to the natural pheromone in the presence of a high concentration of synthetic pheromone or it is possible that males are attracted along false trials to the sources of synthetic pheromone and so do not encounter the female moths.

In collaboration with Herculite Industries Ltd., N.Y., U.S.A. and Imperial Chemical Industries (ICI), United Kingdom, following formulations are being developed for mating disruption.

## Multilayered Lure Tape

Also known as the Hercon dispensor has now been manufactured as a 3 layer plastic strip with the PTM1 + PTM2 pheromone concentrated in the inner layer. The two outer layers act to regulate the release of PTM pheromone and protect the pheromone from degradation by sun and weather. The concentration of the PTM1 + PTM2 pheromone per unit being tested is 2 mg, 1 mg and 2 mg pheromone + 40 mg permethrin. The latter apart from causing mating disruption would kill male PTM moths attracted to the dispensor due to the presence of an insecticide, Permethrin which is highly effective against adult PTM. Details of the Hercon dispensor are published by Kydonieus and Beroza (1977).

## Microencapsulation

The U.K. firm ICI in collaboration with research organizations, Centre for Overseas Pest Research (CORP) and Tropical Development Research Institute (TDRI) has developed microencapsulated pheromone formulations in which the pheromone is contained in minute polymerica capsules about 2 microns in diam for control of cotton pest (Campion & Nesbitt, 1981). Contacts have been now established to formulate a microencapsulated spray formulation with the PTM pheromone. This type of formulation is easily prepared on a large scale and is easily applied to the crop with conventional ground or aerial spray equipment.

## Conclusions and Recommendations

Main emphasis on use of pheromones in developing world must initially be on monitoring. In countries where insecticides are used heavily, experiments designed to reduce insecticidal application through monitoring and establishing relationships between trap catch and tuber damage may be useful.

Mass trapping and mating disruption trials need isolated large areas eg. Campion and Nesbitt (1981) have conducted studies utilising 150 ha of cotton in Egypt. Such an approach is often not possible, we are Investigating the feasibility of using small plots (200 $mt^2$) surrounded by thick rows of a non host plant (corn) to prevent interplot movement of mated females. The validity of this approach needs further research.

Mass trapping for PTM would be feasible in stores, in field farmer cooperation would be essential to do this on an area wide basis. The

use of disruptant sprays can only be considered if the cost of PTM1 + PTM2 pheromone could be reduced further. Chemists need to find alternative cheaper routes to synthesis this pheromone to make it a useful strategy to reduce dependence on conventional insect control agent.

## Sticky Traps to Control Leafminer fly, Lioriomyza huidobrensis

The leafminer fly, L. huidobrensis is a mojor pest of potatoes in Perú and Brazil. Field losses can be as high as 40%. The pest has developed high level of resistance to the conventional pesticides applied by farmers. As sex pheromones have not yet been synthesised for this pest, several trap designs to monitor and control have been tested. Initially for population monitoring, a yellow sticky trap (16 cm x 16 cm, 60 cm height) proved to be very effective. Similar traps (30 cm x 60 cm) were used in mass trapping. Results indicated that traps could capture as many as 16-18,000 adults in three days and leafminer fly population was significantly reduced in plots with traps in comparison to plots without traps (2.0 vs 9.0 leafminer flies/plant respectively). Yield in plots with traps was significantly ($P > 0.05$) higher compared to control plots. Later a light green colored sticky trap was designed to increase female fly capture at 60 cm height (Anon. 1984). At this height a total of 710 females/week were captured. These traps had a catch ratio of 1 female to 2.8 males (Table 4). Further research is now being conducted in farmer fields to evaluate farmer acceptance and use of this technology. The availability of a synthetic pheromone for this pest would greatly increase the applicability of this approach.

Table 4. Evaluation of different colored sticky traps to capture leafminer fly, La Molina, 1983

| Trap Color * | Height of traps (cms) | Total capture $\bar{x}$ /week | $\bar{x}$ No. of female | $\bar{x}$ No of male | Sex ratio female : male |
|---|---|---|---|---|---|
| Yellow | 60 | 1379 | 118 | 1261 | 1: 10.6 |
| | 30 | 919 | 68 | 852 | 1: 12.5 |
| Green | 60 | 1264 | 523 | 740 | 1: 1.4 |
| | 30 | 933 | 436 | 496 | 1: 1.1 |
| Light green | 60 | 2740 | 710 | 2031 | 1: 2.8 |
| | 30 | 2013 | 281 | 1731 | 1: 6.1 |
| | LSD P>0.05 | 490.06 | 131.54 | 459.18 | |

Color codes: yellow: Pantone 113 C
green : Pantone 358 C
light green: Pantone 375 U

Pantone Matching System, Boston Printing Ink, 160 East Second St., Mineola, NY 11501, USA.

# REFERENCES


Anonymous. 1984. Annual Report of the International Potato Center, Lima, Perú.

Anonymous. 1984. Annual Report of the International Potato Center, Lima, Perú (In Press).

Bacon, O. G., J. M. Seiber and G. Kennedy. 1976. Evaluation of survey trapping techniques for potato tuberworm with chemical baited traps. J. Econ. Entomol. 69: 569-572.

Campion, D. G. and B. F. Nesbitt. 1981. Lepidoteran sex pheromones and pest management in developing countries. Trop. Pest Management 27 (1) 53-61.

Campos L. S. M. 1983. Población de la polilla Phthormaea operculella Zeller en el cultivo de la papa en el valle de Huánuco. Ing. Agron. Tesis. Universidad Nacional de Huánuco, Huánuco, Perú.

Kydonieus A. F. and Beroza M. 1977. Insect Control with the multilayered luretape™ Dispensor. Controlled Release Pesticide Symposium, Oregon State University, U. S. A. pp 1-4.

Krambias A. 1979. The development of an integrated control program for potato tuber moth in Cyprus PH.D. Thesis, University of Reading, England, United Kingdom. 212 p.

Persoons, C. J., S. Voerman, P. E. J. Verwiel, F. J. R. Ritter, W. J. Nooijen and A. K. Minks. 1976. Sex pheromone of the tuberworm moth Phthorimaea operculella: isolation, identification and field evaluation. Entomol. Exp. Appl. 20: 289-300.

Roelofs, W. L., J. P. Kochansky and R. T. Cardé. 1975. Sex pheromone of the potato tuberworm moth, Phthorimaea operculella Life Sci. 17: 699-706.

Raman K. V. 1984. Field trials with the sex pheromone of the Potato Tuberworm Environ. Ent. 11 2 367-370.

Raman K. V. and Booth R. H. 1983a. Evaluation of technology for integrated control of Potato Tuber moth in field and storage. Technology Evaluation Series N° 10. International Potato Center, Lima, Perú, 18 pp.

Raman K. V., and R. M. Booth, 1983b. Integrated Control of Potato in rustic potato stores. Proceedings of sixth Symposium of Int. Soc. for Trop. Root Crops. International Potato Center, Lima, Perú (In Press).

Raman K. V., 1984. Evaluation of a synthetic sex pheromone funnel trap for potato tuberworm moths. (Lepidoptera: Gelechiidae) Environ. Ent. 13. 47-50.

Sanchez U. 1984. Evaluación de 8 formulaciones de Pheromona sintética de Polilla de la papa. Biol. Tesis. Universidad Ricardo Palma, Perú.

Voerman, S. and G. M. L. Rothschild. 1978. Synthesis of two components for the sex pheromone system of the potato tuberworm moth, Phthorimaea operculella (Zeller) (Lepidoptera).

Valencia L. 1981. An egg trap to monitor ovipositional activity of the potato moth Phtorimaea operculella (Zeller) (Lepidoptera: Gelechiidae).

J. Aust. Ent. Soc. 20 : 166

# PTM pheromone synthesis for developing countries

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The potato tuberworm moth, Phthorimaea operculella (Zeller) (Lepidoptera: Gelechiidae) can be regarded as a key pest of potato in several tropical and subtropical areas. It is also commonly observed attacking tomatoes. Great reliance is placed upon insecticide treatments for control of this pest. Adherence to a rigid treatment schedule undoubtedly results in unnecessary insecticide applications, undesirable from economical and environmental point of view. A monitoring system to determine the presence of economically important populations would likely reduce the amount of insecticides used unnecessarily in efforts to control this pest. Sufficient knowledge of the relation between the size of the population and the threshold of the damage to the crop has to be available to exploit the possibilities of such control system based on both sex attractants and insecticides. Sex attractants may also be used for mass trapping and/or orientation disruption of male moths.

The attraction of male potato tuberworm moths to virgin females indicates the presence of a sex pheromone. In 1975 Roelofs et al. (Life Sciences 17:699-706) succeeded in identifying one component of the pheromone system of this species. This compounds, trans-4,cis-7-tridecadien-1-ol acetate (also called PTM 1) (see Fig. 1) is rather attractive for males in the field. In the meantime a joint effort of The Institute for Pesticide Research at Wageningen and the Division of Technology for Society TNO at Delft, in The Netherlands, had independently led to conclusions similar to those of Roelofs et al. In addition these laboratories succeeded in isolating, identifying, and synthesizing the second component, the trans-4,cis-7,cis-10-tridecadien-1-ol acetate (also called PTM 2) (see Fig. 1) (Persoons et al., 1976, Entomol. exp. appl. 20:289-300). Field tests showed that combinations of PTM 1 and PTM 2 are very attractive (Voerman and Rothschild, 1978, J. Chem. Ecol. 4:531-542). So far an optimum ratio of the two components could not be discovered. The stability of both compounds, PTM 1 and PTM 2, is remarkable. Rubber sleeve stoppers, impregnated with 0.1 mg PTM 1 and 0.3 mg PTM 2 remained attractive more than 3 months even under hot weather conditions. In well closed containers they can be stored in refrigerator or freezer probably for years without loss of attractivity.

For devising syntheses of such complicated compounds like PTM 1 and PTM 2 it is good practice to start with dividing the molecules into smaller fragments. These fragments could be the building-stones or synthons for the wanted molecules, provided that they are easily avail-

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able and that techniques to couple them exist. In J. of Chem. Ecol. 4:531-542 I described methods to synthesize PTM 1 and PTM 2. Principally PTM 1 could be made from 3-bromopropanol-1, propargyl alcohol, and 1-heptyne. For PTM 2 the same compounds are needed, except 1-heptyne, for which 1,4-heptadiyne has to be substituted. Several steps must be done and, although the yield of each reaction lies between 53 and 78%, the overall yield is relatively low. The reactions can be done in normal laboratory glass work. Handling of liquid ammonia is not too difficult, because the heat of evaporation is rather high. The progress of a reaction can be followed by gaschromatographic analysis of samples, taken at regular intervals. In most cases it can easily be seen that the peak of the starting material disappears and that a new peak appears. The retention time of the latter can be more of less predicted, based on experience with similar reactions The distilled end products can be further purified by argentation chromatography.

Roelofs et al. start with 4-pentyn-1-ol (Jones et al. Org. Synth. Coll. Vol. 4:755-757) for making PTM 1. Their method of making PTM 1 is rather similar to ours and is described in detail in U.S. Patent 3,991,125 and U.S. Patent 4,014,942 of Nov. 9, 1976 and March 29, 1977 respectively. There is a Dutch patent on the synthesis of PTM 2. It is unlikely that patents have been applied for in all countries of interest. Furthermore it is questionable if patents have any value in countries without patent legislation.

J.B. Torres and M.A. Velasco of The Organic Chemistry Department, Facultad de Quimica, Unam, Mexico, propose to synthesize PTM 1 from 1-bromopentane, progargyl alcohol, and 4-pentyn-1-ol. They postpone the trans-reduction to the end. Probably this can be done by $LiAlH_4$ according to Rossi and Carpita (Synthesis 1977: 561-562) or according to Boeckman and Thomas (J. Am. Chem. Soc. 99:2805-2806 (1977)). For the preparation of PTM 2 they propose to reduce 2,5-octadiyn-1-ol with hydrogen and a catalyst and to couple the product with 4-pentyn-1-ol. Here too the trans-reduction has been postponed to the end, which is just the opposite of the other well investigated methods.

These syntheses are all based on acetylenic chemistry. Coupling of 4-pentyn-1-ol with ethylene oxide, reduction with $LiAlH_4$ of the product, replacing the hydroxyl group by a bromide atom, a triphenylphosphonium salt can be made which can be coupled with hexanal giving PTM 1. Using Z-3-hexen-1-al instead of hexanal PTM 2 could be obtained, provided the latter unsaturated aldehyde can be made. There is much literature about similar so called Wittig reactions.

Several routes were indicated to synthesize PTM 1 and PTM 2. The first mentioned lead to good products, the others are not yet fully investigated.

Mass trapping of male moths and/or orientation disruption with them are promising. The chemicals needed for these techniques are more or less easily available. Their applicability in the field and in stores should be investigated with all possible efforts.

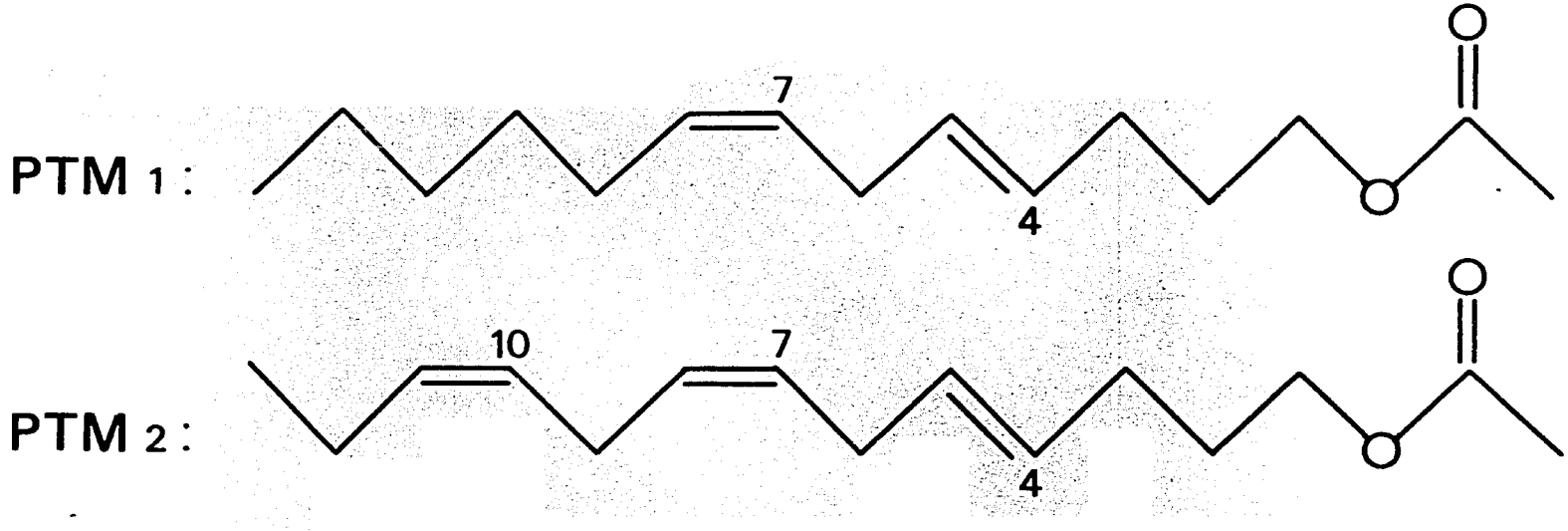


Fig. 1. Structural formulae of the 2 compounds of the pheromone system of the potato tuberworm moth. PTM 1: trans-4,cis-7-tridecadien-1-ol acetete,
PTM 2: trans-4,cis-7,cis-10-tridecatrien-1-ol acetate.

# THE SELECTIVE USE OF INSECTICIDES

Bruce L.Parker

In order to understand many of the implications of the selective use of insecticides, it is essential to first clearly define how chemical control fits into the total IPM program. During this planning conference we have considered the very broad aspects of IPM from its development for different environmental conditions, its need in developing countries to its place in a one crop center such as CIP. We have considered damage assessment, plant resistance, the natural enemy complex and the use of pheromones. Agricultural chemicals are an important component of the IPM system but by no means the major component. Each of the factors we have discussed interact within the system and must be viewed in total (Figure 1).

Chemical control in this sytem is one of the last defense mechanisms that we use. It must be compatible with each of the other controls and careful consideration should be given to assure an absolute minimum impact on the environment and natural enemy complex. For these basic reasons we should be selective in the materials used for control.

Before discussing why we need to be selective, we should first consider the immediate future of pesticide usage. If pesticide usage is to be relatively low or essentially eliminated, we need not worry about selectivity. On the contrary, agricultural chemicals are big business and the projected sales and production outlooks are for a continued increase in business (Anonymous 1977). Many believe that their availability and usage is the only way we will be able to meet the increased demands for more food (Ware 1983). From a practical viewpoint, pesticides will be used more and more in the future (Table 1). Therefore, selectivity becomes increasingly important.

Why do we need to be selective? There are many reasons but I will concentrate on the following:

A. Insecticide resistance
B. Effects on natural enemies
    1) Predators
    2) Parasitoids
C. Effects on other pests
D. Environmental impact

Insecticide resistance has chronologically increased in arthropods since the first records of about 1908. Georghiou (personal communication) reports that resistance to one or more chemicals has appeared in 428 species of arthropods, 50 species of plant pathogens,

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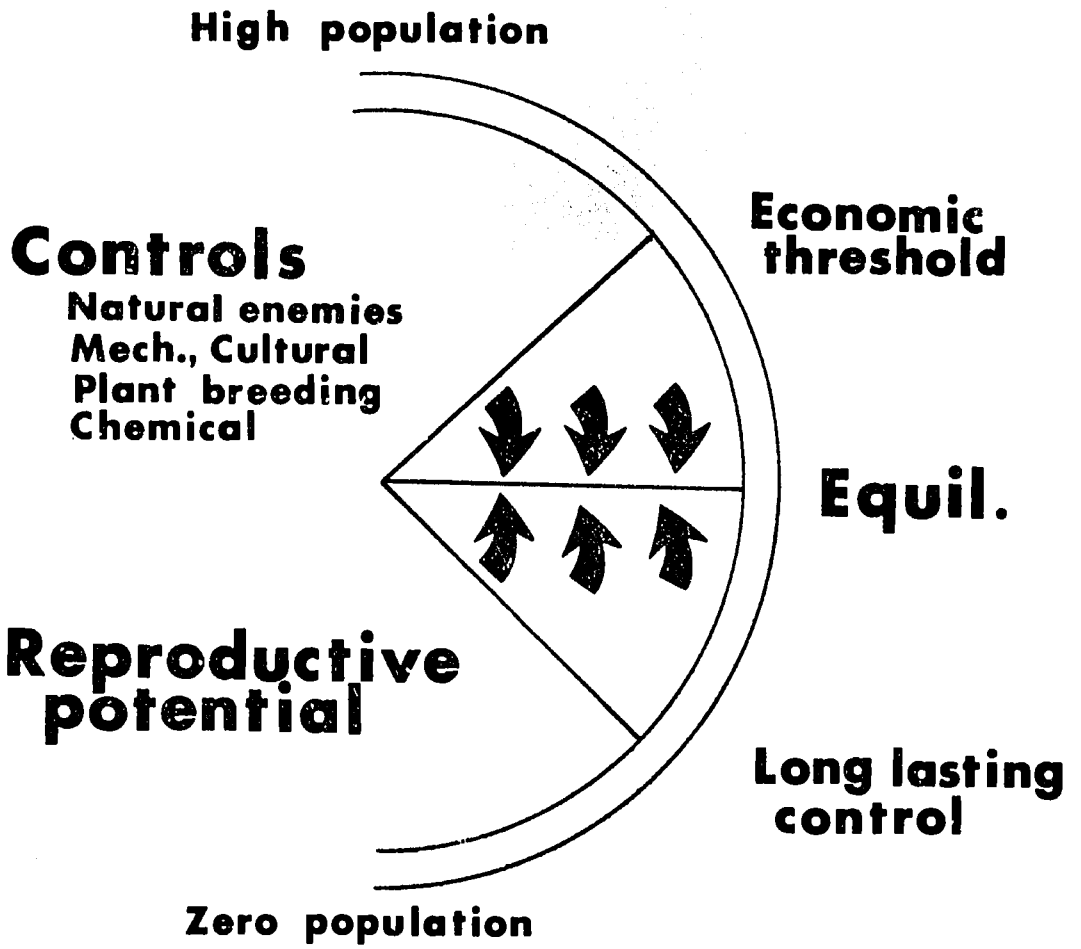


Figure 1. A simplified integrated system for the control of a single species.

Table 1. Distribution of farm crop pesticide purchases by areas of the world, 1974 and projected 1984[a]

| Area | Sales 1974 ($ million) | Sales distribution (%) 1974 | Sales distribution (%) Projected 1984 | Projected sales increase 1974 to 1984 (%) |
|---|---|---|---|---|
| Western Europe and British Isles | 1301 | 25 | 20 | 12 |
| Eastern Europe and U.S.S.R. | 527 | 10 | 9 | 31 |
| Middle East (Egypt, Syria, Greece, Turkey, Israel, Lebanon, Sudan) | 150 | 3 | 4 | 93 |
| Africa | 92 | 2 | 6 | 386 |
| Asia (Iran, Pakistan, Afghanistan, India) | 157 | 3 | 3 | 150 |
| Far East, including People's Republic of China | 480 | 9 | 12 | 95 |
| Australasia | 96 | 2 | 2 | 36 |
| Central and South America | 410 | 8 | 11 | 100 |
| North America | 1977 | 38 | 33 | 25 |
| All areas | 5138 | 100 | 100 | 46 |

[a]Assumes 1974 U.S. prices.

From Farm Chemicals, A Look at World Pesticide Markets, Meister Publishing, Willoughby, Ohio, 1977.

five species of weeds, and two species of nematodes. In addition, the reported cases of "multiresistance" have also increased (Georghiou 1980), and we now have at least 25 species that can resist the four major categories of insecticides (chlorinated hydrocarbons, cyclodienes, organophosphates, and carbamates) and ten species that can resist all 5 chemical classes (the above plus pyrethroids) (Table 2).

Table 2. Development of multiple resistance to insecticides

| Year | All Resistant Species | Stages of Multiresistance* I | II | III | IV | V |
|---|---|---|---|---|---|---|
| 1948 | 14 | 13 | 1 | 0 | -- | -- |
| 1955 | 25 | 4 | 18 | 3 | 0 | -- |
| 1969 | 224 | 155 | 42 | 23 | 4 | 0 |
| 1976 | 364 | 221 | 70 | 44 | 22 | 7 |
| 1980 | 432 | 249 | 95 | 53 | 25 | 10 |

* Species in stage I-IV can resist insecticides belonging to 1,2,3,4, and 5 chemical classes, respectively (DDT, cyclodienes, organophosphates, carbamates and pyrethroids).
From: Georghiou 1980.

Insecticide resistance is widespread geographically. One of the first reports of Myzus persicae, the green peach aphid (GPA), resistance to pyrethroids came from Australia (Georghiou 1980). The frequency of resistant genes in GPA populations is demonstrated by work in England where it was found that in 258 collections of aphid populations only 3 were not resistant to dimethoate (Sawicki et al. 1978).

There are three approaches to the management of resistance by insecticides (Georghiou 1980). These are:

A. Management by moderation
B. Management by saturation
C. Management by multiple attack

Each of these strategies requires the manager or the applicator to be selective in the insecticide used. For example, the basic theory of management by moderation is that we must maintain individuals with susceptible genes in the pest population. How do we accomplish this? From an operational standpoint we should select an insecticide that is relatively non-persistent. The formulation used should not increase

the stability or control the release rate, and the mode of action of the selected material should be different from the mode of action of the insecticide previously used. The application should not be made to extensive areas and, if possible, certain generations of the insect should be left unsprayed. If we can incorporate all or some of these factors when selecting the toxicant to use, we will help to delay or eliminate the resistance component.

An excellent presentation on countermeasures to take for the management of insecticide resistance by saturation and multiple attack was presented by Georghiou (1980) at an IPM workshop in Barbados, and I have placed a copy for your reference in the library. Integrated pest management, because of its non-reliance on agricultural chemicals, is probably one of the most important factors reducing selection pressure and ultimately insecticide resistance.

In selecting insecticides we should consider not only the pest species but also the natural enemy complex. Prey survival is critical and sufficient numbers of hosts, either the pest species or an alternate host, should remain in the system. This means that we must be willing to tolerate some damage to our crop. Most studies of pesticides selective for natural enemies have ignored the necessity for host survival.

In practice the insecticide should have high toxicity to the pest and low toxicity to the natural control organism. If we consider selectivity ratios, which compare the toxicity of an insecticide to a predator and a pest, we have an excellent example of the significance of choosing one material over another. An important predator of Empoasca fabae (Harris), the potato leafhopper, is Reduviolus americoferus (Carayon), a nabid. Work done by Martinez and Pienkowski (1983) indicated a selectivity ratio range of 22.19 for azinphosmethyl to 1.77 for methomyl. Compounds like methidathion and malathion had intermediate selectivity ratios of 9.78 and 6.61 respectively. In these cases a ratio >1.0 indicates insecticidal selectivity favoring the beneficial insect, the nabid predator. It should be stressed that this type of information is urgently needed to enhance IPM strategies, but the toxicant selected has to be tolerated by a rather large group of beneficial organisms. If we concentrate on generating data on just a few natural enemies, the total impact could well be negative because the system is complex and many species are normally involved.

Parasitoids, like predators, are an important component of the natural enemy complex. Phthorimaea operculella (Zeller), the potato tubermoth (PTM), is attacked by a large group of parasitoids. In California 13 major species have been documented as natural enemies

of the larvae (Oatman and Platner 1974). The degree of control will vary, but these investigators noted parasitization of larvae from spring and fall plantings peaked at approximately 90% and 71% respectively. Parasitoids are considered by some the most important factor suppressing PTM foliage feeding populations (Oatman and Platner 1974). Commercial applications of azinphosmethyl, methomyl, and methamidophos gave good control of foliar PTM populations, but parasitism was significantly reduced. In potato fields treated at the rate of either 1.1 kg of AI/ha methamidophos or 1.0 kg of AI/ha methomyl, parasitization was reduced from 50% prespray to 0% postspray (Shelton et al. 1981). To further complicate the parasitoid - pest relationship, a significant rapid resurgence of adult PTM populations followed scheduled applications of some materials. PTM larval resurgence was also recorded, but it took longer to occur. These population increases may be due to a combination of immigrating PTM gravid females and a relatively parasite-, predator-free population of the pest remaining in the field. Care must be taken to select materials having a minimal impact on the parasitoid complex.

The pest complex in a potato ecosystem, in addition to the natural enemy complex, must also be taken into consideration. Actions taken against one pest may influence population levels of another pest. In some areas of the world insecticide resistance has not been noted in potato leafhopper populations. This is because this insect does not overwinter in many locations and arrives anew each season (Cancelado and Radcliffe 1979). However, GPA populations which commonly occur with leafhopper populations are often resistant to many insecticides. Therefore, in selecting an insecticide for potato leafhopper control, it is imperative to get one that is also effective against GPA. If one is not selective, serious aphid outbreaks can be induced. This was demonstrated by Radcliffe (1972, 1973) when he showed certain phorate treatments resulted in 99% control of potato leafhopper but induced late-season outbreaks of GPA.

Non-selectivity can result in rather subtle environmental problems. In many cases these effects are not readily observable. Atrazine has been used worldwide for many years and is an efficient herbicide for use in maize. Little or no research has been done on the effects of sublethal dosages of this material on aquatic organisms (Parker et al. 1982). Field run-off does occur and in our laboratory we initiated a study to determine the effects of extremely low levels of this herbicide on fish growth. A significant reduction in the growth of Salvelinus fontinalis, as measured by weight gains, was readily seen (Figure 2). Further behavioral studies helped to explain why this happened (Figure 3). Fish in contaminated water did not feed as often as fish in clean water.

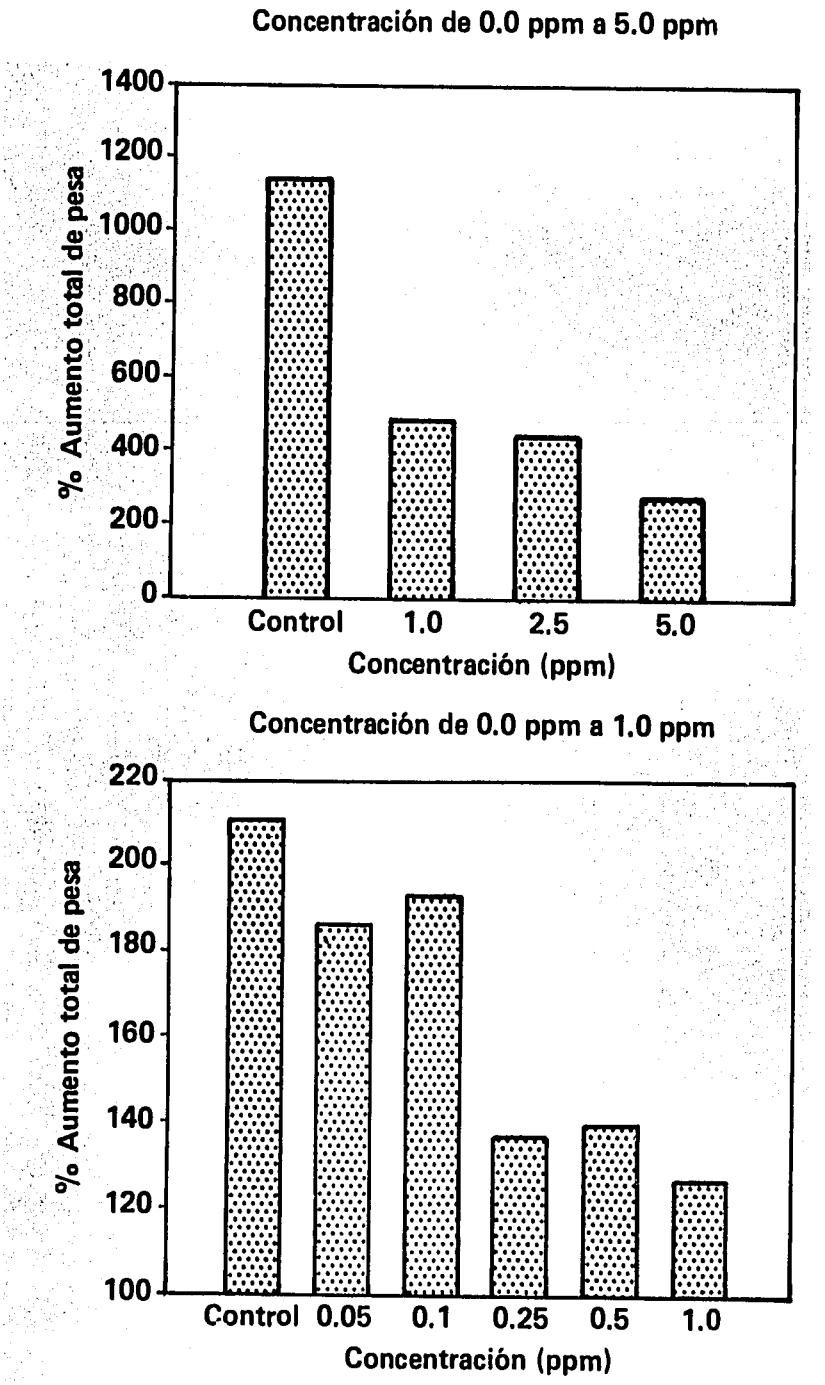


**Figure 2. The effect of atrazine on weight gain of *Salvelinus fontinalis*.**

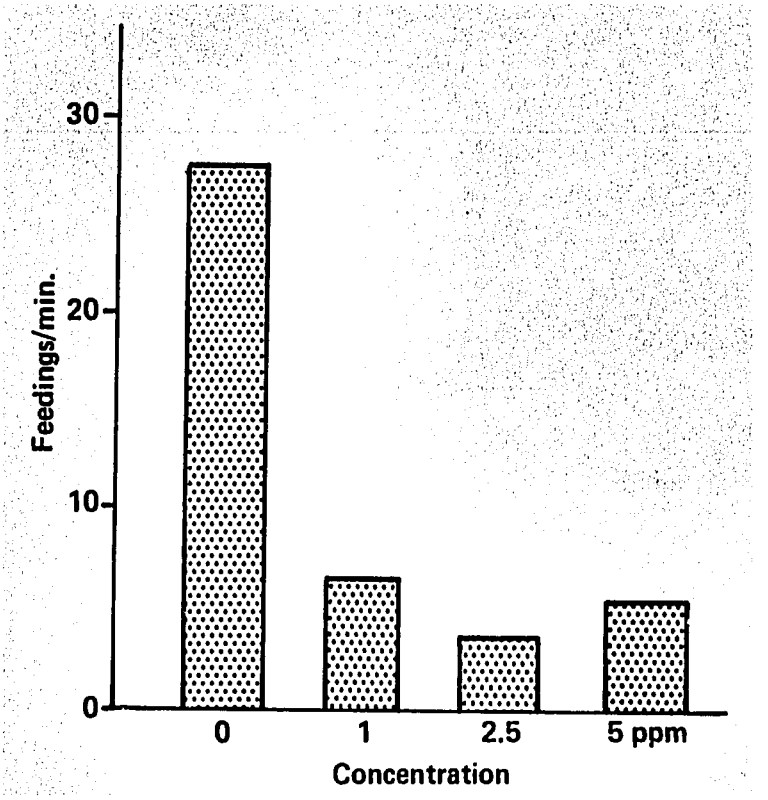


**Figure 3. The effect of atrazine on feeding frequency of *Salvelinus fontinalis*.**

My intention is not to place undue emphasis on aquatic studies, but to illustrate that pesticides do get into the environment, into our water systems, and these effects must be considered when selecting for chemical control.

Chemical control has never been a simple thing and, indeed, it is becoming more complicated. It is encouraging that some of the new toxicants and formulations are not broad spectrum materials, and they are effective only against certain species. These materials must also be used with caution. Bacillus thuringiensis (B.t.) is a microbial insecticide acting primarily against certain lepidopterous larvae with a high gut pH. It is not a new insecticide, but it could be classified as a selective type. Manufacturing capabilities have been improved and its cost is now becoming very competitive. Because of this many feel it will be used more in the future.

Another material, known as Alsystin, is of the biphenyl urea class of compounds and should obtain registration approval in the United States in 1985. This insecticide affects insect growth by inhibiting chitin synthesis. The result of its action is readily observable during the molting period of the insect. It has shown excellent efficacy by controlling heavy populations of organophosphate and carbamate resistant Colorado potato beetles. It also has potential use for the control of leafminers and PTM.

In conclusion, chemical control is certainly one of the important components of the IPM system. However, it has been demonstrated that the user needs to be selective in the material applied. The user must also be fully aware of the other components of the IPM system in order to make the proper selection. To facilitate this process, extension and research must play an active role. This role is strengthened by conferences of this nature and CIP personnel are to be commended for their efforts in this regard.

## REFERENCES CITED

Anonymous. 1977. Farm Chemicals, A Look at World Pesticide Markets, Meister Publishing, Willoughby, Ohio.

Cancelado, R. E. and E. B. Radcliffe. 1979. Action thresholds for potato leafhopper on potatoes in Minnesota. J. Econ. Entomol. 72: 566-9.

Georghiou, G. P. 1980. Implications of the development of resistance to pesticides: basic principles and consideration of countermeasures. Pest and pesticide management in the Caribbean. (ed.) Gooding, E. G. B. Consortium for Intn. Crop Protection and USAID. Proc. of Seminar and Workshop, Bridgetown, Barbados. 3 November 1980.

Martinez, D. G. and R. L. Pienkowski. 1983. Comparative toxicities of several insecticides to an insect predator, a nonpest prey species,and a pest prey species. J. Econ. Entomol. 76: 933-35.

Oatman, E. R. and G. R. Platner. 1974. Parasitization of the potato tuberworm in southern California. Environ. Entomol. 3: 262-264.

Parker, B. L., G. W. LaBar,and P. Stutz. 1982. Efectos cronicos de pesticidas sobre peces de agua dulce y la produccion de pescado en paises en desarrollo: Un repaso y bibliografia. Vt. Agr. Exp. Sta. RR 27. Burlington, VT. 1M-782-VP.

Radcliffe, E. B. 1972. Population responses of green peach aphid in Minnesota on potatoes treated with various insecticides. Proc. N. Cent. Branch Entomol. Soc. Am. 27:103-5.

Radcliffe, E. B. 1973. Population responses of green peach aphid on potatoes to treatment with various insecticides. Proc. N. Cent. Branch Entomol. Soc. Am. 28:100-2.

Sawicki, R. M., A. L. Devonshire, A. D. Rice, G. D. Moores, S. M. Petzing, and A. Cameron. 1978. The detection and distribution of organophosphorous and carbamate insecticide-resistant Myzus persicae Sulz. in Britain in 1976. Pestic. Sci. 9:189.

Shelton, A. M., J. A. Wyman and A. J. Mayor. 1981. Effects of commonly used insecticides on the potato tuberworm and its associated parasites and predators in potatoes. J. Econ. Entomol. 74:303-8.

Ware, G. W. 1983. Pesticides: Theory and application. W. H. Freeman and Company, San Francisco, California. 308 pp.

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Dr. María Scurrah

Dr. Luis Valencia

PLANNING CONFERENCE

on

INTEGRATED PEST MANAGEMEN

# A G E N D A

Monday, June 4

Chairman, O.T. Page

| | |
|---|---|
| 09:00 | Welcoming and opening remarks.<br>R.L. Sawyer<br>Director General |
| 09:30 | Development of IPM programs for different environmental conditions in developing countries.<br>T.R. Odhiambo |
| 10:00 | The need for Integrated Pest Management in developing countries.<br>F. Cisneros |
| 10:30 | Coffee |
| 11:00 | Discussion - The place of Integrated Pest Management in a one crop center. |
| 12:00 | Lunch |

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Monday afternoon

## ENVIRONMENTAL MANAGEMENT

Chairman, K.J. Brown

| | |
|---|---|
| 13:30 | Assessment of insect damage.<br>M. Kogan |
| 14:00 | The role of cropping systems in potato insect control.<br>S. Raymundo |
| 14:30 | Management of potato insects in stores.<br>R. Booth |
| 15:00 | Coffee |
| 15:30 | Discussion - The role of insect management in stores and use of cropping systems. |

Tuesday, June 5

## PLANT RESISTANCE

Chairman, H. Mendoza

| | |
|---|---|
| 08:30 | Utilization of host plant resistance in IPM.<br>F. Maxwell |
| 09:00 | Breeding and screening for resistance to major potato pests.<br>M. Scurrah |

09:30 Progress in research on glandular trichomes and TGA for insect resistance in potatoes.
W. Tingey

10:00 Coffee

10:30 Progress in utilization of aphid resistance.
E. Radcliffe

11:00 Mechanisms of resistance to tuber moth oviposition on foliage.
L. Valencia

11:30 Discussion - How should plant resistance be used in an integrated approach to insect control?

12:30 Lunch

Tuesday afternoon

## BIOLOGICAL CONTROL

Chairman, P. Jatala

14:00 Biological control in IPM.
F. Bennett

14:30 Progress in biological control of pests at CIP
K.V. Raman

15:00 Coffee

15:30 Discussion - The use of components of biological control in a developing country context.

Wednesday, June 6

## BEHAVIORAL CONTROL

Chairman, F. Cisneros

| | |
|---|---|
| 09:00 | Pheromone use in developing countries and new developments in pest control.<br>D.R. Hall |
| 09:30 | Progress in pheromone utilization and other novel control practices at CIP.<br>K.V. Raman |
| 10:00 | PTM pheromone synthesis for developing countries.<br>S. Voerman |
| 10:30 | Coffee |
| 11:00 | Discussion - The use of behavioral control techniques under developing country conditions. |
| 12:00 | Lunch |

Wednesday afternoon

## INSECTICIDE MANAGEMENT

Chairman, P. Accatino

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|---|---|
| 14:00 | Selective use of insecticides.<br>B. Parker |
| 14:30 | Coffee |
| 15:00 | Discussion - The role of chemical control in Integrated Pest Management. |

Thursday, June 7

A small committee will formulate recommendations arising from presentations and discussions during the first three days of the Conference.

Participants not involved in formulating recommendations will be free to visit with CIP staff. If flying conditions permit, a flight to Huancayo may be arranged.

Friday, June 8

09:00 Final discussion and approval of recommendations.

All participants.

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