Proceedings
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protection workshop

CIAT, Cali, Colombia,
7 - 12 November, 1977

Editors: Trudy Brekelbaum
Anthony Bellotti
J. Carlos Lozano

Centro Internacional de Agricultura Tropical

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7

Contents

5 Foreword
7 Participants

Joint sessions

9 Physiological bases of yield loss in cassava due to pests **J.H. Cock**
17 General considerations on cassava pathology **J.C. Lozano**
29 An overview of cassava entomology **A. Bellotti**
41 African mosaic disease in Kenya **K.R. Bock and E. J. Guthrie**
45 Inheritance of linked resistances to African cassava mosaic and bacterial blight diseases **D.L. Jennings**
51 Whiteflies: biology and transmission of African mosaic disease **K. Leuschner**
59 Nematode problems on cassava **D.W. Dickson**
65 Weeds: an economic problem in cassava **J.D. Doll**
71 Caicedonia: an improved cassava-growing area with integrated control **J.C. Toro and S. García**

Pathology sessions

75 Cassava bacterial diseases **E. B. Terry**
85 American virus and mycoplasma diseases of cassava **G. Martínez**
95 Superelongation: a *Sphaceloma* disease of cassava **J.P. Krausz, H. D. Thurston and J.C. Lozano**
101 The Cercosporn leaf diseases of cassava **J.M. Teri, H. D. Thurston and J.C. Lozano**
117 Concentric-ring leaf spot *(Phoma* sp.) of cassava **L.S. Leu**
121 A review of root rot diseases in cassava **R.H. Booth**
135 New developments in cassava storage **J.C. Lozano, J.H. Cock and J. Castaño**

Entomology sessions

143 The cassava mite complex: taxonomy and identification **C.H.W. Flechtmann**
155 *Mononychellus tanajoa* (Bondar): biology, ecology and economic importance **Z.M. Nyiira**
161 Field evaluation of cassava cultivars for resistance to tetranychid mites **E. Doreste, C. Arias and A. Bellotti**
165 Biological control of the cassava mite *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae) in Africa **D.J. Girling, F.D. Bennett and M. Yaseen**
171 The biology and ecology of the tetranychid mite complex in cassava in perspective **J.C. Rodríguez**

177 Thrips on cassava: economic importance, mechanisms and sources of resistance **A. van Schoonhoven**

181 Biological control of the mealybug *(Phenacoccus manihoti)* Matile-Ferrero): prospects and necessity **F.D. Bennett** and **D.J. Greathead**

195 Preliminary observations of the mealybug (Hemiptera: Pseudococcidae) in Zaire **K. Leuschner** and **K. Nwanze**

199 The white scale *(Aonidomytilus albus* Ckll.) on cassava **O. Vargas**

203 Studies on the cassava fruit fly, *Anastrepha* spp. **A. Bellotti** and **J. Peña**

209 Biology and economic importance of a cassava shoot fly, *Neosilba perezi* Romero and Ruppel **V.H. Waddill**

215 Cassava production and vegetative growth related to control duration of shoot flies and fruit flies **J.L. Saunders**

221 Grasshoppers (*Zonocerus* spp.) on cassava in Africa **G.A. Schaefers**

227 Biology, ecology and biological control of the cassava hornworm *(Erinnyis ello)* **A. Bellotti** and **B. Arias**

233 Miscellaneous pests of cassava **A. Bellotti** and **A. van Schoonhoven**

239 Summary conclusions and recommendations **H.D. Thurston, Rapporteur**

Foreword

Cassava is one of the world's most important food crops, especially in the tropics where it has been estimated to be a staple for more than 300 million people. FAO data indicate that annual world production of cassava is exceeded only by six other crops. Cassava is essentially an energy source; and its extremely high efficiency for calorie production over a wide range of ecological conditions, particularly on poor soils, and with few inputs emphasizes its importance for low-income populations. Cassava can also be stored in the ground for up to three years, serving as starvation insurance for the small farmer when other crops fail.

Only recently has concentrated research on cassava production begun. It was commonly believed that cassava was a rustic crop, generally free from pest damage; however, recent studies at CIAT and other institutions have shown that insects and diseases can reduce yields significantly. Information on cassava insects and diseases is very limited; even more striking is the small number of scientists actively engaged in cassava research and the lack of trained personnel in cassava pest management. In Indonesia, for example, there is no crop protection specialist working specifically on cassava although the country produces more than 10 million tons of cassava a year.

Under farm conditions, cassava yields average only 5-10 t/ha, whereas under experimental conditions yields as high as 60 tons have been obtained and commercial farm yields in Colombia have reached 40 t/ha. Among factors limiting yields under farm conditions are diseases and insects. Recent studies show that yield losses due to mites can reach 40-50%, thrips 25%, cassava bacterial blight 10-90%, superelongation disease up to 80%, and frog skin disease up to 90%. At present many of these pests are confined to certain geographical regions of the world and are not widely distributed. However, since cassava is vegetatively propagated and there is a continuous interchange of planting material, there is a great risk of disseminating these agents. Until a few years ago, the green mite *Mononychellus tanajoa* was found only in the Americas. It has now been introduced into many areas of Africa, where, because of the absence of natural enemies, it has become a serious pest, causing estimated yield reductions of 40 percent in Uganda. African cassava mosaic, originally found in tropical Africa and the surrounding islands and India, can cause yield losses as high as 80 percent. It is important that this disease not reach the Americas or Asia, where its vector the whitefly exists and could rapidly disseminate the disease. Bacterial blight was originally found in the Americas but was inadvertently introduced into Africa, where it is causing serious losses.

The Cassava Protection Workshop comes at a crucial time in the development of cassava. There is presently a great increase in acreage planted to cassava and the existent pest/crop equilibrium is being changed by modern technology and the introduction of new material. Since cassava is grown mainly by small farmers and is a low-value product, the use of costly pesticides is prohibitive and often not easily adapted to mixed farming systems. An effective pest management system based on control methods such as host plant resistance, biological control, cultural and phytosanitary practices should be developed.

This workshop was planned to act as a catalyst for the initiation of a large-scale cassava pest management system. Scientists working with cassava pest problems in different parts of the world, as well as scientists from developed countries, representing the best available expertise on the formulation of integrated pest management systems, attended.

The objectives of the workshop were to (1) describe the biology, ecology and geographical distribution of cassava pests, (2) estimate both present and future yield losses caused by each of these pests, (3) describe present control practices for each pest and formulate strategies for developing an integrated control system, (4) discuss possible pest problems that may arise as more cassava production moves into monoculture with high-yielding varieties, and (5) define areas where more research is needed.

A total of 31 papers were presented on current knowledge of all aspects of cassava pests and their control, physiological bases of yield losses due to pests, and new developments in storage of fresh roots. The conclusions and recommendations reached in the final discussions were summarized and presented by the rapporteur of the workshop, in collaboration with the moderators of the individual group discussions.

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A physiological basis of yield loss in cassava due to pests

James H. Cock*

Abstract

Although mites, insects and diseases can cause heavy yield losses, cassava is more tolerant to pests than other crops because it does not have critical periods that affect yield-forming organs. The components of the cassava plant that determine yield are the storage roots, apices, leaves, stems and petioles. The ways in which pests affect these components and thus influence yield are discussed. The optimum Leaf Area Index (LAI) for root growth is approx. 3; above this level yield decreases markedly. The results are presented of a series of simulated experiments conducted in order to determine (1) the effect of partial or total defoliation on the yield of leafy and nonleafy varieties, (2) the effect of shortened leaf life caused by the attack of *Cercospora* spp., (3) the reduction of the photosynthetic rate due to mites and African mosaic, and (4) leaf damage caused by thrips. When damage to the main apex is not continuous and the other apices that become active are not destroyed, there is no reduction in yield and, in fact, yield may increase substantially in leafy varieties. Damage caused by bacterial blight, *Anastrepha* spp., *Erwinia* sp. and *Phoma* sp. always reduces yield. When varieties characterized by a flat-topped density response curve are planted, death of plants at an early age produces only minimal yield reduction if the percentage of population reduction is less than 50% and the initial plant population is high.

Diseases and pests cause severe yield losses in cassava; the extent of loss caused by single diseases may be as high as 90%, or there may even be total crop failure (9), whilst insect pests can cause losses of more than 50% (2). When one considers the enormous array of diseases and pests that attack cassava (2, 9), it becomes evident that the combined effects of these many pests may seriously reduce yields in the field. Nevertheless, cassava may be more tolerant of disease and pest attacks than many other crops because of a lack of critical periods in yield formation. After establishment, growth can be completely stopped at almost any time without destroying the yield-forming organs; this is not generally true of reproductive crops when, for example, stress during flower initiation can cause complete crop failure.

In order to develop an integrated pest management system, it is important to know how much damage a plant can suffer before yield is reduced, when damage causes greatest yield reduction, and what types of damage cause most serious losses. In this paper I have tried to present, wherever possible, quantitative data on losses.

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The components of the cassava plant that determine yield are (a) the apices which determine potential leaf and stem growth, (b) the leaves which produce photosynthates and hence are the source of carbohydrates for root filling, (c) the stems and petioles which act as support for the leaves and as the transport system of carbohydrates to the roots and nutrients to the leaves, and (d) the storage roots which form the basic yield unit and also absorb nutrients and water.

In this paper I will discuss how diseases and pests could affect these basic components and thus influence yield. Field-simulated data refer to modification of the plant in the field; for example, leaf or root clipping and computer-simulated data are obtained using a cassava growth model.

Roots

Yield depends on the number of thickened roots and their size. These two components are related in such a way that when thick root number is decreased, individual root weight increases (3). This compensation is sufficient to keep total yield stable when root number is between 9-12 at plant populations of 1 m^2 (6). When root number is reduced below about 9 roots per plant, yield drops markedly as the roots that remain cannot compensate for the missing ones (Fig. 1). When thick root number is reduced early (1 1/2 mo after planting), the plant compensates by thickening other roots (Fig. 2), and this compensation is greater than that which occurs when root number is reduced later (3 mo after planting). These data suggest that reduction in root number to 9 does not reduce yields; furthermore, if reduction occurs early in the growth cycle the plant compensates for even greater reduction by thickening other roots.

Damage to roots in the field is caused by such pests as small rodents and grubs and by diseases like *Phytophthora* spp.. Severe reductions in thick root number (i.e., to less than 9) will reduce yield and reduction will be greater when the attack occurs later in the growth cycle. The plant does, however, have some plasticity and early damage to two or three roots per plant in a variety that has a high root number will probably have little or no effect on yield. Later damage that causes root rots or destruction of thickened roots will obviously reduce yield.

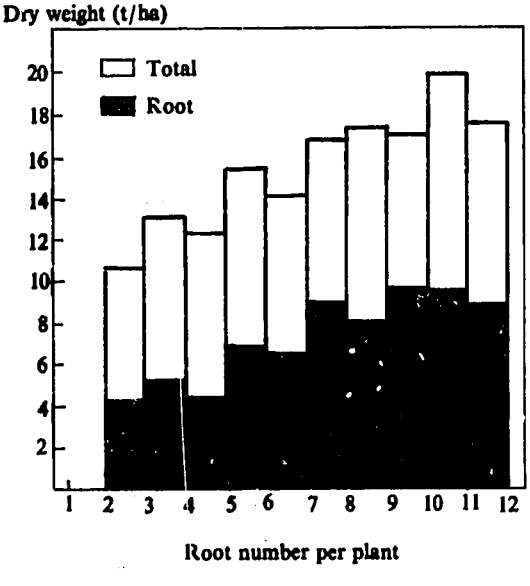

Figure 1. Total and root dry weight as related to root number per plant. Means of all plots that fall in each range are presented. Root number was artificially reduced by cutting at 6 or12 weeks (Var. CMC 84, harvested at 8 1/2 months)

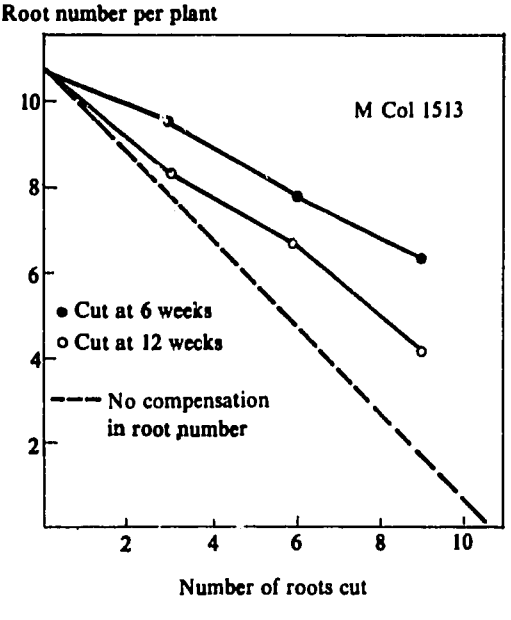

Figure 2. Effect of cutting thickened roots on final root number.

Leaves

As can be seen in Figure 3, cassava has a marked optimum Leaf Area Index (LAI) for root growth; this optimum occurs at approximately three, above which root yield decreases markedly (4-6, 8). Presently cultivated varieties only approach this optimum LAI for rather short periods (Fig. 4). The vigorous M Col 113 in trials at CIAT exceeded the optimum LAI from 4-9 months, was close to the optimum at 9-12 months, but thereafter had a suboptimal LAI. On the other hand, M Mex 11 approached the optimum at 4 months, but from then on was suboptimal.

Insects such as the hornworm *Erinnyis ello* consume leaves and reduce LAI. Hornworm attacks may be either sporadic and devastating, causing severe defoliation, or continuous at low levels of infestation. These two types of attack were simulated in the field by removing 50 percent of the leaves of a leafy and nonleafy variety at one time (Treatment 1) or over a period of time, removing every other leaf as it formed to represent a continued attack (Treatment 2).

In the leafy variety M Col 113, Treatment 2 had no effect on final yield from 100-200 days (Fig. 5).

During this period the controls had LAIs greater than the optimum whilst treated plants had suboptimal LAIs. At other stages yields were reduced, as even the controls had suboptimal LAIs. Similarly, nonleafy M Col 22 always had suboptimal LAIs so continuous leaf removal always

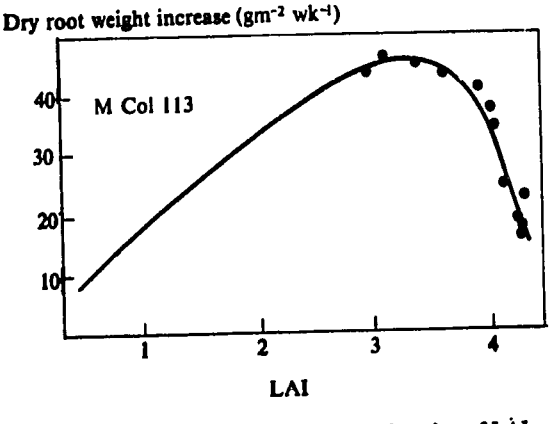

Figure 3. Root weight increase as a function of LAI.

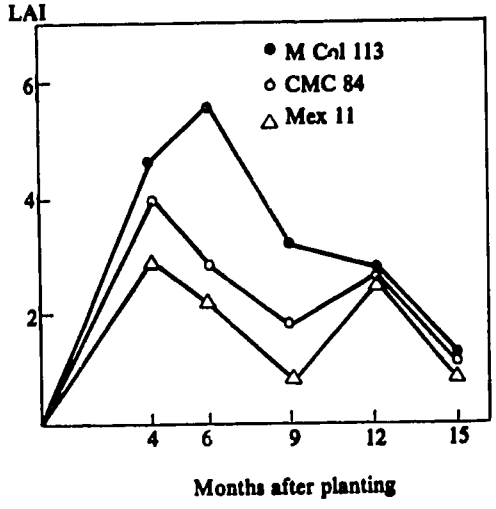

Figure 4. Development of Leaf Area Index in three varieties.

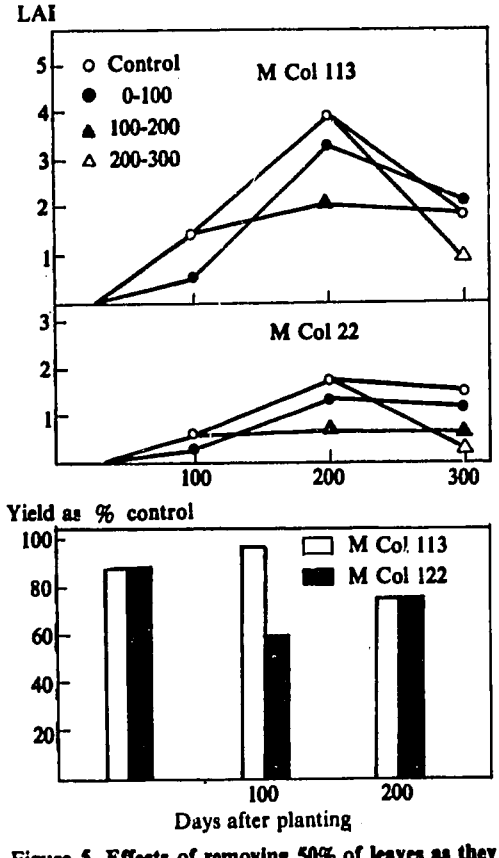

Figure 5. Effects of removing 50% of leaves as they form at different growth stages on yield and leaf area index.

reduced yield. Therefore, continued attacks of diseases or pests that reduce leaf number will reduce yields in nonleafy varieties but will have little effect on yield of leafy varieties during the growth stage when LAI is excessive.

In treatment 1 yield was not reduced when the attack occurred at 50 days (Table 1), suggesting that very early defoliation does not reduce yields. In nonleafy M Col 22, 50% defoliation at 50, 100 and 200 days reduced yields markedly. In M Col 113 defoliation at 200 days when LAI was excessive had little effect on yield. These results suggest that partial defoliation causes severe yield reduction in nonleafy varieties but only minor reductions in yield of leafy types at the time when they have large LAIs.

A growth simulation model (6) was modified to simulate complete defoliation effects on cassava growth. After complete defoliation, root growth ceases and LAI increases rapidly to a level similar to the control (Fig. 6). Thereafter, root growth increases as if there had been no attack. The simulated yield reductions depend on varietal characteristics but in most cases are quite small (Table 2), suggesting that complete defoliation at any time during the growth cycle will reduce yield by about 20%. It should, however, be noted that in the simulated plant types with high yield potential, the reductions are more severe. As plant improvement programs move nearer to these ideal plant types, the importance of controlling pests and diseases that reduce leaf area will increase.

Thus far we have discussed damage due to defoliation; however, diseases and pests can affect leaves in other ways. *Cercospora* spp. attack

Table 1. **Effects of defoliation (50%) at different times on yield of a leafy (M Col 113) and nonleafy (M Col 22) cassava variety.**

Time of defoliation	M Col 113*	M Col 22*
50 days	110	101
100 days	84	85
200 days	92	89
50. 100, 200 days	93	78

* Harvest data (10 mo) presented as percentage of control dry root yield

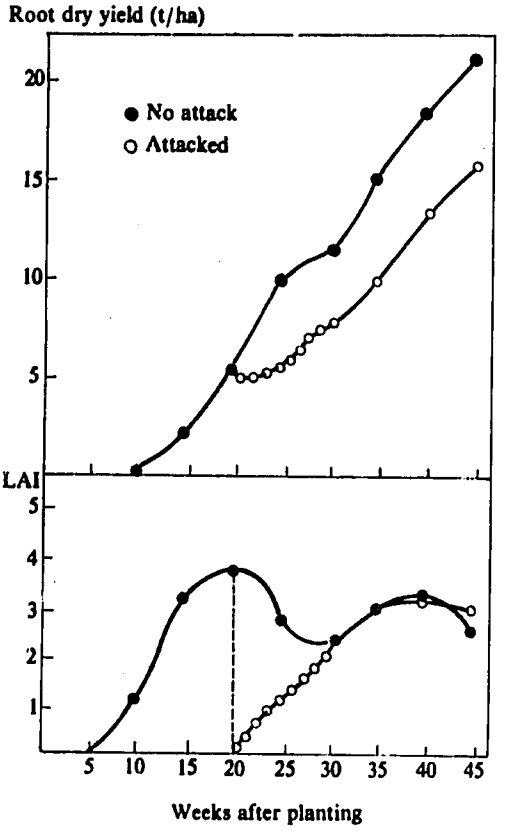

Figure 6. **Effect of hornworm attack causing complete defoliation at 20 weeks (computer-simulated data).**

cassava, producing toxins that cause yellowing, leaf spots and premature leaf fall. The effects of reduced leaf life on yield were simulated, and yield was reduced markedly when leaf life was shortened (Fig. 7). Lozano and Castaño (5) showed that healthy leaves had lives of 85 days whereas *Cercospora*- infected leaves had lives of 68 days; furthermore, yield increased by 14% in protected plots. Cock (6) suggested that one of the major breeding objectives in cassava should be to increase leaf life to levels greater than 100 days. If this becomes a reality, then losses due to premature leaf fall will be greater (Fig. 7).

Leaves with heavy mite infestations will often remain on the plant for long periods of time. Recent data obtained at CIAT (Cock and Mejia, unpublished data) show that although leaf number is not drastically reduced due to premature leaf fall, the mites severely reduce the photosynthetic rate of the individual leaves (Fig. 8). Similarly

Table 2. Effects of simulated hornworm attacks at different growth stages on a nearly ideal cassava plant and leafy type

Time of hornworm attack (weeks after germination)	Near ideal type* (% of control)	Leafy type* (% of control)
No attack	21.0 (100)	7.7 (100)
5	22.5 (107)	8.9 (116)
10	18.8 (90)	6.3 (82)
15	16.1 (77)	6.2 (81)
20	15.9 (76)	5.4 (70)
25	16.8 (80)	4.6 (60)
30	18.0 (90)	5.6 (73)
35	16.4 (82)	5.8 (75)
40	17.6 (84)	5.5 (71)

* Dry root yield (t/ha) at 11 mo

Alagianagalingam and Ramakrishnan (1) demonstrated severely reduce photosynthetic rates in cassava leaves infected with African mosaic. The reduced rates of photosynthesis in mite-infested leaves were present at all light intensities, and it must be assumed that these levels of attack will greatly reduce crop growth rate. Simulations showed that only a 10 percent reduction in crop growth rate decreases yield by more than 20 percent; hence the tremendous decrease in photosynthetic rate caused by mites has a potentially enormous negative effect on yields.

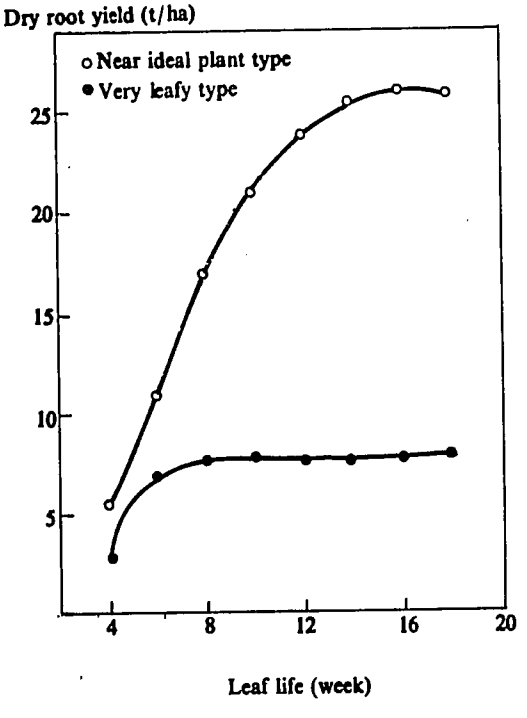

Figure 7. The effects of changed leaf life throughout the growing season on yield of a nearly ideal and very leafy plant type (computer-simulated data).

Certain pests (i.e., thrips) neither cause leaf fall nor greatly decrease photosynthesis; however, they do cause leaf distortion and reduced leaf size. Schoonhoven (4) showed yield losses of 25 percent due to thrips attack. Thrips cause leaf distortion and reduce leaf size. When the effects of leaf size on yield were determined by the simulation model,

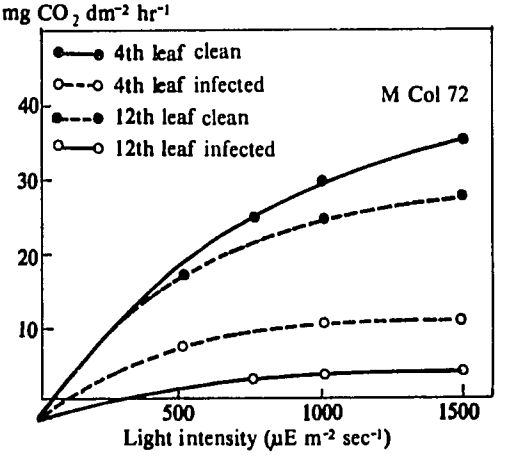

Figure 8. Effect of heavy mite infestations on photosynthetic rate.

it was found that yields could be severely reduced (Fig. 9); however, small reductions in leaf size (600 cm^2 maximum to 400 cm^2 maximum) in near ideal types cause small yield reductions. Hence the plant can tolerate low levels of this type of attack with virtually no loss, and in the case of leafy types, a reduction in leaf size may actually increase yields.

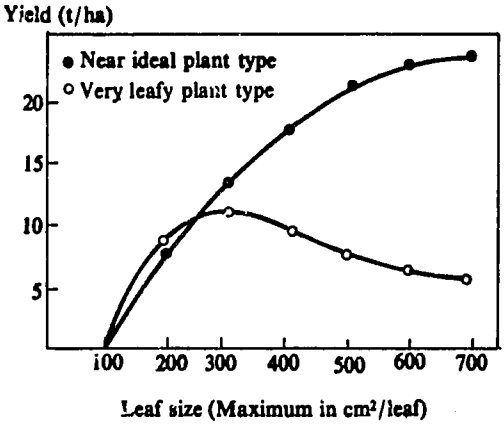

Figure 9. Effect of leaf size maximum on yield of a near ideal and a very leafy cassava variety (computer-simulated data).

Apices

In the initial stages of growth, cassava has a single active main apex. As growth continues, lower axilliary buds may develop into sucker branches; or two, three or more equally sized branches develop from the axilliary buds directly below the main apex.

When apices are damaged by insects such as the shoot fly *(Silba pendula)* and thrips, apical dominance is also destroyed and axilliary buds develop. Except in very severe attacks, one of these axilliary apices becomes dominant and plant growth continues as before. Removal of apices from 6 to 8 months at two-week intervals in M Mex 11 reduced yield of dry roots by less than 10 percent; removal of up to 75 percent of the apices in the very leafy variety M Col 113 increased yields substantially (Table 3). Thus damage to the main apex, if not continuous and attacking all new apices that become active, has little effect on yield and may even increase it in leafy varieties. In fact in Costa Rica higher yields were reported from plots infested with *Silba pendula.* Furthermore, model simulation data suggest that reduction in active apex number, especially from six months after planting, has little effect on yield even in the nearly ideal plant types predicted by the model.

Stems

The cassava stem acts as an active transport system of water and organic material and also as a support system for the foliage. Cassava bacterial blight blocks xylem transport (10), causing wilting of the leaves, which later die and fall. It is self-evident that this type of damage causes yield loss.

Anastrepha spp., in conjunction with *Erwinia* rots, weaken stems so that they are unable to fulfill their supporting role. Stems often double under

Table 3. Effects of reduction of apex number 5 months after planting on growth of M Col 113, harvested at 10 months.

Apex no. reduction (%)	Fresh root yield (t/ha)	Dry root yield (t/ha)	Dry stem wt (t/ha)	Harvest index (%)
0	33.6	11.3	12.5	44
25	38.5	13.3	12.7	47
50	39.7	13.6	12.0	49
75	40.3	14.0	11.8	49
Significant differences	**	**	NS	**

their own weight and the leaves above the break die. Obviously, yields are reduced. The same happens when *Phoma* spp. attack susceptible cultivars.

Loss of plants

In certain cases heavy disease or pest infestations may cause complete loss or death of plants. In the germination phase many fungi (9; Lozano, personal communication) and a large number of insects such as cutworms (2; Bellotti, personal communication) may reduce germination. In addition to reducing plant populations, this results in a plant arrangement that is not square. Cock et al. (6) showed that certain varieties had a flat-topped density response curve between 10 and 30 thousand plants per hectare (Fig. 10). If these varieties are used, yield reduction due to reduced plant population, when population reduction is about 50%, should be minimal if high plant populations are planted. Furthermore, recent work (Castro, unpublished data) shows that changing from square planting to a rectangularity of 1:2 has little or no effect on yield. In other works, if high initial populations are used with varieties that have flat-topped density response curves, early plant death will cause only small yield losses if there is less than 50 percent mortality. If death occurs later in the plant growth cycle, the yield already formed will be lost due to root rots and thus final yield will be reduced.

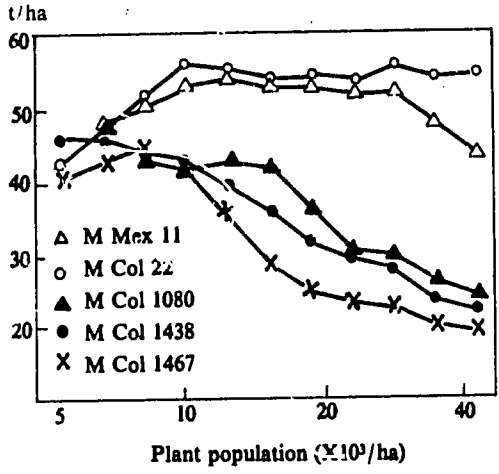

Figure 10. **Fresh root yields of five cassava cultivars harvested at 11 months.**

Conclusions

Both field data and computer simulation confirm that cassava is relatively tolerant to disease and pest attacks because of abundant chances for yield recovery after damage. Relatively minor yield losses result from (a) early plant death on a moderate scale, (b) reduction in active apex number, (c) small decreases in root number, and (d) small reduction in leaf size. On the other hand, yields are severely reduced when (a) leaf life is reduced, (b) photosynthetic rate is reduced, (c) stems are severely damaged, and (d) there is a high percentage of early plant death.

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General considerations on cassava pathology

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Abstract

The increase in the area planted to cassava has increased the pathological and entomological problems of this crop. Emphasis is placed on the little research that has been undertaken in the field of cassava pathology, as well as the lead that the international centers have now taken in this respect. At the national level, special programs have already been established in Brazil, Mexico, Thailand, the Philippines, Malaysia and India. At present, more than 30 diseases of cassava induced by viruses, mycoplasmas, viruslike causal agents, bacteria and fungi have been reported. The principal characteristics of the causal agents are summarized in table form. The special characteristics of cassava that should be taken into consideration by plant protection specialists when designing research programs are discussed. The following methods of control are recommended: (1) establishment of quarantine regulations for imported planting material and formation of centers to produce certified cassava seed; (2) cultural control methods —host eradication, crop rotation, sanitary measures, improvement of growing conditions, preventive measures against high soil moisture and the use of tissue culture techniques to produce AMV- and CBB-free plants; (3) biological control; (4) physical control methods—microwave, ultraviolet and heat treatments; and (5) chemical control. The major problems that may be encountered by plant pathologists during the screening and evaluation of varieties are discussed briefly.

Introduction

Cassava (*Manihot esculenta* Crantz) is a long-season, tropical perennial, which has been grown traditionally with limited inputs on unfertile soils by people from the lower income strata (22).

Cassava has been considered to be a hardy crop, resistant to both diseases and insects; nevertheless, it is now known that there are devastating diseases and insects that can induce heavy losses of more than 50 percent (2-3, 9-12) or even cause complete crop failure in certain areas (9,38). The world average yield of cassava is only 10 t/ha. (22-23, 51). In experimental research stations, 40 t/ha have

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been obtained with relative facility (10-12); and simply by using disease-free planting material and inexpensive cultural practices, more than 20 t/ha have been reached with traditional varieties in regions where yields are no higher than 4 to 7 t/ha (12, 45).

As a result of the shortage of carbohydrates for both human and animal consumption, as well as the many industrial applications of cassava (51), the cultivation of this crop is being expanded continually. This increase in area planted to cassava has obviously led to an increase in pathological and entomological problems.

Research in the field of cassava pathology has been especially limited. Of a total of around 4500 articles on cassava, only 300 deal with cassava pathology, approximately 40 percent of which were written during the past seven years. In addition, few scientists (no more than 20) are presently working in this area; and in many cases they are handicapped by having too many other responsibilities and insufficient physical facilities. A primary objective of this workshop is to suggest how integrated pest control for cassava can be developed. Many of the suggestions will most likely require close cooperation among the different institutes if their implementation is to be successful. I hope that this workshop will provide the bases for this future collaboration.

The status of cassava pathology

Because of the interest several countries have taken in improving the cassava plant and expanding its cultivation, special programs with full-time researchers trained in cassava pathology have already been organized in Brazil, Mexico, Thailand, the Philippines, Malaysia and India, as well as in the international centers. Since some of these researchers were trained at CIAT, a cooperative link has been established with these institutes by means of joint projects, interchange of information, or consultation. This type of link also exists between IITA and several African countries.

About thirty cassava diseases induced by viruses, viruslike causal agents, mycoplasmas, bacteria and fungi have been reported (38). The information available on the etiology of the causal agents, as well as the epidemiology of these diseases, is relatively limited. At present it is not always possible to know whether two scientists are working on the same organism because there is a lack of knowledge as to the true identification of the pathogen. For example, it has not yet been proved that African and Indian mosaic are caused by the same virus. The following is a summary of the most important features of reported cassava diseases.

Viruses, viruslike organisms and mycoplasmas

Five viruses have been reported attacking cassava (3, 16, 35). Geographically speaking, brown streak virus (BSV) and African mosaic virus (AMV) are restricted to Africa, but the latter has also been reported in India (48). Common mosaic (CMV), leaf vein mosaic (LVMV) and latent viruses (LV) are restricted to tropical America, (16,35), but it appears that CMV is also found in Indonesia (Booth, personal communication) and that there is another LV in Africa (3).

In addition to their sharp geographical distribution, there are several differential characteristics for each virus (Table 1). Considering distribution, incidence and losses, AMV is the most important viral disease of cassava because it has a motile vector (the whitefly *Bemisia* spp.), is widely distributed in tropical Africa and can cause losses of more than 80 percent (3).

A great deal of research is needed to elucidate certain aspects of each of these viral diseases. In the case of BSV, for example, there are controversies regarding the shape of its particles (3, 29), hosts and methods of dissemination (3, 20, 29), which have only confused the status of this disease.

A new disease ("frog skin") of cassava was recently described in Colombia (12-13). Plants affected by this disease do not produce swollen roots. Frog skin can be disseminated by diseased cuttings, mechanically, and by grafting (12-13). The etiology of the causal agent and the epidemiology of the disease are still unknown.

A mycoplasmal disease of cassava has been reported in Brazil, Venezuela, Mexico, the Amazonian region of Peru (16, 18, 38) and Guatemala (Cock, personal communication) and in the Ivory

Table 1. **Characterization of cassava viruses.**

Virus	Distribution	Symptoms	Losses	Particle morphology	Transmission	Hosts	Control
African mosaic	Africa, India (33, 48)	Yellow mosaic, leaf curling and crinkling, stunting (20, 33)	More than 50% (3)	Paired polyhydral, isometric (3)	Cuttings, *Bemisia* spp. (3, 7)	*Manihot* spp., *Nicotiana clevelandii* (3, 7)	Roguing, disease-free cuttings, resistant cultivars (3)
Brown streak	East Coast Africa (33-34, 49)	Yellow leaf patches, necrotic vein etch (20, 34, 49)	Unknown	Paired, polyhydral, isometric (3 ?); long flexuous rods (29?)	Cuttings, grafting, mechanical (35), insects (3)	*Petunia hybrida, Datura stramonium N. glucosa, N. rustica, N. tabacum, D. ferox, Solanum nigrum, Salpighosis sinuata* (29)	Roguing, disease-free cuttings (3)
Common mosaic	Brazil, Venezuela Peru, Colombia (16, 38)	Yellow mosaic, leaf curling, stunting (16)	10-20 % based on plant yield (16)	Long flexuous rods (16, 30)	Cuttings, grafting, mechanical (16)	*Manihot* spp., *Chenopodium amaranticolor, C. guinoa, Malva perviflora, Gossypium hersutum* (16, 30)	Roguing, disease-free cuttings (16)
Leaf vein mosaic	Brazil, Venezuela (16, 18)	Vein clearing, leaf tip curling, stunting (16, 18)	Mild (16)	Polyhydral, isometric (30-31)	Cuttings, grafting, mechanical (16,30)	*Manihot* spp., *D. stramonium* (16)	Roguing, disease-free cuttings (16)
Latent	Brazil (16) Africa (3,4)	Symptomless	None	Rhabdovirus (16), paired, polyhdral (3-4)	Cuttings and grafting (16), insects (3)	*Manihot* spp., Euphorbiaceae and Solanaceae (16)	

19

Coast (21). Known as "superbrotamento" or witches'-broom, the disease can be recognized by several different syndromes: (1) stunting, shortening of internodes and proliferation of branches; (2) proliferation of shoots from the cutting; or (3) only a few weak and stunted shoots germinating from the cutting (16, 46). The reason for the occurrence of these different syndromes is unknown, but it has been suggested that they may be due to the existance of different mycoplasmal biotypes (16, 38). As this disease is only disseminated by using diseased cuttings and by mechanical means (16, 18), its incidence is relatively low (16, 38).

Bacterial diseases

Several bacterial species have been reported on cassava (38), but only *Xanthomonas manihotis* (cassava bacterial blight) (36), *X. cassavae* (bacterial leaf spot) (58), *Erwinia carotovora* var. *carotovora (E. cassavae)* (bacterial stem rot) (24, 47) and *Agrobacterium* sp. (bacterial stem gall) (13) have been established as being truly pathogenic to cassava. *Bacterium robici* was reported as a cassava pathogen (56); however, no type culture is known nor has it been isolated since it was first reported. It appears that it was mistaken with *E. carotovora* var. *carotovora (E. cassavae)*. *Pseudomonas solanacearum* has also been reported as a pathogen of cassava (28); but recent inoculations with races of this bacterium have showed that cassava is not a host. Since *X. manihotis* forms white, mucoid, slimy colonies in sugar media, as does *P. solanacearum*, the identification of this pathogen could also have been mistaken.

The bacterial pathogens of cassava can be differentiated on the basis of symptomatology in addition to their cultural characteristics (Table 2). Cassava bacterial blight (CBB) is the most important bacterial disease and the one that has been most investigated (10-12, 25, 36, 38, 40-41, 43); however, there are many aspects of this disease and its causal agent that are still unknown.

Fungal diseases

Around twenty fungal species have been reported as being pathogenic to cassava, inducing foliar, stem or root rot diseases.

Foliar diseases

The most important in this group are superelongation *(Sphaceloma manihoticola)*, Cercospora leaf spots *(C. vicosae, C. henningsii, C. caribaea* and *C. manihotae)* and concentric-ring leaf spot [*Phoma (Phyllosticta)* spp.], inducing yield losses that range from 17 to 80 percent (9-10, 32, 38). *C. henningsii* and *C. vicosae* also reduce the starch content of the roots (13, 57). Their incidence is worldwide, except for *S. manihoticola*, which is present only in the Americas, and *Phoma* spp., which are restricted to the cooler cassava-growing areas (32, 38).

Other diseases whose incidence and severity are moderate and thus considered of minor importance are cassava rust [six species of *Uromyces* (33)], anthracnose *(Colletotrichum* spp. and *Gloeosporium* spp.), cassava ash *(Oidium manihotis)* and Periconia leaf spot *(Periconia* spp.) (12, 38). Anthracnose appears to be the most common, causing defoliation, dieback and stem cankers (38). The extent of damage and yield reduction induced by these minor diseases are still unknown, but anthracnose appears to be quite important in West Africa.

Stem pathogens

This group of pathogens are of importance in cassava because they can affect the quality and sanitary conditions of planting material, reducing germination and plant vigor (45). There are several pathogens that can attack the stems, but their incidence is dependent upon high relative humidities and stem injuries caused either by insects or mechanically. The most common stem pathogens are *Glomerella* spp. and *Botryodiplodia* spp. Several unidentified ascomycetes and basidiomycetes, are also found attacking stored stem pieces and old cassava left in the fields during the rainy seasons (38, 45).

Root rot pathogens

These soil-borne fungi attack cassava roots before or after harvesting. Those that attack the roots prior to harvesting generally induce soft or dry rot. Their presence is related to (a) poor drainage conditions of heavy clay soils *(Phytophthora* spp. and *Pythium* spp.) and (b) the crop or vegetation growing before cassava is

Table 2. **Differential characteristics of presently identified bacterial diseases of cassava**

Diseases	Species	Symptoms	Cultural features	Dissemination	Control
Cassava bacterial blight	*X. manihotis* (40-41)	Leaf spotting, blight, gum exudation, wilting, leaf fall dieback, dry rotting of vascular strands of stems and roots (36, 40)	Fast growth; slimy, mucoid and white colonies (36, 40)	Infected cuttings; rain and soil splashing (10, 36); insects (10); infested tools (41)	Resistant varieties; disease-free planting material and crop rotation (36, 41, 55)
Cassava bacterial leaf spot	*X. cassavae* (58)	Leaf spotting, leaf yellowing, leaf fall (58)	Slow growth, yellow pigment; small slimy colonies (25, 58)	Rain splashing (58)	Unknown
Cassava bacterial stem rot	*E. carotovora* var. *carotovora (E. cassavae)* (12-47)	Top wilting, stem soft rotting, pith necrosis (12, 47)	Fast growth; hydrolyzes sodium pectates (47)	Insects *(Anastrepha* spp.) (47)	Insect-resistant varieties (12, 47), insect control (2, 46), clean planting material (45)
Cassava bacterial stem gall	*Agrobacterium* sp. (13)	Stem galls, stunting (13)	Fast growth; white slimy colonies (13)	Infected cuttings (13); infested soil	Clean planting material (13), crop rotation

planted [*Rigidoporous (Fomes) lignosus, Rosellinia bunodes, R. necatrix, Sclerotium rolfsii, Armillariella mellea, Rhizoctonia* sp., etc. (38).]. Many fungi, both soil-borne saprophytes and parasites, can attack harvested roots through wounds caused during the harvesting operations. The intensity of damage induced by these organisms is related to the flora able to metabolize the root tissues, as well as to the mechanical damage done to the roots during harvesting, packing and shipping.

Characteristics of the host/pathogen relation

When looking at pathological problems, the following facts about cassava should be taken into consideration by plant protection specialists when designing research programs.

1. Cassava is a perennial; this favors the perpetuation of pathological problems in areas where it is cultivated. Although the plants are removed at harvesting, volunteer plants are almost always present because cassava has a good germinating capacity. Volunteer plants may arise from stem pieces that are either left in the field in the form of debris or incorporated into the soil after harvesting. The true seeds also have a good germinating capacity (27).

2. Cassava is a woody crop (53). Many pathogens that attack forest trees, perennial woody crops and even herbaceous annuals can be pathogenic to cassava. Some of these have already been reported attacking cassava (38), and many others are potential pathogens.

3. Cassava is a long-cycle crop, being harvested from 8 to 24 months after planting. Planting is often done over a long time period; consequently, plantations of different ages are found in many cassava-growing areas. Therefore, in the absence of resistant varieties, susceptible tissue is always available so pathogens are under stress mostly from climatic and edaphic factors. When pathogens require insect vectors for dissemination, the latter are also under this stress.

4. Because of its long growth cycle and lack of critical growth stages for yield, it appears that cassava can tolerate moderate attacks of pests and diseases, often with only minor yield reduction (14).

5. Since cassava is normally propagated vegetatively, top-quality planting material is essential for good establishment, healthy stands and high yields (45). Moreover, vegetative propagation facilitates the perpetuation of highly promising hybrid material (27). Great care must be taken in selecting this propagating material since losses in stand, resulting from the use of diseased and/or poor-quality planting material, affect yields (13, 45). Furthermore, the movement of planting material from one area to another always involves the risk of introducing pests and diseases (37, 39).

Suggested control methods

In order to control cassava diseases better, it is necessary to integrate simple control measures related to exclusion, eradication, protection and host resistance. The following methods of control, based on Agrios' system (1), have been or should be taken into consideration by cassava pathologists:

Regulatory control methods

The most important cassava diseases (CBB, African mosaic and superelongation), as well as others that are potential risks (frog skin, American viruses and mycoplasmas, bacterial stem rot and stem gall), are fortunately still restricted to certain continents or geographical areas (37, 39, 42). In order to prevent the introduction and spread of these diseases to other areas, countries must not only establish quarantine regulations and inspections but must also see that they are enforced by their plant sanitation officers. Since several *Euphorbia* spp. and *Manihot* spp., commonly planted as ornamental trees, are also hosts of some cassava diseases (see No. 1 under cultural control methods), quarantine regulations must also cover importations of these species. It might be worthwhile to promote the formation of centers that would produce certified cassava seed under the supervision of sanitation inspectors.

Cultural control

The following cultural methods can be applied to control some cassava diseases:

1. **Host eradication.** *Euphorbia pulcherrima* (12), *E. heterophylla* and other species of *Euphorbia* (12, 54) and *Manihot glaziovii* (32) have been reported as hosts of *S. manihoticola*, the causal agent of superelongation. Other weeds and *Manihot* species have also been reported as hosts of viral diseases of cassava (35). The eradication of these species in cassava-growing areas could prevent the perpetuation of such diseases or even eradicate them.

2. **Crop rotation.** Soil pathogens of cassava can sometimes be reduced in number or eliminated by rotating cassava with gramineous crops or by crop fallowing. Phytophthora root rot, for example, can be eliminated after a six-month period of crop fallowing. Since cassava is a long-cycle crop, this particular control measure could be of great importance.

3. **Sanitary measures.** It has been demonstrated that American viruses and mycoplasmal diseases, as well as AMV, can be controlled effectively by roguing infected plants (3, 16). By using disease-free planting material, disinfesting tools and applying other sanitary precautions for the laborers, CBB dissemination has also been prevented (36, 41).

4. **Improvement of growing conditions** for cassava plants can be achieved by planting healthy, high-quality propagating material (45). Cultural practices such as drainage of fields, planting on ridges, proper spacing of plants and weed control will improve plant growth. These practices can also affect, directly or indirectly, the control of damping-off, root rot and foliar diseases of cassava.

5. The formation of high humidity conditions under the plant canopy can be prevented by leaving greater distances between plants, which may inhibit infections caused by foliar pathogens (*S. manihoticola, Cercospora* spp., etc.). It is interesting to note that Cock (14) suggests a relatively sparse leaf cover for maximum yields, which should also lead to less favorable conditions for such diseases. Good soil drainage can also reduce the number and activity of *Pythium* spp. and *Phytophthora* spp., which have induced considerable losses in areas where rainfall is heavy (more than 1200 mm/yr) and planting is done on the flat (8, 50).

6. Tissue culture has been reported to be a useful technique for producing AMV- (16) and CBB-free plants (43; Takatzu, personal communication).

Biological methods

Varietal resistance to CBB *(X. manihotis)* (36, 41), AMV (3, 56), Cercospora leaf spots (*C. henningsii* and *C. vicosae)* (11, 12), concentric-ring leaf spot *(P. manihoticola)* (10, 11, 12) and superelongation *(S. manihoticola)* (11, 12, 32) has been reported. The use of resistant varieties to control these diseases appears to be the best means of producing acceptable yield without expensive inputs. Results to date on resistance to these four diseases have indicated that the variability of their causal agents is limited and that there is good, field-stable resistance. Possible explanations are that these pathogens are specific to cassava, the plant is heterozygous, and continuous susceptible host tissue is available. In the case of superelongation, it was found that the resistance of certain varieties broke down after three years of continuous cultivation. Recently, the existance of physiological races was reported, which was to be expected since the pathogen has other annual and perennial *Euphorbia* host species (12, 54); this also indicates that cassava is a new host and the pathogen possibly evolved first on these wild host species.

The mycoparasitism of *Darluca filum* reported on *Uromyces* spp., pathogenic to cassava (12, 22), should also be taken into consideration.

Physical control

Microwave, ultraviolet light and heat treatments have been used to eradicate pathogens infecting cassava cuttings (9). Treating cuttings with hot water controls witches'-broom successfully (17).

Chemical control

It is economically feasible to use chemicals (a) to sterilize seedling beds when using the rapid propagation system (15); (b) to treat cuttings before storage and/or planting because of the protectant (11-12) or eradicant [in the case of *S. manihoticola* (12, 45)] effect; (c) to prevent postharvest microbial deterioration of the roots

(44); and (d) to reduce the incidence of AMV and BSV, which are disseminated by *Bemisia* spp. and *Anasthrepha* spp., respectively (2-3, 7). Nevertheless, continued chemical control of foliar diseases would be prohibitively expensive since cassava is a long-cycle crop.

Methodological problems

Several problems may be encountered by cassava pathologists, especially during the screening and evaluation of varieties and hybrids. The following are the most common:

1. Plant yield can be highly variable if appropriate planting material, chemical treatment of cuttings (45), agronomical practices (6, 45) and weed control (19) are not used. As cassava is a shrub, the border effect between plots may also induce variabilities. Optimum plot size should be used (52).

2. Root rot problems can reduce plant population/unit area and thus yield. In many cases they are noticeable only when harvesting. The use of high-quality, disease-free planting material (45), as well as good agronomic practices (6), should lead to the reduction or prevention of these problems.

3. In many cases the sanitary conditions and vigor of the aerial part of the plant do not bear a relationship to high yield. Vigorous, healthy plants can yield less than others because of their poor genetic yielding ability. It should be kept in mind that from a commercial standpoint the roots are the most important part of the plant.

   It takes more than two years to obtain progenies by sexual recombinations (27), and there are always limitations of planting material for the evaluation of desirable characteristics. Consequently, it seems logical that evaluation programs would, in the short term, be more efficient if they were restricted to promising high-yielding progeny of controlled crosses [cross-pollination in cassava is high (27)]. In addition, the incorporation of resistance should be restricted to those diseases that have been shown to cause losses of economic significance.

4. There is a high degree of overlapping of symptoms induced by diseases, insects and environmental or edaphic factors. This can easily lead to mistakes in final evaluations. Consequently, an accurate definition of the different symptoms for each disease must be kept in mind when evaluating for resistance. For example, cassava bacterial blight is able to induce angular leaf spots, blight, gum exudation on shoots and green stem parts, leaf fall, wilting, dieback, and vascular discoloration of the stems and roots. On the other hand, angular leaf spots are also induced by *Xanthomonas cassavae;* blight by *Cercospora vicosae* and *Phoma* spp.; gum exudation by shoot flies or as the result of mechanical injuries; leaf fall by fungi (*Cercospora* spp., *Phoma* spp.), bacteria (*X. cassavae*), soil salinity and drought; wilting by *Erwinia carotovora* var. *carotovora* (*E. cassavae*) and root rot pathogens; dieback by *Phoma* spp., *Sphaceloma manihoticola*, mites, thrips, soil salinity and drought; and vascular discoloration by root and stem fungi, as well as *E. carotovora* var. *carotovora* (*E. cassavae*).

5. Greenhouse evaluations require space and control conditions, which imply costly equipment. Diseases such as Cercospora and concentric-ring leaf spots and superelongation, which are endemic to areas where environments favor their incidence and severity, can be evaluated better under local field conditions. Those diseases where field evaluation does not show even infection and/or there is an overlapping of symptoms induced by other factors such as CBB) are better and more accurately evaluated under greenhouse conditions. Subsequent field evaluations of the greenhouse-selected material are recommended.

The above considerations are given with the hope that they will contribute towards understanding the pathological problems of cassava. Although the uniqueness of this crop requires that pathologists look at these problems quite differently from other crops, the integrated control of disease and pests could be highly successful in cassava.

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An overview of cassava entomology

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Abstract

Research on mites and insects that attack cassava has shown that they are factors that limit yield. Furthermore, the decrease in genetic variability due to the development of genetically uniform varieties tends to increase the incidence of epidemics and epiphytotics. The mite *Tetranychus urticae*, crickets, termites, leaf-cutter ants, grubs, cutworms and the scale insect *A. albus* are considered as universal pests of cassava since they are found in almost all cassava-growing areas. Insects that attack cassava over a prolonged period cause more damage than those that attack the plant only at certain times. The degree of damage depends on various factors; but under conditions at CIAT, it was greatest from the 2nd-6th mo of growth. Insects that attack cassava can be divided into 3 categories: (1) those that attack vegetative planting material (fruit flies, stemborers, scale insects, grubs and cutworms); (2) those that attack the growing plant; foliage consumers, sap-sucking pests, leaf deformers, and bud and stem borers; and (3) those that attack stored cassava planting material and dried products (more than 38 insects, mostly Coleoptera). The status of entomological research on cassava is indicated and the areas where further research is recommended are given. The factors that should be taken into account when establishing a pest management program are presented. Biological control and host plant resistance are described in detail because of their vital importance to integrated control programs that should also include the careful selection of planting material, use of sound cultural practices, resistant varieties as well as the use of phermones, attractants and growth regulators. It is concluded that studies on resistance to diseases in cassava should aim at the development of horizontal resistance since it is stable and involves less risk in the development of biotypes. Since major characters are inherited in an additive manner, this can be an effective tool in increasing resistance in genotypes that have low levels of resistance. A table is presented on the mite and insect complex, giving data on alternate hosts, yield losses, areas where they are found, and types of damage caused.

Introduction

Historically, cassava has received limited attention from entomologists and technologists. Cassava is a perennial shrub of the Euphorbiaceae that is often grown by subsistence farmers throughout the tropical regions of the world. It has often been reported that cassava is a "rustic crop," generally free of arthropod pests. Nevertheless, ongoing research at the international centers, as well as investigation being carried out by several other scientists, is showing that insects and mites are limiting factors in cassava production. Present world cassava yields under small farm conditions

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average only 5 to 15 t/ha. Experimental yields have exceeded 50 t/ha (11, 29) and commercial yields in Colombia have exceeded 40 t/ha. These figures indicate that there are several factors limiting production under farm conditions, one of which is pests.

In recent years there has been an increase in interest in cassava, not only for traditional uses as a human food but also for animal feedstuffs and industrial uses (19). Cassava has traditionally been cultivated by small farmers, often in association with other crops. There is considerable genetic variability in this system as each area or zone is often planted to several different varieties. However, as cassava production increases and traditional methods are replaced by larger plantations with more modern technology, pressure due to insects and diseases may increase. Genetic variability will tend to disappear as new, genetically uniform, high-yielding varieties replace the many traditional varieties presently being grown. This genetic uniformity is an invitation to disaster from pest epidemics and epiphytotics. Since the role of entomologists and pathologists in future cassava production will become more important, it is necessary that systematic entomological and pathological research be initiated in areas where it is presently lacking and the interest of scientists and institutions be sought to assist in this effort.

Distribution of cassava pests

Cassava originated in the Americas, was later taken to Africa and more recently introduced into Asia (23). As expected, the greatest diversity of cassava pests reported attacking cassava is from the Americas (Table 1). Several of these pests, such as the mite *(Mononychellus tanajoa)*, the cassava hornworm *(Erinnyis ello)*, the shoot fly *(Silba pendula)*, the fruit fly *(Anastrepha manihoti, A. pickeli)*, the cassava lace bug *(Vatiga manihoti)*, the white scale *(Aonidomytilus albus)*, thrips *(Frankliniella williamsi)* and certain stemborers, do not appear to have a wide host range, mainly attacking cassava or other *Manihot* species. Of these, only the green mite *M. tanajoa* (Africa) and the white scale *A. albus* (Africa and Asia) are reported attacking cassava outside of the Americas.

Those pests that are identified attacking cassava in nearly all cassava-growing areas are usually universal pests with a wide host range. These include the mite *Tetranychus urticae*, grubs, cutworms, leaf-cutter ants, crickets and termites. Because of the few entomologists working on cassava, it is difficult to get a precise picture of pest distribution, and accurate identification of many pests is lacking. Indications are that surprisingly few pests specific to cassava have disseminated to other areas. The advent of jet travel probably precipitated the movement of the *M. tanajoa* mite into Africa. The white scale *A. albus*, found in nearly all cassava-growing areas, appears to be the most universal cassava pest. The dissemination of this scale probably dates back to the initial shipment of vegetative planting material by boat to Africa and later to Asia. It is difficult to detect the presence of this grayish colored scale on vegetative planting material. It is also possible that some movement of stemborers occurred through the movement of planting material.

Crop losses due to insects and mites

Insects can damage cassava plants by attacking the buds and leaves, reducing growth and photosynthetic area and efficiency; by attacking stems, which weakens the plant, inhibits nutrient transport and reduces the quality of planting material; and by attacking planted cultivars, which leads to microbial invasion, reducing germination and yield. Some insects such as whiteflies or fruit flies are vectors or disseminators of diseases while others attack the roots, which can lead to secondary rots (3).

Depending on ecological conditions, the growing period of cassava is from 8 to 24 months. Recent studies indicate that insects that attack the plant over a prolonged period, such as mites, thrips, scales, mealybugs, whiteflies and stemborers, may reduce yield more than those that defoliate or damage plant parts for a brief period; i.e., hornworms, fruit flies, shoot flies and leaf-cutter ants. This is because the cassava plant appears to be able to recover from this type of damage under favorable environmental conditions, with rainfall being the critical factor. Cassava is often grown in regions with prolonged dry seasons and infertile soils. These additional

factors of water stress and poor fertility will compound damage caused by mites, thrips, lace bugs and scales, whose populations tend to increase during dry periods (13).

Yield losses in cassava due to a particular pest are often difficult to measure, and most of the literature available does not include good economic loss data. Cassava is often attacked by a complex of several pests, making it difficult to determine losses due to just one. Losses due to the mite *M. tanajoa* are reported as high as 46 percent in Africa (33), while experiments at CIAT (14) with a complex of four mite species *(M. tanajoa, M. mcgregori, Tetranychus urticae* and *Oligonychus peruvianus)* resulted in a 20 to 53 percent loss, depending upon plant age and the duration of the attack. Yield losses due to thrips range from 6 to 28 percent, depending upon varietal susceptibility (13, 39). Field studies in Colombia resulted in a 15 to 20 percent reduction in yield due to a single hornworm attack. Repeated attacks over the prolonged cassava-growing season would undoubtedly result in greater losses. Scale *(A. albus)* attacks at the CIAT farm resulted in a 20 percent yield reduction of a susceptible variety. Similar attacks under less favorable environmental and soil conditions may result in greater reduction. Losses due to fruit flies, stemborers, mealybugs, lace bugs, grasshoppers and others are mentioned but often unsubstantiated.

The growing period at CIAT (Valle del Cauca) and nearby cassava-growing regions is from 10 to 12 months. Data collected from actual pest attacks and from simulated damage studies indicate that yield losses are greatest when the attack occurs between the second and sixth month of plant growth. If there is a similar critical period for pest damage under other growing systems, this knowledge would be extremely useful for pest management programs.

The cassava mite and insect complex

Cassava pests represent a wide range of arthropodal fauna; approximately 200 species have been recorded (3). Cassava appears to be the preferred host for several of these pests (Table 1), including the hornworm *(E. ello)*, the fruit fly *(A. manihoti, A. pickelli)*, the shoot fly (S. pendula), the mite *(M. tanajoa)*, the lace bug *(V. manihotae)*, and the scale *(A. albus)*.

In addition there are several universal plant feeders with a wide host range that will also attack the cassava crop. These include grasshoppers, the two-spotted mite *(T. urticae)*, cutworms, leaf-cutter ants, termites, crickets, and certain whiteflies and stemborers.

It is important to note that cassava is often grown in areas with poor soil and prolonged dry periods where many other crop plants cannot be cultivated. During these prolonged dry periods, we have observed that cassava may be one of the few plants able to survive and thus be utilized as an alternate host for insects or mites. In some instances these attacks can be severe, and we have observed plant mortality due to exotic pests during these periods. An armyworm attack in Malaysia (personal observation) caused plant girdling and a 25 percent yield reduction in a 3000-acre plantation.

We can categorize insects attacking cassava into three general groups:

Insects attacking planting material

This includes those pests that will attack stems while the parent plant is still growing, thereby affecting the germination or yield of these stems when they are used as vegetative planting material (scales, fruit flies, stemborers). In addition there are those pests that attack planting material in storage for future use; scales, termites and stemborers have been identified causing this damage. After the cutting has been planted, germination can be reduced considerably by cutworms, grubs and termites, among others.

Insects attacking the growing plant

This group can be further divided into four subgroups: foliage consumers, sap-sucking pests, leaf deformers, and bud and stem borers. Foliage consumers consist of the cassava hornworm *(E. ello)*, grasshoppers and leaf-cutter ants. Severe attacks by all three of these pests will result in complete defoliation, often of large plantations. Sap-sucking pests include mites, whiteflies, scales, mealybugs and lace bugs. Except for scales, all are

Table 1. **The cassava mite and insect complex.**

Common Name	Important species	Reported from	Alternate hosts	Yield losses	Type of damage
White grubs	*Leucopholis rorida*, *Phyllophaga* sp.	All regions but mainly Americas and Indonesia	Numerous	95% loss germination	Feed on planting material and roots
Termites	*Coptotermes voltkevi*, *C. paradoxis*	All regions but mainly Africa	Numerous	Unknown	Tunnel in planting material roots, stems and swollen roots
Cutworms[1]	*Prodenia litura*, *Agrotis ipsilon*	Americas and Madagascar	Numerous	Unknown	Feed on planting material, girdles stems and consumes foliage
Scales [1 3]	*Aonidomytilus albus*, *Saissetia* sp.	All cassava-growing areas	Unknown	(a) 20%, (b) 50-60% loss in germination	Attack stems, which dry, causing leaves to fall. (b) Use of infested stems reduces germination of planting material
Fruit flies[1 5]	*Anastrepha pickeli*, *A. manihoti*	Americas	Unknown	(a) Unknown; (b) 20-50%	(a) Boring of fruit (seed) and stems; causes rotting of pith area. (b) Use of infested stems for planting material results in yield loss
Cassava hornworm[2]	*Erinnyis ello*	Americas	*Manihot glaziovii*, poinsettia, rubber, papaya, milkweed	20%	Foliage, tender stems and buds consumed
Grasshoppers[2]	*Zonocerus elegans*, *Z. variegatus*	Mainly Africa	Numerous	Unknown	Defoliation and stripping of bark
Leaf-cutter ants[2]	*Atta* sp., *Acromyrmex* sp.	Americas	Numerous	Unknown	Consume foliage

Cont.

Table 1 cont.

Mites[3]	*Mononychellus tanajoa,* *Tetranychus urticae* *Oligonychus peruvianus*	Americas and Africa All regions Americas	*Manihot* sp. Numerous *Manihot* sp.	46% Unknown Unknown	Leaf deformation and defoliation; heavy yield reduction or death Leaf necrosis and defoliation Leaf spotting and defoliation
Whiteflies[3]	*Bemisia tabaci,* *Aleurotrachelus* sp.	Africa, Asia Americas	Numerous Unknown	Unknown Unknown	Vector of African cassava mosaic Severe mottling or curling of leaves, presence of sooty mold
Mealybugs[3]	*Phenacoccus gossypii,* *Pseudococcus manihoti*	Americas Africa	Numerous	Unknown	Foliage and stems attacked, causing stem drying and leaf fall
Lace bugs[3]	*Vatiga manihotae*	Americas	Unknown	Unknown	Leaves with yellow spots that turn reddish brown
Thrips[4]	*Frankliniella williamsi,* *Corynothrips stenopterus,* *Caliothrips masculinus*	Mainly in Americas but also in Africa	Unknown	6-28%	Deformation of foliage, death of buds and browning of stem tissue
Gall midges[4]	*Jatrophobia brasiliensis*	Americas	Unknown	Unknown	Yellowish green to red galls formed on upper leaf surface
Stemborers[5]	*Coelosternus* spp., *Lagochirus* spp.	All regions but mainly Americas	Unknown	Unknown	Boring into and tunneling into stems and possibly swollen roots
Shoot flies[5]	*Silba pendula,* *Lonchaea chalybea*	Americas	*Mammea americana,* *Mangifera indica,* *Inga feullei,* *Eugenia* sp., *Atrus* sp.	15-34%	Larvae bore into and kill apical buds, causing plant deformation and stunting

[1] Insects attacking planting material

[2] Insects attacking the growing plant; foliage consumers

[3] Sap-sucking insects and mites

[4] Leaf deformers

[5] Bud and stem borers

primarily leaf feeders; mealybugs will feed on both stems and leaves. At least 13 species of mites have been identified as feeding on cassava, and there are undoubtedly others that have not yet been reported. The three most important are *M. tanajoa, T. urticae (= T. telarius)* and *O. peruvianus*. Seven species of whiteflies have been reported as feeding on cassava; the most important is *Bemisia tabaci* since it is the vector of African mosaic in Africa and India. This disease is not present in the Americas; and although *B. tabaci* has been reported in this hemisphere, there is some doubt as to its capacity to feed on cassava here. The most common whitefly feeding on cassava in the Americas appears to be *Aleurotrachelus* sp.

Mealybugs have frequently been reported as attacking cassava (12, 18, 25); and in recent years they have been reported as causing considerable damage in Brazil (1) and Zaire (Leuschner, personal communication). Lace bugs *(V. manihoti)* have been reported only from the Americas. Information on this pest is limited and there is no report of yield losses.

Thrips (37-38) and gall midges (7, 20) can cause cassava leaf deformation. Thrips is the more important of these two pests and can reduce yields considerably.

Insects that bore into the buds and stems of cassava are shoot flies *(S. pendula)* (5), fruit flies and the true stemborers. Shoot flies will cause death of the growing points and plant stunting. The adult fruit fly will oviposit in the tender stems of young plants and the larva becomes a borer (13-14). The bacterial pathogen *(Erwinia carotovora* var. *carotovora* is often found in association with fruit fly larvae and can cause severe rotting of stem tissue (13).

Numerous species of true stemborers have been identified as attacking cassava, especially in the Americas but particularly in Brazil (22, 27). Seven species of *Coelosternus* are reported attacking cassava in the Americas (9, 25). *Coelosternus manihoti* is reported as a pest in Africa (9), and *Lagochirus* sp. is reported from Asia (35).

Storage pests of dried cassava

Approximately 38 insects, mainly Coleoptera, are reportedly found on dried cassava chips or products (15, 35, 40). Many are polyphagous pests; others, which are able to reproduce on dried cassava, are the most important.

The status of cassava entomological research

Concentrated research in cassava entomology is recent. Few national governments have cassava research programs, and entomology seldom occupies any significant role in any program that does exit. Insect studies at various levels are being carried out in about 15 countries. It is therefore feasible to establish guidelines and recommendations for future research goals and the implementation of a sound pest management program.

An extensive range of studies should be conducted before an effective pest management program can be developed. These studies should be oriented toward a minimal use of pesticides and the development of alternative control methods that will not destroy the ecological balance between pests and parasites or predators existing in cassava plantations. There is a lack of scientific information in the following areas: yield losses and levels of economic injury for the major pests or combinations of pests; the role of the environment and the influence of plant age on pest incidence and severity of damage; studies on the biology and ecology of all important pests; identification and importance of natural enemies. Research should be practically oriented and give emphasis to low-cost, environmentally sound control practices.

As cassava acreage increases, monoculture cropping systems will replace multiple and scattered systems. On the other hand, new high-yielding hybrids will replace the traditional varieties being grown at present; consequently, genetic uniformity will replace much of the existent variability. If we study the effects that these changes have had on other food crops, we can conclude that insect and disease problems in cassava will increase in the future. Research programs are needed in all cassava-growing areas to investigate the following: potential pest problems that could occur if cassava acreages increase and monocultures, nonrotation and continuous planting of cassava are practiced; the danger of major or secondary pests becoming

increasingly important as high-yielding varieties are released; pest problems during the storage of planting material and the establishment phase of the plant; the production of insect- and disease-free planting material. In addition a worldwide survey should be undertaken to identify cassava pests accurately and establish their true distribution.

Crop protection

Anticipating that in the near future there will be an increase in cassava production as well as a change in production technology, the importance of a relevant and sound crop protection program increases. As previously stated, cassava has historically been cultivated on a small scale. The genetic variability in this system has acted as a safeguard against major epidemics of pests and diseases. In recent years we have seen a shift in this system toward large cassava plantations, employing a limited number of high-yielding hybrids in monoculture. These new hybrids will be ideal plant types; that is, efficient plants that will not produce excessive foliage as many traditional varieties do at present. The reasonably stable equilibrium that presently exists between pest and genotype in subsistence agriculture will be almost impossible to maintain in modern agricultural systems.

We must therefore study the implementation and relevance of the various pest control methods available. The major objective of a cassava pest management program should be to suppress insect pests and maintain populations below their economic threshold. This should be accomplished with a minimal use of costly inputs, especially pesticides. Advantage should be taken of the favorable factors involving the insect/plant/environment interaction that makes a cassava pest management system an attractive and practical goal. These factors include:

1. Cassava is cultivated from 8 to 24 months, making the continual use of pesticides uneconomical.
2. Being a long-season crop, it is ideally suited for a biological control program especially in areas where there is considerable acreage and continual planting of cassava. Biological control agents have been identified for many of the major pests.
3. The cassava plant is often able to recover from insect damage. Vigorous cassava varieties can lose considerable foliage (40 percent or more) without reducing yields. During periods of adequate rainfall, high levels of defoliation can result in little or no yield reduction.
4. Many pests are not widely distributed and pest incidence is often seasonal. The dry periods favor population buildup of many pests, but the plant's ability to withstand long periods of drought will usually result in recovery at the onset of rains.
5. Few, if any, pests will actually kill the plant, enabling it to recover from damage and produce edible roots.
6. The selection of healthy, vigorous planting material, combined with low-cost fungicidal and insecticidal treatments, initiates rapid and successful germination, ensuring early plant vigor during the important establishment phase and ultimately increasing yield (24).
7. Studies have shown that there are sources of pest resistance in cassava which, although of low level, may be adequate to prevent serious crop losses.
8. Cassava is often grown on small farms and under multicropping conditions. This system not only reduces pest incidence but also insures against pest outbreaks over extended areas.
9. Evidence is that insects can cause yield reductions during specific periods in plant development. These periods should be identified for different ecological zones so that control practices can be intensified during these periods.

The role of different control methods

There are several methods for reducing pest populations below the economic injury level. An integrated control program utilizing cultural practices, selection of planting material, use of resistant varieties, biological control and alternative methods such as phermones or attractants should be developed. Insecticides will be used because they offer the most immediate and rapid means of reducing pest populations. However, we strongly feed that no pest management program should be dependent upon pesticides, and they

should be used only as a last resort, on a short-term basis. However, treating cuttings with pesticides is economical and effective for certain pests.

In several cases insecticidal applications have proven to be ineffective over a long period as they also reduce predator populations. Mite populations, for example, reappear rapidly whereas buildups of predator populations are much slower (4). Chemical control of the hornworm resulted in more frequent infestations in chemically treated than in untreated fields (16).

There are several cultural practices that can reduce pest populations, but the implementation and practicability of these may be reduced as more modern agricultural technology is applied to cassava production.

Alternative means of control such as the use of pheromones, juvenile hormones, attractants and growth regulators are future possibilities, but their use may be economically prohibitive.

We have previously stated that many cassava pests are not widely distributed, especially from one continent to another. It is of great importance, therefore, that an efficient quarantine program be developed and enforced. As new high-yielding hybrids are developed, there will be an increase in the movement of planting material. Since cassava is vegetatively propagated, many insects and diseases can be transported from one area to another. Precautions should be taken to send only insect- and disease-free planting material, and all vegetative material should be treated with an insecticide to prevent the dissemination of insects such as scales, mites, mealybugs, thrips and other pests. Material should also be free of stemborers or fruit fly larvae.

Biological control and host plant resistance are two links in an integrated control chain that appear to play an important role in cassava pest management. Extensive studies in both of these areas have been initiated for several cassava pests.

Biological control

The factors making cassava well suited for biological control programs are its long growing period and high economic threshold; and few, if any, pests will actually kill the plant. Concentrated biological control studies for cassava pests are a rather recent effort. A review of the literature reveals that natural enemies of many cassava pests have been observed by field workers and entomologists (6,10,21,27,29). However, only recently two systematic studies and consequent programs have been initiated to control cassava pests using biological control. Bennett and Yaseen (4) have evaluated the effectiveness of biological control of the mite *M. tanajoa* with the Staphylinidae *Oligota minuta*. This predator was introduced into East Africa, where it is being evaluated for controlling the mite.

Studies on the biological control of the cassava hornworm have been initiated at CIAT (11-13). A program is being evaluated that combines egg parasitism *(Trichogramma* spp.), larval parasitism *(Apanteles congregatus)*, larval predation by the paper wasp *(Polistes canadiensis* L., *P. erythocephalus)* and a larval disease *(Bacillus thuringiensis)*.

Several other cassava pests offer the possibility of being controlled effectively by natural enemies. Studies on the predators and parasites of the mealybug *Phenacoccus gossypii* and the scale *A. albus* have been initiated at CIAT, Trinidad and Africa. Control of the white grub *(Phyllophaga* sp.) using the muscardine fungus *Metarhizium anisopliae* in also being evaluated at CIAT. Natural enemies of whiteflies, the gall midge and the fruit fly have been identified. There is excellent potential for the implementation of biological control of cassava pests; however, a great deal of basic information is needed to initiate these programs.

Host plant resistance

Resistance to pests attacking cassava is not reported extensively in the literature; most reports deal only with field observations. On-going systematic evaluation of germplasm has been limited because until the CIAT collection was assembled, extensive germplasm was not available to cassava researchers in one site. Host plant resistance offers the most economical means of controlling many cassava pests.

Varying degrees of varietal resistance have been reported for mites (2,4, 13-14, 31), thrips (37),

whiteflies (13-14, 17), stemborers (30) and shoot flies (8,29). The CIAT germplasm bank is being evaluated for resistance to mites, thrips, scales, mealybugs, whiteflies, fruit flies and lace bugs.

The decision to identify and utilize host plant resistance for specific cassava pests depends upon various criteria that should be taken into consideration when establishing a program of this nature. There criteria include:

1. The level of economic damage being caused by a particular pest should be significant.

2. Resistance should be sought for those pests only where it is considered feasible.

3. The availability of adequate, low-cost alternative methods of control of certain pests could negate the need for entering into an extensive resistance breeding program.

4. The level of resistance needed to reduce pest populations below an economic injury level should be considered. Since some cassava varieties have a high economic threshold, high levels of resistance may not be necessary.

5. Low levels of resistance can be combined with other methods of control (i.e., biological control or cultural practices), to maintain insect populations below economic damage levels.

6. Multiple cropping systems may require lower levels of resistance since these systems may have reduced insect populations.

Cassava is a leafy, highly heterozygous, naturally cross-pollinated, woody perennial. It has a long growth cycle and is easily propagated by seed or cuttings. It is grown in a scattered cultivation pattern with many traditional varieties that have various degrees of susceptibility to insects and diseases. These characteristics indicate that there is a minimum of selective pressure being exerted by pests in cassava cultivation. Vertical resistance in terms of the gene-for-gene theory would probably not evolve within such a system; therefore, resistance is probably of the horizontal type inherited multigenically. Resistance to major cassava diseases appears to comfirm this assumption. Since horizontal resistance is stable (36) and entails less risk as to the development of biotypes (33), cassava insect and disease resistance studies should have horizontal resistance as their goal.

When breeding for insect resistance, it must be remembered that cassava is propagated vegetatively and that major characters are inherited in an additive manner; therefore, once a type is obtained, the genotype can be multiplied indefinitely. If the additive effect is equally important for resistance characters as it is for yield characters, it can be an effective tool in increasing resistance where only low levels exist in a single genotype. By crossing cultivars containing low resistance levels, the presence of additive genes could result in increased resistance.

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African mosaic disease in Kenya

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Abstract

Results of field observations and experiments suggest that African mosaic can be controlled in Kenya by the use of mosaic-free planting material. The low rate of spread of mosaic into mosaic-free plots (2.2% in 12-14 mo) and also within plots (12.9%) indicates that whiteflies are comparatively inefficient vectors and that man is the principal vector in his indiscriminate use of infected cuttings as propagation material. A reappraisal of locally adapted cassava in relation to hybrids seems necessary in view of these results; they also suggest that susceptibility to mosaic might not be a factor limiting the usefulness of high-yielding varieties being developed by breeders.

Breeding for resistance: background

African mosaic disease (AMD) is the most important single factor limiting cassava yields in East Africa. This was recognized almost 50 years ago when H.H. Storey inititated his studies on the disease. Storey's contributions were considerable: He was the first to recognize severe and mild strains and demonstrated that both types were transmitted by the whitefly *Bemisia tabaci* (5). Storey did not study the epidemiology of AMD although he referred to the possibility of control by the use of mosaic-free cuttings (4). Instead, he directed his attention to resistance. In 1935 he started to search for resistance among local East African varieties and also began to import cassava from Ghana, Java, Brazil, Madagascar and Zaire, observing strict quarantine procedures.

It soon became apparent to Storey and his co-workers that an acceptable degree of resistance could not be found within *Manihot esculenta*. In 1937 attention was turned to interspecific crosses, using *M. glaziovii, M. dichotoma, M. catingae,* "tree" cassava (considered to be a natural hybrid between *M. esculenta* and *M. glaziovii), M. melanobasis* and *M. saxicola*.

The system involved backcrossing the F_1 hybrid to various cassava clones in an endeavor to restore storage roots; successive generations were backcrossed and selection made for mosaic resistance combined with other desirable qualities such as palatability. Finally, attempts were made to obtain higher resistance by intercrossing resistant hybrids (3).

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By 1958 it was concluded that further breeding was unlikely to offer any substantial advances. The original hope that immunity might be obtained was not realized, but some degree of resistance or tolerance had seemingly been achieved (2).

Over the period 1950-1960, the most promising lines were released to research stations in East Africa. Virtually all of these (approximately 90 in number) are still maintained in variety collection plots in Kenya; more than half are backcross hybrids of *M. glaziovii*. Also included are cultivars of *M. esculenta*, among them the material from Java, Zaire and Madagascar selected by Storey in 1935.

The impact of the breeding program is difficult to assess, but it had one decisive effect on cassava research in Kenya. Local varieties were largely ignored, and from 1950 to 1970 agronomy trials were conducted with hybrids or imported selections. This approach was perhaps a logical consequence of the breeding program, but it has not resulted in the wholesale replacement of local, traditional varieties. It seems that only 46106/27 and F279 in Coast Province, and F100 and possibly 50284/33 in West Kenya, were distributed and are now grown in varying extent (but never on a large scale) outside the research stations. The "improved" varieties, therefore, have not replaced the local ones.

There are probably many reasons for this, but it seems likely that there were three factors of particular significance. The breeders encountered serious difficulties in selection for "sweetness," owing to wide variations that were apparently connected with site, age and time of harvesting. More significantly, perhaps, resistance appeared to "break down." (We now know that it was not resistance that altered, but the health status of the clones. When issued by the breeding program, a clone was presumably "clean," but subsequently became increasingly mosaic-infected in the field). It can be seen why the farmer had no incentive to use new material that seemingly was in no way superior to his own traditional varieties in taste, yield, or disease resistance.

What, then, is the face value of the hybrid selections which were the endpoint of 25 years of intensive breeding for resistance to AMD. This material may yet prove of value for a number of reasons, but a more precise evaluation will depend on the future development of the cassava industry and on cassava agronomy research in Kenya, particularly with regard to a reassessment of their yield potential and performance in comparison with traditional varieties.

Perhaps of great potential value is the fact that members of at least one group of hybrids contain resistance to cassava bacterial blight *(Xanthomonas manihotis)*, which seems to be linked with resistance to mosaic (3). Finally, the East African program evaluated the use of interspecific crossing in cassava breeding.

Recent research on AMD

Our involvement in research into African mosaic was prompted initially by an apparently complete breakdown in resistance of a hybrid and by the high incidence of AMD in the resistant hybrid collections. We thus proceeded to make a survey of the incidence of AMD in the field, assessed crop losses and conducted observational studies on the epidemiology of the disease.

Incidence

Our observations suggest that over 80 percent of all plants in the field were infected with mosaic. This figure, taken in conjunction with the average loss in yield caused by AMD (around 70 percent), gives an estimate of the staggering loss in production in Kenya due to AMD. Fortunately no clone so far studied has been found totally infected with mosaic; therefore, it has been possible to find apparently mosaic-free individual plants of all varieties used in our field experiments and to reestablish mosaic-free plots from these.

Crop losses

We have estimated the effect of mosaic on yield by comparing the weight of roots harvested from mosaic-free plants with that of plants derived from infected cuttings. While our field design varied, all data were subjected to statistical analyses. In one such experiment a line of 35 infected cuttings was planted between two lines of 35 healthy ones; two varieties were compared, a moderately resistant

hybrid (46106/27) and a susceptible *esculenta* (F279). In other experiments we used the more widely acceptable randomized block design. Table 1 summarizes some of the data.

The average crop loss is on the order of 70 percent. Looking at the figure for hybrid 46106/27 and the susceptible F279 *esculenta*, the mean loss for the former is 70 percent and for the latter, 86 percent. However, the difference between a loss of 70 percent and one of 86 percent would not impress a farmer unduly, and the use of a "moderately resistant" hybrid, in this particular instance, has clearly not exercised satisfactory control.

The data also suggest that yields of mosaic-free, local, traditionally grown varieties are at least comparable to yields of "improved" cassava, which is an important issue.

Field spread of AMD

In 1973 we began the task of trying to assess the rate of spread of AMD in the field. For this we required "clean" or mosaic-free material, so we began with the selection and bulking of cassava that was free of mosaic. Apparently healthy cassava was selected and propagated in isolation; and by exercising care, we were able to bulk sufficient healthy cassava for use in studies on the field epidemiology of mosaic.

Two simple designs were used: one to study the rate of spread into clean plots; the other, the rate of spread within plots where AMD is present. In the former, 100 or more mosaic-free plants each of two varieties (one referred to as moderately resistant and one susceptible) were planted in 10 alternate rows of 20 plants (plants were 1 m apart with 2 m between the double rows). Plants that became infected during the course of the experiment were rogued. For studying rate of spread within a plot, seven mosaic-infected cuttings were surrounded by concentric hexagons of a total of 156 mosaic-free cuttings, usually of the same variety. Plants that became infected in these plots were not rogued. Recordings were made at weekly intervals for the duration of the trial, which was usually 12-14 months, this period being the normal crop cycle in Kenya.

The "spread-into-clean" cassava plots were located in areas that differed widely: open grass fields, close to cashew trees, sheltered from the NE and SE monsoon winds by citrus, and open cultivated land. We thus hoped to detect any possible effects of microclimate on spread.

Results of seven such plots, all found in Coast Province, are summarized in tables 2 and 3. All previous workers in Kenya had reported that mosaic incidence is significantly higher in coastal areas than inland.

Table 1. Mean yield (kg/plant) of plants derived from infected and healthy cuttings.

Variety	Mosaic-infected	Without mosaic	% loss
46106/27 (resistant hybrid)	1.19	3.86	69.2
F279 (Indonesian *esculenta*)*	0.52	3.67	85.8
Sifwembe (local, traditional)	1.68	5.10	67.1
Tamisi (local, traditional)	0.94	3.24	71.0
Mean	1.08	3.97	73.3

* This clone was also infected with cassava brown streak virus.

Table 2. Spread of AMD into mosaic-free plots

	No. of plants infected		
	46106/26 (hybrid)	F279	Total
Plot 1 (1974)	2	7	9/200
2 (1975)	0	0	0/200
3 (1975)	2	5	7/200
4 (1975)	3	4	7/200
5 (1975)	0	2	2/200
6 (1976)	2	2	4/200
7 (1976)	1	1	2/200
Total	10/700	21/700	31/1400
Percentage	1.4	3.0	2.2

Table 3. Spread of AMD within plots.

	No. plants infected/ no. exposed	%
1973 (Coast)*	84/156	53.8
1974 (Coast)*	2/156	1.3
1975 (Coast)*	14/135	10.4
1976 (Coast)*	12/156	7.7
1976 (W. Kenya)	0/156	0.0
1976 (W. Kenya)	6/139	4.3
Total	118/898	12.9

* Rainfall (mm) for coast sites was 1283 in 1973, 681 in 1974, 1189 in 1975 and 945 in 1976.

Discussion

Our observations suggest that rate of transmission of cassava mosaic by the whitefly vector is slow (in Table 2 we recorded an average incidence, in 12-14 months' exposure, of 2.2%). This is further emphasized by the generally low rate of spread of mosaic from a central core of infected plants to healthy surrounding plants in the same plot (Table 3), an average incidence of 12.9% . In only one trial out of six was there significant spread (53.8% in 14 months), which can be attributed to local conditions which were possibly unusually favorable to the maintenance of dense whitefly populations.

We have observed heavy whitefly populations in coastal cassava areas for a short period immediately subsequent to the rainy seasons only; during the rest of the year, their numbers are comparatively low. In addition, it seems doubtful that whiteflies are migratory in the sense that other virus-transmitting insects are (e.g., the well-known seasonal migrations of aphids).

Although whiteflies may be efficient vectors of mosaic, no critical studies have been made. Storey and Nichols(5) used 100 adult whiteflies in each transmission test; Chant (1) generally used batches of 30 to 50 insects. He showed that while transmission could result from the feeding of a single fly (10% transmission rate), the number of successful transmissions increased to 70 percent when 15 or more whiteflies were used.

Storey and Nichols (5) demonstrated that while whiteflies are able to maintain themselves successfully on mature leaves, they are able to transmit mosaic only to immature ones. Presumably, this would greatly influence the probability of successful transmission during the prolonged dry season in East Africa, when cassava growth is retarded and the production of new leaves is slow.

It is possible, therefore, that at least three factors— comparatively inefficient transmission, seasonally low population densities and behavior of the vector, and cassava growth patterns— all contribute to the observed low rate of spread of AMD to healthy plants in Kenya. In any case, it seems likely that mosaic can be controlled effectively by the use of mosaic-free planting material. It also seems clear that man is the principal vector of mosaic, at least in East Africa, because of his indiscriminate use of infected cuttings as propagation material.

These results call for a reappraisal of cassava agronomy in Kenya, particularly in relation to a comparative study of the yields of traditional varieties and interspecific hybrids. They also suggest that susceptibility to mosaic might not be a factor limiting the usefulness and utilization of high-yielding varieties being developed at international centers such as CIAT.

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Inheritance of linked resistances to African cassava mosaic and bacterial blight diseases

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Abstract

The relationship between resistances to African cassava mosaic disease (AMD) and to cassava bacterial blight (CBB) was studied at IITA in 1975. Resistances to AMD and CBB, derived from *M. glaziovii*, were conferred by recessive quantitative genes with additive effects. For both diseases the degree of recessiveness was influenced by environmental factors which also had correlated effects on the 2 resistances. *M. glaziovii* progenies segregated in a discontinuous way for joint resistance to AMD and CBB. A similar type of segregation occurred in progenies of 58308, a hybrid 7 generations removed from the interspecies cross. The following hypotheses are considered: (a) that linkage occurs between genes affecting AMD resistance and others affecting CBB resistance, (b) that genes affecting AMD resistance have pleiotropic effects on CBB resistance, (c) that linkage occurs between AMD and CBB, but pleitropic effects also occur, increasing the degree of correlation.

The occurrence of linked resistances to African cassava mosaic and bacterial blight diseases (AMD and CBB) was first reported by Hahn in 1973. Resistance to AMD, inherited from the *Manihot glaziovii* derivative 58308, was largely conferred by recessive additive genes and was associated with resistance to CBB with a correlation coefficient of 0.36 (2). It was later reported that the relationship held for the half-sib progenies of 1973 selections tested in 1974 (3); and a further 52 half-sib families tested in 1976 showed both phenotypical and genetical correlations with coefficients of 0.42 and 0.90, respectively (4). Although Hahn's germplasm originated from *M. glaziovii*, it should be emphasized that the hybrid clone used (58308) was six generations removed from the first interspecific cross and is essentially cassavalike (5).

I was able to study the relationship between resistances to AMD and CBB during a stay at IITA in 1975. In a replicated experiment, 107 genotypes from six families were propagated for a trial planted in April 1975 and recorded at 14-day intervals from June to August. The severities of the two diseases were scored in new growth only, using a 0 to 5 scale for AMD and 0 to 6 for CBB. AMD

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was recorded on six occasions and CBB on four, and the sums of the scores were expressed as a percentage of the maximum possible. These figures were subtracted from 100 to give resistance percentages. Correlations between resistance to AMD and CBB were found as follows:

	d.f.	r
Between families	5	0.567 NS
Between genotypes within families	105	0.212*
Between plants within genotypes	403	0.385**

Although significant, the between-genotypes correlation was less than that within genotypes, which can be attributed to nongenetic effects. No conclusion on the occurrence of genetic linkage was therefore possible, but it was clear that nongenetic factors were affecting the two resistances in a correlated way.

The problem was studied further in a 6 x 6 diallel cross recorded in the same way, and using the six parents shown in Figure 3. Since the frequency distribution of progeny for resistance to both diseases in the 58308 selfed family (resistant x resistant) was nearly discontinuous from that obtained for all the families obtained from crosses between susceptible parents (Figs. 1 and 2), it was considered that the data were suitable for analyses by Wr/Vr regressions (6), which can be used when the parents are true breeding, or nearly so. The results (Fig. 3) emphasize the strongly recessive nature of the genes for resistance to each disease (the positions on the graphs of 58308 indicate that this parent carries mostly recessive genes for each resistance and the positions of LCN66 and LCN 174 indicate that these parents are heterozygous). The analyses also showed that resistance to each disease was inherited in an essentially additive way, with very small, though significant, interaction effects.

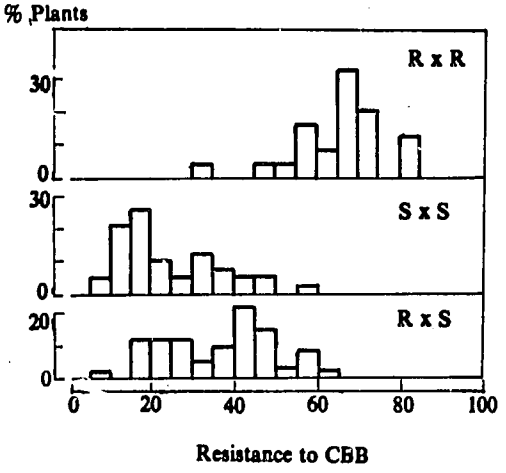

Figure 2. Frequency distributions of plants for resistance to CBB in three types of crosses in the 1975 diallel. R and S are as for Fig. 1.

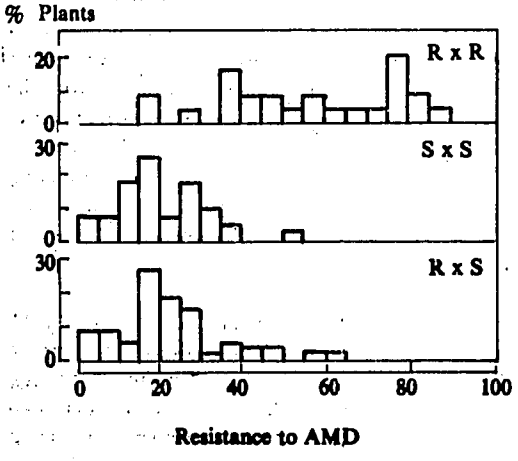

Figure 1. Frequency distributions of plants for resistance to AMD in three types of crosses in the 1975 diallel recorded at IITA. R = resistant 58308; S = the combined susceptibles Isunikakiyan, 60444 and 671287.

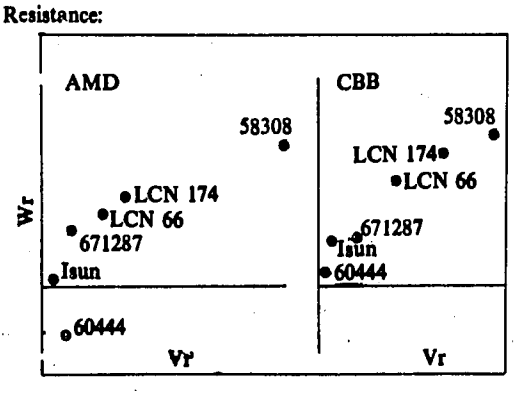

Figure 3. Wr/Vr analyses for resistance to AMD and CBB in the 6 x 6 diallel recorded at IITA. 58308 is a resistant hybrid of *M. glaziovii* origin; LCN 174 and LCN 66 are selections from the cross 58308 x Isunikikayan; Isunikikayan, 60444 and 671287 are of moderate to high susceptibility to both AMD and CBB.

Families with high resistance to AMD invariably had high resistance to CBB; hence there was a high coefficient (r = 0.7732) for the between-family correlation. But evidence for linkage in inheritance depends on finding correlated resistances within the families, and a nonsignificant coefficient of only 0.1372 was obtained for the total within-family variation; a significant one (r = 0.588) was found for only one family, the cross of 58308 x LCN174.

The evidence for genetically linked resistances in the two 1975 experiments was thus equivocal, largely because of the high correlation in the intensity of the two diseases found between plants of the same genotype, and there was a suggestion that genetic linkage, if present, might be limited to germplasm derived from the *M. glaziovii* derivative. Three larger families were therefore studied, one from the cross of 58308 x LCN174, another from 58308 selfed, and an open-pollinated population of *M. glaziovii* itself. Clone LCN174 and clone 58308 were included to assess nongenetic variation in the two diseases, and there was an open-pollinated population of the susceptible 60444. The experiment was recorded from 29 July to 7 October, a longer period than in the previous experiments.

The progress of the two diseases is most easily seen in the two clonal treatments and in 60444 (Fig. 4). Both diseases increased in severity from 29 July to 9 September 1976, and I refer to this as their "agressive" phase. For both diseases considerable recovery occurred from 22 September to 7 October — the "recovery" phase— and a slight reversal of this trend occurred from 24 October to 10 November—the "reversal" phase. Resistances during these three phases are referred to respectively as M1, M2 and M3 for resistance to AMD, and B1, B2 and B3 for resistance to CBB.

Since LCN174 is from the cross between 58308 and the susceptible Isunikakiyan, it must be highly heterozygous for both resistances. The results (Fig. 4) show the great superiority of 58308 for both resistances and the recessive nature of these resistances in its hybrid (LCN174); however, the relative resistances of LCN174 increased during the recovery phase, indicating that the recessiveness of its resistance genes was less complete during this time. Both resistances varied similarly over this period of time. Table 1 shows the correlations

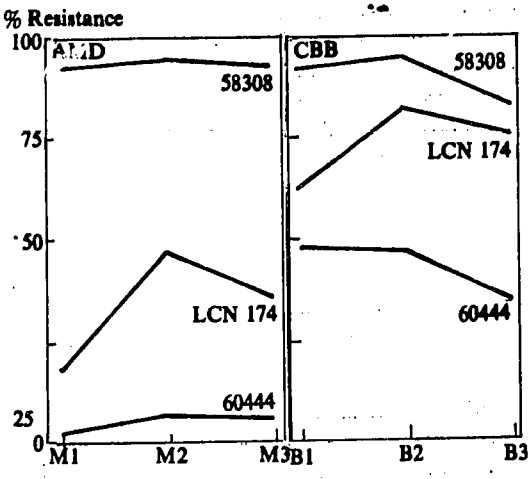

Figure 4. Variation in the expression of resistance to AMD and CBB at three stages of the 1976 experiments at IITA. 58308 and LCN 174 are clonal treatments and 60444 is an open-pollinated progeny. (See text for explanation of M and B values)

obtained for plants within the six treatments at each phase of the experiment. Correlations were high for clone LCN174 and clone 58308 during the final phase of the experiment but not before this. Variations within these treatments are entirely attributable to nongenetic factors, and it is interesting that correlations were not found earlier in the experiment. However, if joint segregation due to genetic linkage occurred, the correlations obtained in the segregating families would have been higher than in the two clonal treatments, where only nongenetic factors operated. To test if this were so, the *r* values were converted to *z* values (from tables) and values calculated for the expression $z1\text{-}z2/\sqrt{(1/n_1\text{-}3 + 1/n_2\text{-}3)}$, where *z1* and *n1* are the *z* values and number of individuals for the families, and *z2* and *n2* the corresponding values for LCN174. The results (Table 2) are compared with tables of *t* values to test their probability levels.

The most interesting result is the one for the *M. glaziovii* progeny, which shows clear evidence of genetic correlation in the aggressive phase, though correlations at later phases are not greater than those found in the clonal treatments and must therefore be due to nongenetic causes. The 58308 x LCN174 family, but not the family of 58308 selfed, also shows evidence of genetic correlation, though at a lower probability level.

Table 1. Correlation coefficients (r) between resistances to AMD and CBB

	58308 x LCN	58308 x self	*M. glaziovii* O.P.	60444 O.P.	Clone LCN	Clone 58308
Aggressive phase M1/B1	0.394++	0.070 NS	0.573+++	0.215 NS	0.101 NS	0.062 NS
Recovery phase M2/B2	0.491+++	0.391 NS	0.293 NS	0.260 NS	0.273+	-0.096 NS
Reverted phase M3 B3	0.565+++	0.591++	0.340+	0.285+	0.455+++	0.404++
Degrees freedom	62	21	36	57	61	46

+ ++ and +++ denote significant levels of 0.1, 1 and 5% and NS = not significant

Joint segregation in individual families

The data were also tested to see whether segregation of the joint resistances was continuous or discontinuous. For this purpose it is preferable to use the whole of the data in a way that maximizes the differences between resistance levels, so a canonical analysis was made to find the weightings of M1, M2, M3, B1, B2 and B3, which maximize the differences among 60444, LCN174 and 58308, the representatives of low, intermediate and high resistances. These weightings were then applied to the plants of the three segregating families. The following two canonical vectors were obtained:

Variate	Vector 1	Vector 2
M1	0.0823	-0.0400
M2	0.0044	0.0431
M3	0.0133	-0.0165
B1	0.0176	-0.0091
B2	-0.0011	0.0117
B3	0.0020	0.0381

Vector 1 clearly describes the tendency of both resistances to vary together and vector 2 denotes differences in capacity for recovering from these diseases; they account for 93.4 and 6.6% of the variance, respectively.

The most interesting result of this analysis is the segregation shown for the *M. glaziovii* progeny (Fig. 5): the 38 individuals divide easily into two discontinuous clusters, one with high resistance and one with lower resistance, and there are only a few individuals that do not fit either cluster. Individuals in the former cluster had resistances similar to 58308 and those of the latter had resistances similar to LCN174. It seems clear that segregation of this joint resistance is of a discontinuous nature. Although the corresponding analysis for the 58308 x LCN174 family shows segregation of a wider range of resistances, there is a similar group of 5 highly resistant plants that

Table 2. Values of the expression $z1-z2 / \sqrt{(1/n -3 + 1/n -3)}$

Aggressive phase	1.66+	-0.15	2.49+++	0.58
Recovery	1.39	0.49	0.10	-0.07
Reverted phase	0.81	0.73	-0.62	-1.09
t values for				
P = 0.05	1.96	2.07	1.96	1.96
P = 0.10	1.64	1.71	1.64	1.64
P = 0.20	1.28	1.32	1.28	1.28

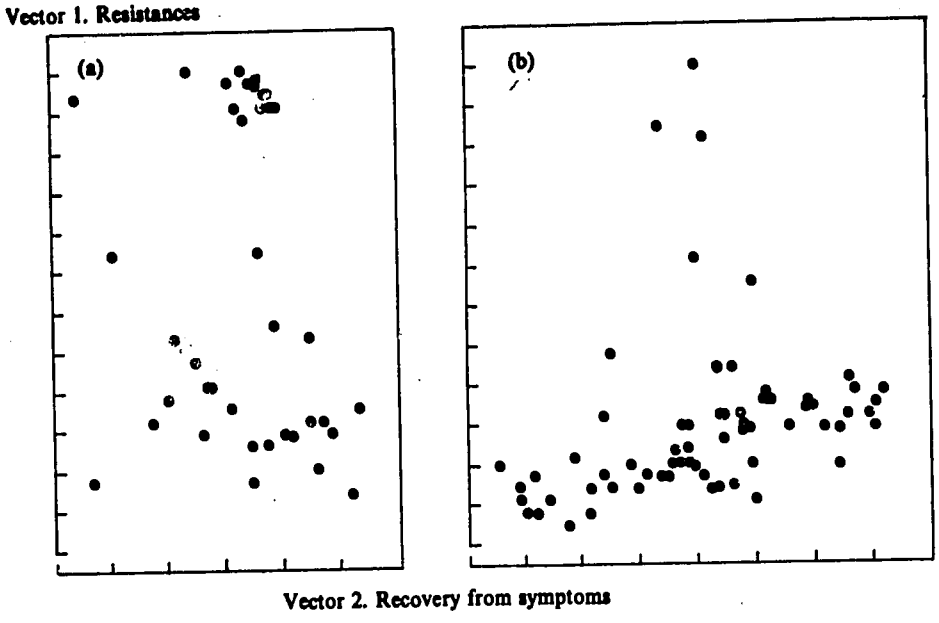

Figure 5. The distribution of plants according to their canonical weightings in the 1976 experiment at IITA: (a) a seedling population of *M. glaziovii*, (b) progeny from the cross 58308 x LCN 174.

separate easily from the remaining group of 59 less resistant ones. The family of 25 plants obtained from selfing 58308 gave one such highly resistant plant.

The numbers of highly resistant and susceptible plants obtained in these families do not fit any predictable segregation ratio. The result suggests that some kind of genetic unit is frequently but not invariably present in *M. glaziovii* and that this confers resistance to both AMD and CBB. Furthermore, it seems that this unit has been retained through seven generations of breeding following the cross between this species and cassava. We may speculate that this unit is a group of closely linked genes, or possibly a gene or genes that have pleiotropic effects on each disease.

It is known that AMD disrupts enzyme metabolism (1), and it is conceivable that it also affects the physiological processes that confer resistance to CBB. If this were so, genes that confer AMD resistance would inevitably have some pleiotropic effect on CBB resistance; and non-genetic effects that affect AMD resistance would affect CBB resistance as well. It seems unlikely that pleiotropic effects could explain all of the correlated resistance found, for example, in the *M. glaziovii* progeny; however, the experiments did not provide firm evidence that the postulated genetic linkage could be broken. No definite instances of low CBB resistance combined with high AMD resistance ocurred in the segregating families since such variations that occurred could have been due to nongenetic causes.

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Whiteflies: biology and transmission of African mosaic disease

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Abstract

The biological aspects of *Bemisia* sp. and its relationship to the transmission of African cassava mosaic virus (AMV) are reviewed. Whitefly activity depends on temperature, light and rainfall. Whiteflies feed on succulent young leaves; and since they are strongly attracted to the color yellow, cassava varieties with yellowish petioles attract more whiteflies than those with darker petioles. They fly only short distances, but wind contributes to their dissemination. *Bemisia* populations vary during the year depending on climatic conditions, predators and the condition of the host (adequate no. of succulent young leaves). Results are given of transmission experiments which show the close relationship between the population density of *Bemisia* sp. and the development of AMD. Control methods discussed include control of the vector (*Bemisia* sp.), sanitation measures and the use of AMD-resistant varieties.

African mosaic disease is one of the most important and widespread diseases of cassava. It was originally described in 1974 by Warburg in East Africa. Since then it has been reported in all parts of East, West and Central Africa and Madagascar. Yield losses of about 25 to 30 percent have been reported by Chant (4). The agent causing the disease is still unknown. There is evidence that several strains of the disease exist, and symptom expression varies with the variety, strain and environmental conditions (2). The spread of the disease in the field is caused initially by the practice of using infected material for vegetative propagation and secondly by vector transmission (10). The vector is a *Bemisia* sp., probably *B. tabaci* (Aleyrodidae). To date *Bemisia* is the only known vector and it is present in all cassava-growing areas of Africa. Because of this relationship, the spread of AMD and seasonal infection pressure are closely related with the vector's biology, behavior migration and population dynamics. For these reasons, we felt it was necessary to do more work on the vector in order to get better understanding of the vector/host/disease relationship.

Vector taxonomy and host range

The taxonomic identity of the whitefly (*Bemisia* sp.) is highly obscure. Mound (8) has shown that variation in the form of pupal cases was not genetically determined but actually host induced. He did this work by using inbred strains of *Bemisia* and exposing them to *Dolichos lablab*, tobacc.

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cotton, *Centrosema* sp. and *Hibiscus* sp. Such host-induced variation is not unknown in the Aleyrodidae family. Mound (7) mentioned that there is a possibility that *B. tabaci* is a group of sibling species, each with the texture of the host leaf and the morphology of the pupae case. Therefore *B. tabaci* Genn. and B. *nigeriensis* Corb. might be regarded as synonymous (8).

Bemisia species have a wide host range. They have been observed breeding on tomatoes, sweet potatoes, cowpeas, cotton, tobacco, peppers and cassava.

Biology and life cycle

The life cycle of *Bemisia* varies with temperature, which is reflected in the different seasons of the year. With a temperature of 26°C, 17 days are needed from egg to adult, which is in line with the observations of Avidov (1). Within a range of mean temperatures from 12 to 26 degrees, he reported a total development period from 11 to 50 days. The threshold of development of eggs was 12.5°C, which does not occur in the lowland humid tropics of Africa but is certainly important for the arid areas and higher altitudes. According to Avidov (1), adult whitefly life varies from 18 to 84 days in Israel, depending on the season of the year. Chant (4) found an average of 12 days under greenhouse conditions.

During hot, dry weather and low relative humidity, no eggs are laid. This is the case during harmattan time when hot, dry winds from the Sahara come into West Africa.

Behavior

Whitefly activity depends on temperature, light and rainfall. Temperature and light seem to have an interacting effect on flight activity. In an experiment with various temperatures and additional light, it was found that temperatures from 27 to 28°C increased activity but did not induce flight (Table 1). As soon as additional light was given to this temperature range, flight started. Additional light had only a slight influence on flight activity when the temperature was lower than 27°C. This is in agreement with Mound (8), who stated that whiteflies become increasingly active as a result of increasing light rather than temperature. Whiteflies fly away from cassava in the morning. There is a significant reduction in the number of adults resting on a plant at noon compared to 9 am (8). They congregate and feed on the very young succulent leaves and have a tendency to rest under the higher fully expanded ones. Eggs are laid near the growing tip of the plant. During development the leaves expand and pupae are found mostly on the sixth to tenth fully expanded leaves. It was discovered that whiteflies are strongly attracted to the color yellow (8). This seems to be one of the reasons why cassava varieties with yellowish petioles are more attractive than those with darker ones.

Migration

It has been observed that whiteflies normally fly only short distances, from plant to plant, but Mound's (8) observation that whitefly numbers are reduced at noon, gives evidence that there must also be an upward movement. In this case they can easily be picked up by the wind. Suction traps 18 m above the ground caught ten whiteflies in 24 hours during the population peak in June.

In July the catch dropped to one within 24 hours. This indicates that whiteflies can be transported by wind over some distances.

Population studies of *Bemisia*

Population studies carried out at IITA from 1976-77 showed clearly that there were marked seasonal fluctuations. Adult whiteflies were caught with yellow traps and counted weekly. Pupae population was also counted weekly on the sixth to tenth fully expanded leaves Figure 1 shows a rapid increase of the adult population during the first rainy season. The population then remained low until a new increase during December and later in March 1977. The first peak clearly shows that heavy rains do not affect whitefly development, which is not in line with the finding of Mound (8), who reported that heavy rains reduced the number of adults markedly.

Possible explanations for these fluctuations are as follows:

1. The fact that temperature and light interact certainly has something to do with the flight

Table 1. Results of whitefly activity under various temperature regimes and different light positions.

		14-22°C			22-27°C			27-32°C			32-38°C			38-48°C		
Position of light	Control intervals (min)	Resting	Active moving	Flying	Resting	Active moving	Flying	Resting	Active moving	Flying	Resting	Active moving	Flying	Resting	Active moving	Flying
High temp side	10	2	-	-	14	-	-	-	2	1	1	3	4	-	3	-
	10	2	-	-	9	5	-	-	-	3	1	2	5	-	3	-
	10	2	-	-	7	3	-	1	4	4	1	3	5			
	10	2	-	-	3	1	-	1	6	8	2	4	2	-	-	1
	10	2	-	-	3	1	-	-	5	4	1	8	5	-	1	-
	10	2	-	-	0	3	-	1	7	2	-	7	7	-	1	-
Medium temp side	10	2	-	-	0	2	1	-	13	10	-	2	-	-	-	-
	10	2	-	-	1	5	3	3	10	6	-	-	-	-	-	-
	10	2	-	-	4	1	2	2	9	5	-	3	2	-	-	-
	10	2	-	-	3		4	2	5	9	2	1	2	-	-	-
	10	2	-	-	3	1	2	1	7	11	1	2	-	-	-	-
	10	2	-	-	3	3		3	11	8	-	-	-	-	-	-
Low temp side	10	8	2	-	14	-	2	1	1	1	1	-	-	-	-	-
	10	13	1	-	14	2	-	-	-	-	-	-	-	-	-	-
	10	10	3	-	13	1	-	3	-	-	-	-	-	-	-	-
	10	16	1	-	12	1	-	-	-	-	-	-	-	-	-	-
	10	18	0	-	11	1	-	-	-	-	-	-	-	-	-	-
	10	17	1	-	12	-	-	-	-	-	-	-	-	-	-	-

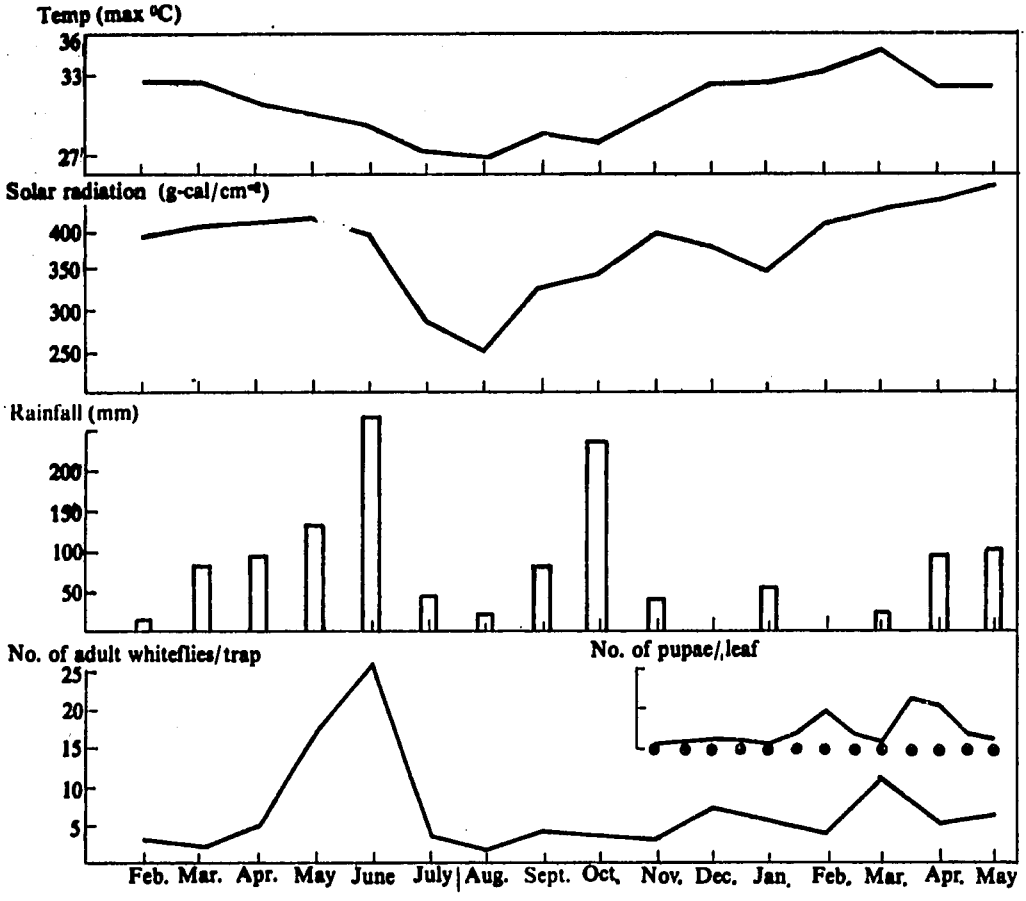

Figure 1. Population development of *Bemisia* in relation to temperature, solar radiation and rainfall (1976-77).

and egg-laying activity of the adults. During the first rainy season there was increasing solar input with decreasing temperatures, but temperature did not drop much below 30°, which means no decrease in activity. After the rains, solar input and temperature dropped, probably resulting in very low activity and development. Only when solar radiation and temperature rose considerably were development and activity renewed, with the exception of harmattan time during January, which was hot and dry.

2. Parasites and predators may be important. Only one efficient predator, probably a typhlodromid mite, was observed this year at the end of the rains. This may also have contributed to the decrease of the population at the end of June 1976. No other parasites or predators were observed, but Squire (9) reported a beetle *Serangium cinctum* and a wasp *Prospaltella* sp. (Encyrtidae) parasitic on whiteflies. However, the incidence in general was as low as 12 percent.

3. Another reason for the fluctuation of the whitefly population may be the host itself. Reproduction depends on succulent young leaves which are readily available on a flushing cassava plant during the rainy season. This explains the increase, but not the decrease of the population. Probably at this point parasites, predators and ecological factors combined are responsible for the abrupt decrease.

We do not know at present to what extent this population study explains the situation in different ecological zones of Africa. Certainly the situation would be different in dryer and higher altitude areas (6), where the incidence of AMD is lower, as in northern Nigeria and the Cameroon mountains. There are also indications that the whitefly population behaves differently in mixed cropping systems.

Vector population development and AMD incidence

Vector density and AMD incidence appear to be related. This is not obvious in farmers' fields because they use diseased cuttings. The knowledge of this relationship is important, however, for AMD resistance screening or for cleaning up purposes, as recommended for AMD in the coastal areas of East Africa.

To understand this relationship better, a randomized trial was conducted, using three cassava varieties: 60444, susceptible; Isunikakiyan, moderately susceptible; and 58308, resistant. Planting of uninfested open-pollinated cassava seedlings took place every month. 60444 was planted as infected cuttings in three border rows to give the necessary source of infection; 24 traps were placed along the border rows and a new trap was placed in each monthly planting in order to follow infestation progressively. The sticky yellow traps and pupae were counted weekly. AMD incidence in each set of planting was recorded weekly for two months.

In Figure 2 the number of adult whiteflies was plotted against AMD incidence. The results show clearly that AMD incidence is highly related to vector density. However, the disease incidence of the April planting was high while vector density

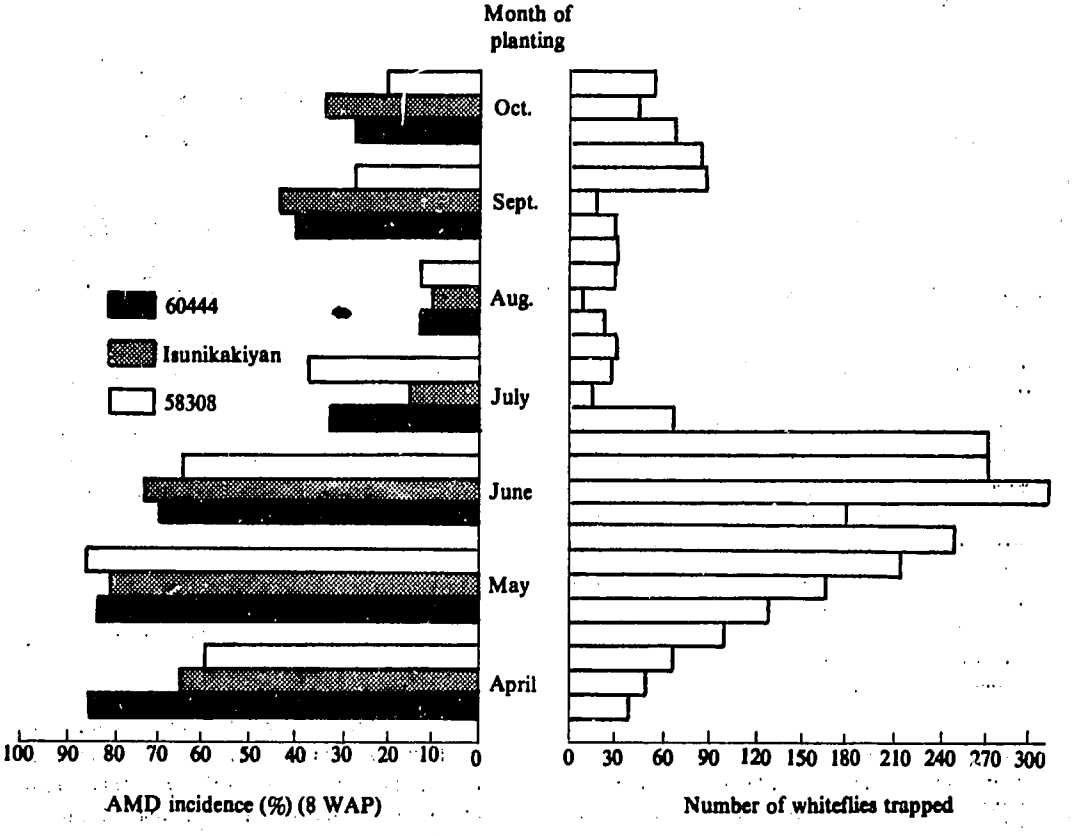

Figure 2. Effect of monthly planting and vector density on AMD incidence.

was low; this was due to different recording methods. AMD was recorded for each planting over a two-month period, while whiteflies were counted weekly. Therefore, the April planting was probably infested with AMD in May. Furthermore, the results show that even a small increase in the *Bemisia* population is reflected in increased AMD symptoms.

Adult whitefly trapping in the monthly planted plots showed that infestation started as early as one week after planting; then trapping followed the pattern of the border row. The same happened to the pupae population, with a delay in the first peak of about one month. Newly planted seedlings are probably not readily accepted for egg laying and are used only when they are fully established. This was supported by observations on January and February seedlings, which grew very poorly because of the lack of rain. Only a few pupae could be found in the plots, but on the border row there was a peak in Februrary and March.

The whole experiment shows that *Bemisia* population fluctuations are clearly reflected in the incidence of AMD; and even a small increase in whitefly population is reflected in increased AMD symptoms.

This raises the question of how efficient whiteflies are as vectors in the field and how quickly a plot with no symptoms will become infested when it is planted some distance away from another plot.

AMD transmission and vector efficiency

Transmission of a cassava mosaic virus by a species of whitefly was first reported by Ghesqueri in the Belgium Congo in 1932 and confirmed by Storey in 1934 and Golding in 1936 (5). In his studies on the virus vector relationship, Chant (4) demonstrated that whiteflies need to feed for at least 4 hours on the young leaves of a mosaic-infested cassava plant to acquire the "virus" and another 4 hours to become viruliferous, after which they are able to transmit the disease after a minimum feeding period of 15 minutes; but longer periods gave more infections. Chant (4) further showed that once whiteflies are viruliferous, they are capable of transmitting AMD for at least 48 hours. The success of the transmission also increases with the number of infective whiteflies per plant. All these experiments were done in the greenhouse; unfortunately, no results are available for vector efficiency under field conditions. Nevertheless, we can assume from our population studies that transmission efficiency is dependent on the flight activity of the adults, the population density and the availability of young infected leaves. All three postulations are found during the first rainy season; therefore, this season is ideal for screening for AMD resistance.

The IITA seedling nursey, comprising about 100,000 seedlings, is planted in the dry season and irrigated until the onset of the rains. The seeds are obtained from selected clones from all yield trials. In this way the seedlings are exposed at a very early stage to AMD; this appears to be a reliable method since only a few escapes have been observed.

Control measures

AMD could theoretically be controlled in three different ways:

Control of the vector

One way of controlling the whitefly vector is by using insecticides. This would, however, have only a limited impact as vector transmission is just one way in which the disease agent is spread in the field. The numerous wild hosts for *Bemisia* would also have to be taken into consideration as new populations can build up quickly from these sources. Chemical control is, therefore, not recommended.

The only way to reduce the whitefly population effectively would be to develop resistance, but it is not very likely that we shall find antibiosis. The chances of finding moderately resistant cassava plants are higher, and some clones have already been identified at CIAT. This means that transmission pressure is only reduced. In order to get the full benefit from these screening efforts, one also has to remove the source of AMD infection. For this purpose, large quantities of resistant and AMD-free planting material have to be made available. This involves multiplication units which have to be placed in AMD-free areas and would have to produce enough cuttings in order to plant vast areas all at one time; otherwise, the material

could be reinfested by neighboring fields and the results would be rather doubtful.

In addition to these technical difficulties, the farmer who does the actual planting work has to be persuaded to do this job and made to believe in the benefit of what he is doing. All these implications make the advisablility of using *Bemisia*-resistant material for control of AMD doubtful.

Sanitation measures

In regions where the whitefly population is low, it might be possible to eliminate AMD by roguing infected plants. This might be possible, for example, in the coastal area of Kenya (3). Experimental results suggest that satisfactory field control of mosaic might be achieved by the use of mosaic-free propagation material moderately tolerant to AMD, with rigorous roguing of infected plants. This means that in the intial stage, stocks of AMD-free planting material would have to be provided to farmers for replacing infected material. After the disease incidence is lowered, the farmer can continue to replace infected plants with his own clean stocks. The success of this cleanup method depends entirely on the removal of infected material.

As this method looks promising, future plans are to clean up the whole coastal area. This means that vast areas have to be planted at once with clean planting material in order to reduce the disease pressure. For this purpose multiplication units have to be set up in AMD-free areas to provide the necessary planting material. At the same time the farmer has to be persuaded to do the planting and roguing and to be made to believe in the benefit of what he is doing.

When one takes all these implications into consideration, the question arises why not use AMD-resistant material at once. Multiplication units have to be established in any case and the difficulties of getting the varieties to the farmers are fewer, as will be pointed out.

Use of AMD-resistant varieties

The use of AMD-resistant cassava varieties seems to be a very promising way of control. The advantage is that research has already made good progress, first in Amani (Tanzania), later in Moor Plantation (Nigeria) and today at IITA. Varieties such as 30395 and 30211 with high levels of resistance to AMD have already passed multilocational screening under different environmental conditions and give yields up to more than 30 t/ha. They are now available for multiplication on a large scale for distribution to the farmers. The use of resistant planting material also has the advantage that it could be multiplied in any area, but preferably in AMD-free ones.

Moreover, it is not necessary to plant vast areas at once. Small samples can be given to a farmer; and if he accepts the variety, he may gradually replace his own with the improved one by doing the further multiplication himself.

The chances of resistance breaking down due to new disease strains is not very high as we are dealing with multigenic horizontal resistance, but this aspect should not be overlooked.

Three different methods of controlling AMD have been described. Each has its advantages and disadvantages; therefore, it seems logical to combine them in order to get the maximum control effect.

A high vector population might lower the effect of sanitary measures if the source of infection is not removed completely; it could also spread new disease strains quickly. Therefore, vector resistance should be emphasized and incorporated into AMD-resistant material, which is already available. As we do not have totally resistant clones, the material should be multiplied in AMD-free areas. This material should be provided to the farmers, together with instructions to remove infected plants as soon as they are observed.

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Nematode problems on cassava

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Abstract

Although nematodes can attack cassava alone or interact with soil-borne microorganisms and may cause losses of economic importance, information on the subject is scarce. This article reviews the geographic distribution, biological and ecological aspects of the following nematode parasites of cassava: *Meloidogyne* spp., *Pratylenchus brachyrus, Rotylenchulus* spp., *Helicotylenchus* spp., *Rotylenchus* spp. and *Criconemoides* spp. As more cassava production moves into monoculture and as new high-yielding varieties are released, nematodes have the potential to cause severe reductions in root yield and quality. Various control measures are discussed and areas that need to be investigated are outlined.

There is a paucity of information available on nematode problems in cassava, which probably does not come as a surprise to anyone attending this workshop. In fact, the lack of references on disease, insect and nematode problems of cassava was in part responsible for the development of this workshop. In the area of nematology only 22 references are cited in the literature. Of these, 17 report on associations of nematodes with cassava, 3 review nematode problems of cassava and 2 report on breeding for resistance to nematodes. There is no information available on pathogenicity, control or economic losses, yet cassava is one of the world's most important food crops in the tropics where nematodes pose their most serious threat to food production.

Lehman (10) reports that at least 14 species of nematodes are known to be parasitic on cassava roots. Undoubtedly the most important ones would include the genera *Meloidogyne* and *Pratylenchus*; however, there is only one report in literature indicating *Meloidogyne* may be a serious disease of cassava when grown simultaneously in the same field with okra or eggplant (13). Other important nematode genera that have been reported to occur frequently include *Rotylenchulus, Helicotylenchus, Rotylenchus* and *Criconemoides*. Besides having the potential to reduce yields of cassava, these nematodes may interact with other soil-borne disease organisms to cause economic losses.

Biology, ecology and geographical distribution of several nematode parasites

Root-knot nematodes (*Meloidogyne* spp.)

Root-knot nematodes are more widely distributed throughout the world than any other major group of plant-parasitic nematodes.

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Furthermore, they rank among the most damaging pests of important economic plants. Thus far 35 species have been described; however, only four are widely disseminated: *Meloidogyne incognita, M. javanica, M. arenaria* and *M. hapla.* These four species, which are known to have a wide host range, have been reported in the USA, Central and South America, Africa, India, Europe and Japan. With the exception of *M. hapla,* they also occur in Southeast Asia, Australia and the Fiji Islands. Thus they are found throughout the semitropical and tropical regions where cassava is grown. *M. hapla* would be expected to occur in the higher elevations in the tropics because it is adapted to cooler climates.

Identification of *Meloidogyne* species is a formidable task, often stumping well-trained nematologists. Morphology of larvae, males and females is used, with special emphasis on the perineal pattern of adult females. Other important characteristics are cytology, physiology and reaction on a series of host differential plants. Physiological races of root-knot nematodes are detected on the basis of host differential tests.

Root-knot nematodes are endoparasites. The motile larval stage penetrates plant roots or tubers. They develop into adults and the female develops into a swollen, pyriform-shaped sedentary endoparasite laying eggs in a gelatinous matrix called an egg mass. The life cycle is completed in from 20 to 30 days after penetration, depending on environmental conditions.

During the feeding process the nematode initiates the formation of galls of varying sizes. Root-knot galls are generally numerous, ranging in diameter from 1/8 to 1 inch or greater. The size and shape of galls vary depending on the species, the host and other factors.

Storage tissue such as Irish potatoes, yams or sweet potatoes becomes infected and remains in such a condition that larvae reinfect the structure in which they were produced and few, if any, escape into the soil. Root-knot nematodes may react in a similar manner in cassava roots, thereby greatly reducing their quality if they are left in the ground for long periods of time.

Root-lesion nematodes (*Pratylenchus* spp.).

This is probably the second most widely distributed nematode pest. It is reported as frequently infecting cassava roots. Of some 45 species of *Pratylenchus* that have been described, only one, *P. brachyurus,* is reported to infect cassava. Obviously, this is one area that needs additional study. The pathogenic capabilities of other species of *Pratylenchus* on cassava should be determined. The nematode is distributed throughout the tropics, with some species apparently better adapted to warm regions than others.

P. brachyurus has a wide host range including several agronomic crops; e.g., tobacco, cotton, maize, peanuts, forage and cereal crops.

Lesion nematodes are migratory endoparasites. Any stage of development can be called infective because larvae and adults of various ages go into and out of roots. The nematodes generally enters near the root tip and migrates in the root cortex. After entering a root the nematode feeds on the parenchyma tissue and, in so doing, inflicts extensive injury. Lesions and cavities form and become filled with large numbers of the nematode. Roots and tubers can harbor large numbers of lesion nematodes, and all stages of the nematode may be extracted from infected roots. The nematode remains eelworm shaped throughout its life. The females lay single eggs and the life cycle is completed within 30 to 40 days after penetration, depending on environmental conditions.

Other nematodes

While very little information has been published on the effect of these nematodes on cassava, they are reported to be found associated with the crop frequently. These nematodes do occur in tropical and subtropical regions where many species affect a variety of crops and trees. They are all migratory ectoparasites, except *Rotylenchulus* spp., which is an endoparasite. A female *Rotylenchulus* becomes established either completely within the root or with more or less the posterior end protruding, whereas ectoparasites feed by thrusting their stylets into plant cells from the exterior root surface.

Yield losses

From the information that is presently available, it is impossible to estimate yield losses that plant parasitic nematodes may cause on cassava. DeGuiran (5) reports a vast area near Ganave (Togoland) has been cultivated with cassava since 1951 in order to provide a local starch factory with raw material. A gradual decline in yields has been noted. Nematological investigations revealed 12 plant parasitic nematodes present. *Pratylenchus brachyurus* and *Helicotylenchus erythrinae* were encountered most abundantly and frequently.

If one can extrapolate from other nematode/host relationships, we can predict that as more cassava production moves into monoculture and when new high-yielding varieties are released, nematodes can cause serious reductions in root yields and quality. From past experience we have learned that the monoculture of any crop generally leads to the development of very heavy nematode populations. Moreover, soil-borne disease organisms (e.g., *Phytophthora, Fusarium, Verticillium* and *Pseudomonas*) which have the potential to interact with nematodes can cause serious damage on other crops and may react similarly on cassava.

Control measures

Damage caused by plant parasitic nematodes on cassava can be greatly reduced or eliminated by proper sanitation, land management practices, development of resistant cultivars and chemical control.

Sanitation

The first line of defense to prevent losses due to nematodes is to prevent their introduction into agricultural land. Nematodes are readily transported by man, animal and environmental forces such as water and wind. Obviously little can be done to prevent "mother nature's" spread of nematodes; however, man can control his activities. One of the chief means that man has used in spreading nematodes in the tropics is through planting of infected root stocks; e.g., banana, coffee, citrus, vegetable and ornamental transplants. Growers and other agribusinessmen need to be educated to grow pest-free transplants or to use only nematode-free planting stocks. This can be accomplished by preparing seedbeds treated with steam or multipurpose soil fumigants. Infected planting stock such as bananas can be treated with hot water or chemical dips.

Land management practices

Nematologists have long employed integrated management systems to control nematodes. Such practices as crop rotation, crop residue disposal, flooding and fallowing, and timing of planting dates are a few examples.

Crop rotation

The continuous planting of crops on the same land year after year leads to the build-up of heavy infestations of nematodes. Crop rotations can often be used to help reduce nematode populations to below damaging levels. This method of control is based on the fact that some nematode species reproduce well on certain host crops but less well or not at all on others (nonhost crops). Nevertheless, because of the wide array of crops susceptible to nematodes and the different kinds of nematodes often found in a single field, it is difficult to find a rotational crop that will not favor the increase of at least one kind of nematode.

Crop residue disposal

Crop residues allow pest populations to continue increasing long after the final harvest. Reduction in pest population can be obtained simply by plowing or disking under crop residue and allowing the field to lie fallow for at least two weeks before replanting or planting a cover crop. Cultivation during the fallow period will aid in further reduction of nematode populations in the upper soil depths.

Flooding and fallowing

This practice is applicable to certain crops and areas where controlled flooding with clean water can be obtained. Alternating periods of flooding and fallowing (drying) is most effective. The flood/fallow cycle should be alternated at two-week intervals for two months, if possible. The soil should be cultivated during periods of drying to increase aeration and facilitate drying. This helps

prevent weed growth on which nematodes can reproduce if they are left there for a sufficient period of time.

Resistant varieties

The use of varieties resistant or tolerant to nematode attack offers an ideal method of control. Cassava cultivars are being evaluated at CIAT for resistance to nematodes (3-4). However, most programs are generally developed to solve a particular nematode/plant interaction; thus cultivars are released with resistance to a specific nematode and are usually susceptible to attack by other nematodes even within the same genus.

Chemical control

At present chemicals are the most effective and reliable means of controlling a wide variety of nematode pests of most crops. Chemicals known as nematicides (soil fumigants or nonfumigants) are used to control nematodes, whereas chemicals effective in controlling nematodes, certain soil-borne diseases, insects and weeds are called multipurpose soil fumigants. These chemicals vary in their effectiveness; consquently, it is necessary for each product to be evaluated fully under different conditions before its efficacy can be established.

Areas where more research is needed

Although there have been several reports associating plant parasitic nematodes with cassava, very little research has been done to establish their pathogenic effect. Pathogenicity experiments need to be conducted under controlled conditions. Different population densities and combinations of nematodes should be evaluated. Histopathological studies should be carried out, and the disease cycle of each nematode pest should be determined. The possible interaction of nematodes with other soil-borne organisms should be determined. Greater emphasis should be placed on developing control practices for nematode problems of cassava.

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Weeds: an economic problem in cassava

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Abstract

Normally, the highest costs in cassava producton are for labor, mostly for weeding operations. Although yield losses due to weeds are not so obvious as those caused by insects or diseases, they may reach 25% after 30 days and 50% after 60 days. In Colombia and in other countries with similar labor conditions, cassava growers can easily afford to weed their fields 4 or more times, the first 3-4 mo being the most critical for keeping cassava free of weed competition. Some control measures suggested are (1) integration of chemical and manual control, which eliminates early weed competition and gives higher yields, (2) increased plant populations, (3) mixed cropping, which may also reduce weeding inputs. The socioeconomic advantages and disadvantages of these measures are discussed. The need for people trained in weed science is stressed; research should be done on allelopathy, mixed cropping systems, and on weeds of economic importance in the tropics, especially in Latin America (i.e., *Cyperus rotundus* L., *Rottboellia exaltata* L. and *Bidens pilosa* L.).

Since man first selected certain plant species and started to cultivate them as crops, he has tried to reduce the infestation of less desirable species known as weeds. For centuries the means of keeping weeds in check were based upon the use of human energy and hand implements, and for thousands of people in developing countries this is still the case. Improved weed control technology is available to modern farmers in the form of mechanical or chemical energy (herbicides). In addition to removing the drudgery and improving the effectiveness of repeated hand weedings, these developments also reduce the losses caused by weeds in many countries in temperate regions of the world.

Cassava (*Manihot esculenta* Crantz) is typically grown by small farmers using traditional methods of weed control. The economic losses caused by weeds in cassava are usually unrecognized by the growers. Such losses are not as obvious as those caused by insects or diseases since farmers do not readily miss a portion of the crop that was never produced because of weed competition. Weed scientists in several countries have shown weeds to be a serious limiting factor to increasing cassava yields. Some of the economic considerations of weeds in cassava are discussed in this paper.

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Yield losses

Most of the world's cassava is grown by small farmers and weeded by hand. If performed at the right times and frequency, yields in hand weeding systems can be as high as those from other weed control methods. Since cassava is a relatively slow-growing crop in the early stages, weedings performed during the initial weeks are very important.

Studies conducted by Doll and Piedrahita (2) have shown that when weeds compete with cassava for light, nutrients and water for 30 days, crop yields are reduced by 25% and after 60 days of competition, by 50% (Table 1). Two weedings performed 15 and 30 days after planting were less effective than two weedings at 30 and 60 days. Highest yields were obtained when the cassava was kept weed free until the canopy had formed; this required four or more weedings or preemergence and postemergence herbicide applications.

Similar studies conducted in Nigeria also indicate that once a crop canopy is formed (3 to 4 months after planting), further weeding is no longer neccesary (8). Such data are in direct contradiction to the popular view that cassava is a rather competitive plant, able to survive and produce in the presence of weeds (9). When left to compete with weeds, cassava generally produces some yield, whereas other crops do not. Neverthcless, cassava does require an adequate weed control program for optimum yields.

Weed scientists seldom consider economic details when discussing weed losses in competition studies. Using the data in Table 1 and a value of US$67/ton for cassava roots (12), we see that the value of the cassava weeded once (at 15 days), twice (at 30 and 60 days) or four times (at 15, 30, 60, and 120 days) increased from US$389 to $1092 and $1306/ha, respectively. Assuming an average of 18 man-days/weeding (12) at a cost of US $2.00/day, each weeding costs approximately $36.00. These values are admittedly limited to the situation in Colombia; nevertheless, similar trends would exist for any country with similar labor costs, and it is easy to see that under these conditions cassava growers can well afford to weed their fields four or more times.

Table 1. **Effect of hand weedings at different times and frequencies on the fresh root yield of cassava (CMC-39) at 280 days after planting.**

No. of hand weedings	Frequency of hand weedings (days)	Fresh root yield (t/ha)	Fresh root yield % of control*
4 + **	15, 30, 60, 120, UH***	18.0	86
3 +	30, 60, 120, UH	16.0	76
2 +	60, 120, UH	11.0	52
1 +	120, UH	7.0	33
4	15, 30, 60, 120	19.5	92
3	15, 30, 60	12.9	61
2	15, 30	13.3	63
1	15	5.8	28
2	30, 60	16.3	77
2	15, 45	15.4	73
0	Weedy check	1.4	7
0	Chemical control****	21.1	100

* Percentage of the yield of cassava weeded with herbicides

** The "+" indicates additional weedings.

*** UH = until harvest, as needed

**** Alachlor + fluometuron were applied in preemergence, and directed applications of paraquat were made with a shielded nozzle as needed in postemergence.

It must not be forgotten, however, that the number of weedings is only one aspect of a good weed control program and that the timing of the weedings is equally important. Kasasian (5) postulated that the critical period of weed competiton is equal to approximately one fourth or one third the life span of a crop. If cassava is grown as a 12-month crop, his rule of thumb holds true since the first 3 to 4 months are the most critical for keeping cassava free of weed competition.

Labor requirements

Normally the highest costs in cassava production are for labor, and the greatest proportion of labor is used for weeding operations. Estimates from Colombia, northeastern Brazil, the Caribbean and Nigeria indicate that 55, 46, 42 and 25%, respectively, of the labor required to produce a

cassava crop is devoted to weeding (3,7,8,10). These figures do not include the labor used in preparing the seed bed for planting, which in the process also removes the major portion of the weeds present. In Colombia, this represents 48 man-days/ha. Krochmal (7) reports that this can be reduced to one man-day/ha if herbicides are applied; however, some supplemental weeding is normally required to assure adequate full-season weed control with herbicides (2, 11). The economic value of this tremendous investment of human energy can be calculated for any country or region by using the particular cost of labor and cassava acreage figures for each.

Reducing losses

To prevent losses in cassava caused by diseases and insects, breeding programs are often established to identify sources of resistance to the common pests. These capabilities are then incorporated with other desirable plant growth characteristics, the end results being high-yielding varieties, resistant to many insects and diseases. This approach is not possible for combating weeds. What is required is the integration of sound agronomic practices (including the planting of improved varieties), together with appropriate weed control measures to achieve maximum production.

The use of chemical energy could increase the efficiency of weeding, reduce labor costs and probably increase yields. Doll and Piedrahita (2) found that higher yields in cassava were obtained by using herbicides than hand weedings. Piedrahita et al. (11) reported that the use of preemergence diuron followed by one hand weeding gave as high a yield as three hand weedings, whereas diuron alone produced only 50 percent as much cassava as did the three hand weedings. The integration of chemical and manual control measures reduced labor requirements, eliminated early weed competition and gave high yields.

Another way to reduce the labor requirements for weeding cassava is to increase the plant population per hectare. Albuquerque (1) indicated that two or three weedings are required in Brazilian cassava planted at normal populations* but that only one weeding was required when 15,000 plants/ha were present. CIAT researchers (2) found similar trends in Colombia. As the cassava density increased, weeding intensity could be decreased and reasonable yields were still obtained. The obvious application of this interaction is to recommend higher plant populations in areas where labor shortages exist or are expected; nevertheless, the size and number of commercial cassava roots may be reduced if excessively high populations are planted.

Another interesting approach in areas where labor is somewhat limiting has been suggested by Versteeg (13), who applied half rates of preemergence herbicides to tropical crops in Peru. This controls the most sensitive weed species for up to several weeks after treatment and inhibits the normal growth of others long enough for the crop to emerge and gain some growth advantage over the weeds. Subsequent hand weedings are employed to maintain adequate weed control. This approach has several advantages: (1) There is very little risk of crop injury from the herbicide since very low rates are used; (2) the herbicide cost is greatly reduced; (3) the farmer has several extra weeks before weeding operations must begin, during which time he can perhaps plant additional land; and (4) the crop is able to develop more rapidly when weed pressure is reduced.

There is disagreement as to whether or not cassava grown as a mixed crop has greater or fewer weeding requirements. Jones (4) reports that in Africa, cassava intercropped with yams requires 36 percent less weeding than cassava grown alone, whereas a Colombian report (6) indicates that cassava grown with maize and yams needs to be weeded just as frequently as cassava alone. Certainly, the area of mixed cropping is so complex that variations in any of several conditions could account for these differences. Theoretically, the labor requirement for weeding can be reduced if an early-maturing crop is grown with cassava to replace the normal weed infestation during the first few months of establishment. Although this may often reduce cassava yields, it still allows reasonable production with lower labor inputs.

Socioeconomic impact

The high labor requirement for weeding cassava is often viewed as both a blessing and a curse. It is considered a blessing in countries where labor is

* Specific plant density not mentioned

cheap and abundant, inasmuch as it keeps people employed and occupied. As seen from the social point of view, it is a curse because it frequently means that children and women must participate in the physical drudgery of weeding operations. In addition to disrupting family life, this prevents youth from obtaining an education whereby they and their families can advance.

Likewise, the use of herbicides in developing countries has immediate advantages and disadvantages. Their use can make weeding more efficient, economical and effective, and at the same time, release many workers from their jobs. If this labor force can be occupied with more rewarding employment, there is no problem; however, this is not usually the case. Unemployment levels are already a serious concern in most developing countries, and to add to the number of unemployed may only worsen the overall economic situation of a country. In family farm situations, the use of chemical energy may mean that families can plant greater areas than previously because they can redistribute their labor to tasks other than weeding. However, the economic and educational levels of small farmers are often serious limitations to the widespread use of herbicides for selective weed control.

In any event, the decision to use or not to use herbicides should be made at the government level because of their socioeconomic impact. If left to the individual farmer, he will analyze only his personal situation when deciding whether or not their use is advantageous.

This discussion, although obviously a deviation from the biological impact of weeds in cassava, is a very important aspect that must be considered in any review of the economic impact of weeds in a crop. If a substantial replacement of the labor force by the use of herbicides is undesirable, we should at least consider ways of making the task less burdensome than is the case today. The adoption of better agronomic practices and new varieties will indirectly reduce the labor required for weeding by providing a more vigorous crop that competes better with weeds. The use of half rates of certain herbicides or herbicide combinations is another aspect that deserves exploring as a means of lowering current labor requirements for weeding cassava.

Recommendations

Much of the ground level research on how to control weeds in cassava has been done, yet the adoption of new weeding methods has been at best slow and more often nonexistant. One way to speed the flow of information to cassava growers is to train the extension agents, agronomists and other people working with farmers. They need to know the importance and methods of weed management in general, as well as the specific information regarding cassava. Some work in this area has been done in Colombia and Brazil (and certainly other countries as well), but the need for more trained people in weed science is great. Future training programs should include those practices appropriate to (1) cassava growers with large acreages who can readily use an integrated weeding system built upon cultural, mechanical and chemical control measures and (2) small farmers who for the foreseeable future are probably limited to cultural and physical control measures.

The previous discussion has dealt with the direct effects of weeds on cassava. An area of research still in its infancy is that of the interrelationships between weeds, insects and diseases. We do not know how many weed species may be serving as hosts for insects and diseases of cassava. Similarly, we do not know how many beneficial effects of certain weed species may exist. It is possible that some species may repel or otherwise reduce insect infestations and that by leaving either narrow strips of these weeds or low, noncompetitive levels in the field, insect damage may be reduced. Better yet would be a cropping association that would have a complementary effect of reducing pest problems.

Another unexplored area of weed science with regard to cassava is that of allelopathy. Very little is known for any crop regarding how plants interact with one another and whether or not certain crops or varieties are able to inhibit the growth of some weed species and vice versa. In a preliminary effort along these lines, I did observe that fresh cassava leaves were able to reduce the seedling vigor of some weeds (unpublished data). Further research might identify which varieties have the greatest potential for doing this and also which weed species are most affected by the inhibitors found in cassava.

Another area needing further research is that of cassava grown as a mixed crop. The aspects of weed competition in associated cropping systems have not been studied, and equally urgent is the need to find herbicides selective to both cassava and the crops commonly grown with cassava. With this information, an integrated program of weed control methods (cultural, mechanical and chemical) should be developed for these associations.

The possibility of using no-till establishment techniques for cassava also deserves evaluation. If appropriate and practical, they would greatly reduce the labor requirement at planting time and perhaps lower the weed pressure early in the season as well. Herbicides are already available for such systems and are widely used for soybean and maize planting in many countries, including Brazil. These products are nonselective and leave no soil residue, therefore killing most or all weeds present at the time of application so planting can be done almost immediately. Dying weed vegetation often forms a mulch that reduces soil moisture loss and prevents the germination of weed seeds.

Lastly, I encourage research on special problem weeds in tropical crops including cassava, such as *Cyperus rotundus* L., *Rottboellia exaltata* L. and *Bidens pilosa* L. These and other species present particular problems to cassava growers in Latin America. Measures to prevent their spread and to control them more effectively need to be explored. Hopefully, national and international research organizations will commit themselves to the challenges of improving weed management in cassava production systems.

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Caicedonia: an improved cassava-growing area with integrated control

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Abstract

The results are given of 6 yr of technical assistance from CIAT, integrated with a program of the National Coffee Growers Federation, designed to diversify crops being grown in the region of Caicedonia (Colombia). From an initial 60 ha and 8 farmers in 1971, the program has developed more than 1300 ha with 90 farmers. This has been achieved through a combination of factors including favorable environmental conditions, high net profits, a high-yielding local variety (Chiroza Gallinaza), market proximity, farmer receptivity to technical assistance, and availability and timeliness of credit. Special problems dealt with successfully include biological control of *Erinnyis ello* and CBB eradication. Optimal plant density recommended for this region is 7000 plants/ha. The region has benefited both socially and economically.

Background data

Caicedonia is a township in the Valle del Cauca (Colombia) with an area of 243 km² and 126,000 inhabitants, mostly farmers, whose principal cash crop is coffee. In a development program to diversify this region, the National Coffee Growers Federation initiated a project in 1971 to produce cassava on 2000 hectares available for this purpose. An agronomist was selected to receive one year of training in cassava production at CIAT.

When this agronomist began work in July 1972, there were only 60 ha (8 farms) planted to cassava. The crop was planted on hilly, marginal soils with practically no weed and pest control since cassava was considered as a subsistance crop. There was no technical assistance or credit available to farmers.

As regards cultural practices, the farmers used a subsoiler to prepare the land, planting the cuttings in a horizontal position in the row made by the plow. This practice was used because there was a severe problem of root rot; however, there was more root rot than before because they had planted cassava in the rows opened by the subsoiler.

Factors related to the project's success

In six years the area planted to cassava has increased more than 20 times (1300 ha, 90 farms).

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This increase can be attributed to the following interrelated factors:

Environmental conditions

Edaphic and climatic conditions in the region are favorable for high cassava yields: altitude, 1100 m; mean temperature, 22.5°C; RH, 81%; annual rainfall, 1900 mm, well distributed throughout the year. The soils are of volcanic origin, characterized by excellent physical properties: organic matter, 5.3%; pH, 5.5; P (Bray II), 70.0 ppm; K, 0.68 meq/100 g; texture, sandy loam.

Crop profitability

Net profits from cassava are higher, and less risk is involved than any other crop in the region (2). In 1973 some coffee was uprooted to plant cassava. The highest net profit reported by a farmer was more than US$1800/ha (Table 1). Net profits in this region depend on marketing methods, which have changed with time. At present, the crop is sold while still on the plant (age 8 months) and harvested by the buyer himself at his convenience (at 10-13 months).

Variety

Chiroza Gallinaza is an excellent local variety with a high yield potential and good-quality roots. For these reasons, the farmers prefer it.

Table 1. **Profitability of operations where farmers received technical assistance.***

Farmer	Production cost/ha		Net profit/ha	
	Col.$	US$**	Col.$	US$**
		1973		1973
1	7,000	194	37,078	1,032
2	7,020	195	36,370	1,038
3	5,299	147	67,323	1,898
4	5,959	169	28,888	802
5	7,824	217	49,726	1,403
		1975		1975
6	5,300	153	57,407	1,594
7	4,900	140	54,991	1,571
8	5,000	142	37,333	1,037
9	4,700	134	29,999	862

* Source: Diaz, R.O. (2)

** One dollar equivalent to Col$36

Proximity of markets

The plantations are well located with respect to important markets. Cassava harvested in this region arrives at these markets in less than 12 hours.

Farmer acceptance

Because the project was sponsored by the Federation, which is a highly accredited national institution, farmers were highly receptive. Another factor was the close relationship between project leaders and the farming community, in addition to the effectiveness of the technical assistance provided.

Credit

Not only was unlimited credit available to farmers, but it was always given on time. Technical assistance was provided as part of this plan. As can be seen in Table 2, farmers receiving technical assistance reached a peak in 1975 and 1976, falling considerably in 1977. The reason for this is that the Federation did not lend money to the same farmers each year. Nevertheless, technical assistance was given to farms who had had it previously if they required it. Hectares with credit followed the same pattern, but total number of hectares increased constantly.

All these interrelated factors are important; nevertheless, the project would not have been as successful if there had not been an agronomist with

Table 2. **The situation of cassava production in Caicedonia over a 7-year period.**

Year	Farmers with technical assistance	Hectares with credit	Hectares without credit	Total area
1971	0	0	60	60
1972	5	93	60	153
1973	12	152	270	422
1974	23	214	300	514
1975	35	380	600	980
1976	34	297	770	1,067
1977	6	83	1,300	1,383

Source: Garcia, P. Samuel. Monthly activity reports to the Coffee Growers Federation, July 1972 - Sept. 1977

a solid knowledge of the crop, trained to pass this know-how on to the farmer. The agronomist was on top of any problem that arose, communicating new developments to the cassava team at CIAT. There was a continuous flow of information between researchers and farmers.

It is important to point out that new cultural practices were introduced more readily when stipulated as part of the credit plan for farmers. These practices included planting on the ridge and use of the variety Chiroza. Loans were not granted to farmers who did not use the improved techniques.

Collaborative research at the regional level

At the Federation's request, a series of experiments were conducted to solve specific problems that arose during this period of collaboration. For example, a population experiment showed that optimum plant density for the region was around 7000 plants/ha for good-sized commercial roots (1). Based on a series of trials, a mixture of herbicides was developed and has been in use since 1973 (3). Entomologists introduced biological control of the hornworm *Erinnyis ello* with larval predation by the *Polistes* wasp, egg parasitism by *Trichogramma* wasps and spraying of the bacterial disease of larvae, *Bacillus thuringiensis*. A regular regional trial with promising varieties is planted every year. At harvest time CIAT participates in a field day organized by the Federation. At this time, a special presentation is made, whereby all farmers in the region are provided with data on varietal performance, new cultural practices, and delivery of "seed" to farmers who may select the variety they would like to evaluate under their own conditions.

Problems encountered

The variety Chiroza is susceptible to Cercospora leaf spots, cassava bacterial blight and thrips. Since cassava is now intensively and extensively cultivated in this region, it is a continuous host of many pests. A biological control program was recommended. In spite of the fact that the farmers had been informed that the effects of this control were not immediate and that the variety would recover from pest attack because it was a vigorous type, they applied organophosphate insecticides to the crop, which also killed the predators of these pests, upsetting the ecosystem. It was not until many of their fields had been defoliated by the hornworm that they paid more attention to biological control.

In 1974 an outside businessman wanted to plant cassava, but since no one sold him planting material, he unknowingly bought CBB-contaminated material from a neighboring county. In this way they introduced the disease into a region. The agronomist detected the problem and organized a field day to alert the farmers. Diseased plants were rogued and burned. As a result, the disease was eradicated and cooperation among farmers was stimulated. The continuous observation of preventive measures has prevented the introduction of new diseases.

Conclusions

The results obtained during these six years of technical asistance provided in close collaboration with a national institution are a clear example of how a region can be aided in developing and improving production, keeping the crop free of major problems. Cassava has increased the benefits for the people of this region, both socially and economically. This is an illustration of how technology can be applied effectively when administered by the appropriate channels, resulting in the farmer's benefit.

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Pathology sessions

Cassava bacterial diseases

E.R. Terry *

Abstract

Bacterial disease of cassava—leaf spots, stem rot and blight—are discussed, with emphasis on cassava bacterial blight *(Xanthomonas manihotis)* in Africa. The following aspects are dealt with in detail: distribution in Africa, factors contributing to the pattern of CBB development (cultivation systems, rainfall and soil conditions), economic importance, etiology and symptomatology, factors influencing dissemination of the disease (propagating material, vectors, rainfall, soil conditions, sources of inoculum) and integrated control. Yield losses range from 14-100%, depending on variety, locality, time of year and cultivation system. CBB also reduces starch content and availability of planting material and foliage as a source of protein.

Introduction

Cassava is grown in a wide range of environmental conditions, extending from the hot humid tropics to the warm border of the temperate zones. In 1975 the total world production grown on approximately 11 million hectares was 105 million tons, about 41% of which was produced in Africa, 29% in South America and 27% in Asia (9). The increasing importance of cassava in global agriculture has recently generated interest in the crop, resulting in a considerable commitment of personnel, effort and funds for research. This increased attention has resulted in the realization that cassava is susceptible to various diseases that cause significant crop losses.

This article attempts to document the available knowledge on cassava bacterial diseases as a basis for developing an integrated control system for cassava diseases and pests. Because of the scanty information on bacterial stem rot (*Erwinia* spp.) and bacterial leaf spot *(Xanthomonas cassavae)*, these two diseases are only discussed briefly; major emphasis is on cassava bacterial blight *(Xanthomonas manihotis)*.

Bacterial leaf spots

Incidence of bacterial leaf spots on cassava have been reported in Mauritius (27), Malagasy Republic (3), Malawi (40) and Uganda (12). The disease in Mauritius and the Malagasy Republic has been attributed to *X. manihotis* (10), while those in Malawi and Uganda have been attributed to *X. cassavae* (40). The latter bacterium has also been reported as the causal organism of a leaf spotting and defoliation of cassava in Zaire (5). It is

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possible, however, that in these earlier reports the pathogens involved were inadequately identified.

It has been argued that *P. solanacearum*, *Erwinia cassavae* and *X. cassavae* are obviously not related to *X. manihotis* (20). Disease symptoms reportedly induced by the first two pathogens and the morphological, physiological and biochemical characteristics of each of these bacteria are apparently very different from those of *X. manihotis*. For instance, *X. cassavae* induces leaf spots but these are initially circular, not angular, and are surrounded by a yellow halo with radial necrosis of the veins. In addition, the pathogen is restricted to leaf tissues and produces a yellow pigment on sugar-containing media.

Bacterial leaf spot diseases of cassava do not appear presently to be a major source of crop loss. Furthermore, information on aspects relevant to the formulation of an integrated control system has not been documented.

Bacterial stem rot

This disease has only recently been reported from Colombia. Preliminary cultural, morphological and biochemical tests, as well as symptomatology, show that the bacterial species and the disease it induces are different from the cassava blight bacterium (7). Tests show that the pathogen is a gram-negative, rod-shaped organism belonging to the genus *Erwinia*.

The organism is apparently restricted to stem tissues, and infected plants show blackish necrosis, wilting and finally dieback. Buds located along infected stem portions are first invaded and necrosed; thus infected stem cuttings may be lost for planting purposes (7).

Investigations are being conducted at CIAT as regards the importance of this disease and its epidemiology. Formulation of strategies for the control of the disease must, therefore, await the results of this research.

Cassava bacterial blight

Although this disease has been reported recently in Colombia (21), Taiwan (18), Malaysia and Thailand (6), this article will deal almost exclusively with the disease in Africa. While some aspects of the disease in Africa are similar to those reported in Latin America and Asia, the cultural, environmental and socioeconomic factors that affect the development, spread and control of CBB in Africa are sufficiently different to warrant special considerations.

Geographic distribution in Africa

Within the last five years outbreaks of CBB have been reported in nine African countries; viz., Nigeria (41), Zaire (11), Cameroon (Terry and Ezumah, unpublished data), Republic of Benin, Togo and Ghana (38), Republic of Congo (32), Rwanda (Mostade, personal communication) and Uganda (Otim-Nape, personal communication) (Fig. 1).

It is important to mention that these countries represent locations where surveys for the disease have been made and its incidence confirmed. The possibility exists that the disease is unreported in other African countries where detailed surveys have not been made. The nine countries with confirmed incidence of CBB fall into three major regional groupings: West Africa (Western Cameroon, Nigeria, Benin, Togo and Ghana), Central Africa (Eastern Cameroon, Zaire and Republic of Congo) and East Africa (Rwanda and Uganda).

West Africa

Cameroon. The disease was first observed in the Northwestern, Western and Littoral provinces of Cameroon in 1974 (Terry and Ezumah, unpublished data). CBB is now known to occur in both forest and savanna areas but is more prevalent in the savanna where cassava is grown as a monocrop (28).

Nigeria. The disease was first reported in the central and southern regions of the country in 1972 (41). The highest incidence was observed in the high rainfall, forest regions in the south-central and southeastern areas where total crop destruction was found (Terry, unpublished data).

Republic of Benin. The disease is widely distributed in the southern part of the country, occurring frequently between Cotonou and

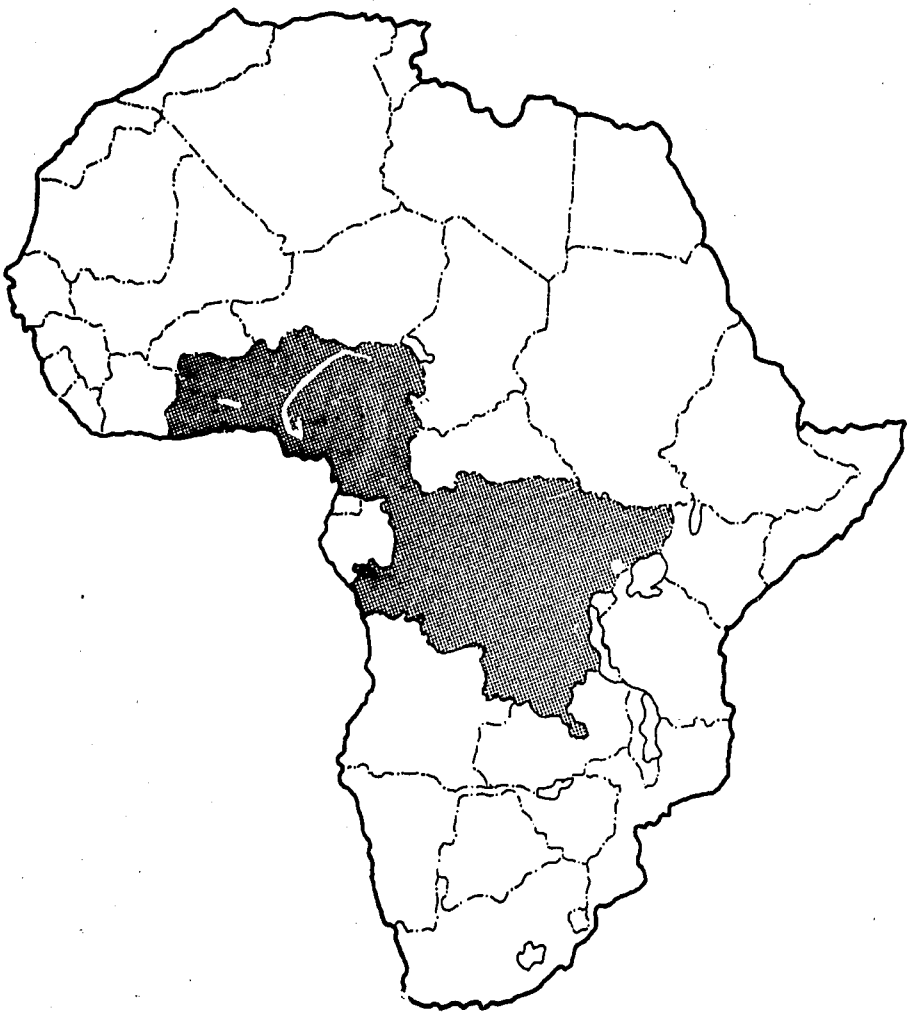

Figure 1. Geographic distribution of CBB in Africa (May 1977).

Abomey and in the Save region near the Nigerian border. There appears to be considerable informal trade of cassava cuttings from western Nigeria to the Republic of Benin, especially in the Save region (31).

Togo. The disease was first observed on the cassava collections at the IRAT stations in Davie and Amoutochou. At Amoutochou, it was observed only on cultivars introduced from the Malagasy Republic and an adjacent collection of local cultivars (31). There have been other reports of the disease on local farms along the coast between Agbessie and the Ghana border (Adam, personal communication).

Ghana. In 1975, the disease was of apparently limited distribution, occurring in the Volta region near the Togolese border and in the Pokase region west of Accra. It has apparently spread to the coastal savanna areas of the central regions (Kogang-Amoakoh, personal communication).

Central Africa

Zaire. Although the first official report of the recent outbreak of CBB was made in 1973 (11),

Maraite and Meyer (24) state that the disease had been observed in the southern part of Zaire since 1970. The disease appears to have spread from Bandundu Province into Bas-Zaire and Kasai Provinces and is generally more severe in the savanna than in the forest areas (11).

Republic of Congo. Reports from the Brazzaville area, the Konkonya plateau at Londima and the Monyondzi region indicate a high incidence of CBB in these areas (Batsimba, personal communication). The disease is very severe at Mbe in the grassland savanna zone where all three local cultivars are highly susceptible (Terry, unpublished data).

East Africa

Rwanda. CBB was first observed at Mont Julu (altitude 1750 m) in 1977 and later at Nyabisindu; however, incidence at both sites was quite low, and the disease was only moderately severe (Mostade, personal communication).

Uganda. A recent report indicates that incidence of CBB was first confirmed in the Nile and northern provinces in 1976. The disease appears to be more severe in the South Nile districts, tending to decrease in both incidence and severity northward (Otim-Nape, personal communication).

Factors contributing to the pattern of CBB development

Cultivation systems

The predominant cultivation systems in the three regions where CBB incidence has been confirmed are characterized by the following:

1. Farms are usually small, ranging from less than 1 ha to 5 ha. Farm sizes tend to be larger as one moves from the rain forest to the savanna areas, but the number of crops in mixtures lowers.
2. The most common land-clearing practices involve the use of fire.
3. Crop establishment and growth are almost entirely dependent on rainfall. Cropping patterns and mixtures are related to the uncertainties in rainfall distribution and intensity.
4. Intercropping is the most widespread practice with the highest complexity on compound farms, especially in the rain forest where annual staples, vegetables and perennial fruit trees are intercropped.
5. Crop rotations take the form of mixed intercropping with different species followed by different sets of dominant and subsidiary crops (26).

Rainfall

West Africa: Climatically, this area is characterized by an average annual rainfall of more than 3000 mm along the coast, which decreases rapidly to about 750 mm in the northern areas. The rainfall distribution is primarily monomodal (May-October), but some areas have a bimodal distribution (May-July/September-October). In some areas along the coast of Cameroon and Nigeria, rainfall may exceed 4000 mm and can reach a peak of 10,000 mm a year.

Central Africa. This area is characterized by a typical equatorial climate with an average annual rainfall of 1500 to 4000 mm, which is evenly distributed throughout the year. The savanna has a lower annual rainfall (750-1500 mm), largely concentrated in a few months, with a dry season from November through February or from May to August, depending on whether the location is north or south of the equatorial belt.

East Africa: This area is characterized by a mean annual rainfall of 500 to 1000 mm although in some areas around Lake Victoria and Lake Nuasa, rainfall may be as high as 1500 mm. Most of this rain falls in a few months: south of the equatorial belt this occurs in the period between October and May, and north of the equatorial belt between March and October.

Soil conditions

Cassava is grown extensively in those areas of Africa where shifting cultivation is practiced. The crop does not require high fertility or good physical soil properties, but it cannot tolerate high ground water. Thus it is the preferred crop in many areas with poor soils that have been depleted by the production of more nutritionally demanding crops such as yams, maize or grain legumes.

These soils have the following general characteristics: They are dominated by Kaolinite clays with a low mineral reserve for supplying nutrients to plants; their low cation absorption capacities make them particularly susceptible to leaching. When forests are cleared by the traditional slash and burn method, their natural fertility is gradually exhausted by leaching and the surface becomes depleted even below the subsoil.

These soils generally have a low water-holding capacity; and since the beginning of the growing season coincides with the onset of the rainy season, the soil profile during this period is partly or wholly devoid of available water. Drought stress at the beginning of the growing season and dry spells during the growing season are, therefore, limiting factors in the production of most crops in these areas (8). Once cassava is established, however, it can utilize soil moisture better and from greater depths than most of the other annual food crops. Thus, it is the main and often the only crop grown in sandy soils that are particularly prone to drought stress after short, rainless periods.

Economic importance

Cassava bacterial blight is considered the most devastating of several bacterial diseases of cassava because it often results in total loss of both yield and planting material under conditions favorable for its development (21).

Estimates of the incidence of CBB made during field surveys vary with varieties, location, time of year and type of cropping system. These estimates range in Nigeria from 14% (Arene, unpublished data) in cassava plots interplanted with both maize and melon to 100% with cassava as a sole crop (34).

In Zaire, destruction of cassava farms in Kikwit (south-central) and of young plantations in the southern part was reported by Hahn and Williams (11) and Maraite and Meyer (24). In Uganda, the results of a detailed survey indicate that up to 84% of cassava farms were infected in some areas (Otim-Nape, personal communication).

Reduction in yield due to CBB varies with the location, level of susceptibility of the varieties, seasonal fluctuations, time of planting and the magnitude of inoculum disseminated. Yield loss has been difficult to assess because of the susceptibility of the currently favored varieties to other major cassava diseases.

In a yield assessment of three varieties in Nigeria during 1975, variety 60444 (8.8 t/ha) was more susceptible than 53101 (9.7 t/ha) or Isunikakiyan (12.2 t/ha). The CBB severity ratings for these three varieties were 3.2, 2.9 and 2.8, respectively (on a 1 to 5 scale of increasing severity). The 1971-72 yields of the same varieties in the absence of CBB ranged from 19 to 21 t/ha (39). While there are other factors that might have contributed to these differences in yield, it seems likely that CBB infection was at least partially responsible. Arene (unpublished data) reported that root yields of variety 60444 were reduced by 90% as a result of early CBB infection in Nigeria.

Crop loss due to CBB is also manifested in the reduction of starch content of roots from infected plants. In Nigeria, Obigbesan and Matuluko (25) reported an average reduction of 5 to 7% in root starch content for varieties 53101 and 60506, respectively, when severely affected by CBB.

The destruction of planting material for the succeeding year's crop due to dieback of cassava stems represents a considerable loss. In Zaire, cassava leaves are widely used as a leafy vegetable for protein; in Shaba and Kivu provinces the root is of minor importance since the crop is grown mainly for its leaves (Ezumah and Sebasigari, unpublished data). The large-scale defoliation of cassava in recent years due to CBB has therefore led to a shortage of leaves and a search for an alternate source of protein.

Etiology and symptomatology

The causal agent of CBB is *Xanthomonas manihotis*. This pathogen can cause an unusually wide variety of symptoms and is the most commonly encountered cassava bacterial pathogen.

The bacterium normally penetrates the host via stomatal openings or through epidermal wounds (20), and initial symptoms appear as water-soaked angular spots, which often exude sticky yellowish

droplets on the lower leaf surface and along the veins. If undisturbed, these droplets may dry to form tiny pellets (36). The spots eventually turn brown, enlarge and coalesce, forming large necrotic areas which later turn purplish brown. When one or more lobes or the entire leaf lamina becomes necrotic, the manifestation is called "blight."

The development of the disease and the pattern of symptom expression resulting from the propagation of infected cuttings differ from those that occur after stomatal penetration by the bacterium. With the former, the following may be observed: (a) loss of turgidity of one or more leaves, which rapidly wilt; (b) the base of the petiole collapses, but the dried leaf may remain attached for some time; (c) all leaves located above those showing the first symptoms wilt progressively (24); (d) gum exudation may be observed on the stem close to the first wilted leaf; and (e) the unlignified tops die while new shoots appear at the junction of the dead and healthy woody stem.

Three different bacteria have been reported as causal agents of cassava diseases: *Xanthomonas manihotis* (Arthaud-Bertet) Starr, *X. cassavae* Wiehe and Dowson, and *Pseudomonas solanacearum* (E.F. Smith) (4). It has been suggested that *X. cassavae* is a yellow strain of *X. manihotis*, but Bradbury (4) believes that this is unlikely. Preliminary reports from Kenya (Onyango, personal communication) indicate that what is presumed to be a yellow Xanthomonad has been isolated from cassava showing symptoms of a bacterial disease. The field symptoms observed and those induced by inoculation with this isolate are apparently similar to those observed in western Kenya in 1973 (35). Pathogenity tests and identification of this bacterium are in progress.

Brief reference has already been made to the other bacterial diseases of cassava that are characterized by leaf spotting. It appears, however, that an important distinguishing factor between these diseases and CBB is that infection is limited to the foliage and that the massive defoliation observed is due to severe blighting and not to wilting. According to Wiehe and Dowson (40) in Malawi, the necrosis of infected leaf veins extends radially from the margins of the spots, but the leaves are shed before the petioles are badly infected so that the stems are not attacked. Under very humid conditions, the spots coalesce causing destruction of large areas of the lamina, followed by severe defoliation, and such plants appear to be more susceptible to attack by the fungus *Botryosphaeria ribis* Gr. and Dug., which causes a dieback often extending to ground level.

Factors influencing CBB dissemination

Propagating material

The propagation of infected cuttings obtained from the previous year's diseased crop is largely responsible for the continuity and dissemination of the disease through successive growing seasons. The widespread movement of infected planting material in an area also contributes to the rapid spread of the disease. Lozano and Sequeira (21) reported that 86% of the plants in a plot established with cuttings from a CBB-infected planting became infected.

Vectors

Insects have been suggested as possible agents for disseminating CBB (2). In Nigeria, during the early part of the rainy season (March to April), the "dry season" population of the variegated grasshopper *Zonocerus variegatus* is high. These grasshoppers move around infected cassava plants quite freely and their mouth parts and appendages become contaminated with wet bacterial exudation. This suggests a possible role for *Z. variegatus* in disseminating the disease (37). The role of other insects in disseminating the bacteria has also been demonstrated in Colombia; however, these investigations indicated that spread attributable to insects occurred only over short distances (22).

Rainfall

Rain splash is probably the most important factor in the lateral dissemination of CBB from plant to plant. The incidence of CBB in a Nigerian field planted with a susceptible variety (Isunikakiyan) was monitored by counting the number of plants with angular leaf spots at monthly intervals from November 1973 to August 1974. The rainfall distribution for the period was also recorded. The results (39) indicate that there was a decrease in the incidence of angular leaf spots after the rains subsided in November. The

incidence remained low from November until March, increased in April, and continued to rise until August. This pattern concided with the rainfall distribution for the same period. According to Lozano and Sequeira (21) rainfall provides the conditions necessary for mobilization, distribution and penetration of inoculum, and it is probably the most important environmental factor affecting CBB development.

Soil conditions

Although some reports from surveys in Africa indicate that CBB is most severe on cassava growing on soils of poor nutritional status (13, 24), data on the effect of low soil fertility on the severity of CBB are inconclusive.

In an experiment with variety 60444 as the CBB indicator, there was a significantly ($P < 0.05$) higher number of plants killed by CBB in an unfertilized low-fertility soil than in the same soil fertilized with NPK (39). In Nigeria, significant reduction of CBB was obtained when a susceptible variety 53101 was grown in soils fertilized with 90 kg/ha potassium (1). In Warri, Nigeria, an area with sandy soil of low fertility, the effect of various NPK treatments on disease development was tested. No significant effects were detected from the various NPK combinations on disease incidence and yield. Leaf analysis showed no significant difference in the nutritional status of the plants from different treatments. This suggests that some other factor was limiting.

It is important to note that although cassava can be grown under a wide range of environmental conditions, the crop performs better on soils with good physical characteristics and in areas with well-distributed rainfall. Therefore, on sandy soils with low water-holding capacity and low nutrient status, it is possible that CBB expression may be more severe because of these combined factors.

The critical factors involving various aspects of climatic and edaphic conditions and their effect on CBB expression merit further investigation.

Sources of inoculum

Disease development is reduced appreciably during dry periods, but the survival of dry bacterial pellets on a few leaves provides a ready source of inoculum. These pellets contain between 100,000 to 1,000,000 viable cells (37) which become active during subsequent rainy periods.

The rapid spread of CBB has prompted investigations into long- and short-term survival of the bacteria. According to Ikotun (14) survival in soil is not as important as survival in bacterial exudate and in host tissue. In Nigeria, bacterial cells within pellets remained infective after 22 months' dry storage at room temperature (15).

An epiphytic population of *X. manihotis* has been detected on the surface of apparently healthy leaves during the dry season (January) and also during the growing season (June). This suggests that a low population of the pathogen can survive the dry season as an epiphyte (17).

Preliminary investigations (30) revealed that seeds from infected plants which had been stored in a cold room (5°C) since 1975 carried the bacterium. This indicates a potential for seed transmission of the pathogen.

Integrated control

Since cassava is a subsistence crop, intercropped in small holdings, the disease is not a practical target for chemical control. Furthermore, bactericides have not proven effective against CBB, especially in systemically affected plants. On the other hand, chemical control is uneconomical because of the comparatively low returns. A 1974 analysis of estimated returns for selected crops in the forest zone of Nigeria indicated that cassava would yield US$2.54 man-day of labor while cocoa and oil palm would yield $5.43 and $5.00, respectively (33).

Crop rotation may be practiced as a control measure for CBB. The removal and destruction of all infected debris by burning is recommended by Lozano (22) since an interval of six months between successive crops is probably sufficient to prevent the carry-over of the pathogen in the soil.

All planting material should be selected carefully from fields and plants apparently free of CBB. Stem sections with suspicious signs of the disease must be eliminated (23). Bacteria-free plants can also be produced successfully by using a method developed by Lozano and Wholey (19).

The most practical control method is host plant resistance, and the IITA Root and Tuber Improvement Program has assigned high priority during the past five years to breeding for resistance to CBB. Hybridizations of selected parents have been made with resistant clones, and large numbers of progenies have been tested for resistance under field conditions in Nigeria and Zaire.

During 1975 some 100,000 seedlings from 1270 families were raised from seeds of crosses and introductions and then screened for CBB resistance. The 300 most promising clones were evaluated without fertilizer in yield trials at four different sites in Nigeria. Several selections outyielded the local standard varieties by 2 to 18 times; the highest average yield was about 50 t/ha, primarily because of resistance to diseases, especially CBB (16).

Different screening methods developed include stem puncture, leaf infiltration, leaf spraying and leaf clipping. Advantages include (a) standardization of the inoculum dose, (b) simulation of natural field infection and (c) rapid symptom inducement and disease development. Leaf clipping is the most suitable for routine screening because it facilitates the rapid inoculation of a large number of plants (16).

Nevertheless, this approach involves long-term breeding programs for the selection, evaluation and release of high-yielding resistant varieties; therefore, it is imperative in the interim to utilize presently available knowledge to develop short- and long-term integrated control systems. These systems should incorporate aspects of exclusion and eradication of the pathogen by crop sanitation practices, as well as host plant resistance.

In spite of the rapid spread of CBB into many of the major cassava-growing areas in Africa, there is still an urgent need to contain this trend and prevent its introduction into CBB-free areas. Furthermore, the possible existence of different strains within *X. manihotis* (16,24) demonstrates the need for strict exclusion procedures. The existence of three similar bacterial diseases (4) emphasizes the importance of careful quarantine measures. Cassava vegetative material should not be imported from countries where CBB has been reported. As regards true seeds, the possibility that they can carry viable *X. manihotis* over a considerable period of time highlights the need for an effective seed treatment procedure prior to shipment and distribution. Treating seeds in hot water and 60°C for 20 minutes can apparently eliminate the bacterium (3).

There are still some aspects of this disease that should be investigated to facilitate the development of an efficient integrated control system: (a) a survey of countries where CBB has not been reported to document its presence or absence, which has immediate implications relating to the movement of infected planting material; (b) the effects of agronomic practices, especially mixed cropping, on the development of CBB, with a view to improving recommendations on cultural control; and (c) determination of the existence and significance of pathogenic variation of *X. manihotis* to improve screening for host plant resistance so that ratings reflect the likely performance of varieties in the field under natural infection.

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American virus and mycoplasma diseases of cassava

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Abstract

The following aspects of virus or mycoplasma diseases in cassava (common mosaic virus, leaf vein mosaic, latent virus, witches'-broom and frog skin) are presented: geographic distribution, economic importance, strains, host range and symptomatology, transmission, serology, stabililty, purification and properties of particles. Aspects requiring further research are discussed.

Cassava, one of the most important tropical crops, is attacked by several diseases that can reduce yield or cause complete loss when conditions are appropriate for the development of an epiphytotic. Some of these diseases are produced by plant viruses or mycoplasmalike organisms. At present they are restricted to limited areas; however, with the increased interchange of vegetative material, they may be introduced to areas where there are natural vectors or conditions favor their development.

Only two virus diseases and one mycoplasma disease have been identified in the Americas: cassava common mosaic, cassava leaf vein mosaic and witches'-broom disease, produced by the only mycoplasmalike organism registered in cassava. These diseases have been studied mainly in Brazil; little is known about their incidence elsewhere (3-4,6,8-10,12-18,20-24).

Bacilliform viruslike particles have been observed in electron microscope studies of cassava plants that do not show any disease symptoms. These particles have received the name of cassava latent virus (8). Recently, a new disease (frog skin) was registered in Colombia (1), the causal organism of which is not known. To date, evidence suggests that it is not caused by a bacterium, fungus or nematode, nor is it due to mineral deficiencies or toxicity (1; Lozano and Castaño, personal communication).

In general little is known about these causal organisms, their dissemination under field conditions, geographic distribution, quantitative yield losses and control measures.

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Cassava common mosaic disease (CCMD)

CCMD, which was first recorded in 1938 (23), is characterized by the development of typical mosaic symptoms, with or without malformation of the leaf blade. In some varieties the symptoms may be of the yellow mosaic or vein-banding type; in others symptoms are very mild and in mature leaves may escape detection (Fig. 1). Symptoms are similar to those produced by the African cassava mosaic virus, which is not registered in the Americas; AMD is transmitted by whiteflies and completely unrelated to CCMD (2,6,8,11,18-19).

Geographic distribution

CCMD occurs in practically all cassava-growing areas of Brazil. It has also been reported in Peru and probably occurs in other Latin American countries where large collections of cultivars from Brazil have been introduced (6). The virus was also found on quarantined plants in Colombia (18) and on isolated plants in South Sumatra, Indonesia (Booth, personal communication).

Economic importance

CCMD is considered of minor importance, even though it can cause losses of 10 to 60 percent in individual infected plants, because it does not spread very fast in the field and is easily controlled when care is taken in selecting stock for propagation (3,6,8,18).

Pathogenicity

Host range and symptomatology

In nature the virus has been found only in *Manihot* spp. (6). In transmission tests it produces disease symptoms in several plants and multiplies without symptoms in *Euphorbia prunifolia*, a very good species for propagating the virus (6). After mechanical inoculation in cotton (*Gossypium hirsutum*), it induces irregular chlorotic local lesions followed by systemic vein clearing and then recovery of the inoculated plant (6,8). In castor beans (*Ricinus communis*) the virus produces a mild type of mosaic that tends to disappear as the

Figure 1. Symptoms of cassava common mosaic virus in cassava: stunting of the diseased plants, the presence of yellowish areas on the leaf blade and leaf distortion.

leaves become older (6). In *Gomphrena globosa* it produces local necrotic lesions a little larger than those produced in this host plant by potato virus x (6). In *Chenopodium* spp. CCMV produces local chlorotic or necrotic lesions, but there is no systemic invasion (6,8). Besides these *Malva parviflora* and *Datura stramonium* (26) have been reported as hosts.

Properties of infectivity

The thermal inactivation point (10 min) is between 70 and 75°C; the dilution end point above 10^{-4}; and longetivity in vitro is more than 64 days but less than 128 (3, 6). There is no information about the effect of the source plant on these properties, nor the effect of adding antioxidants or reducing agents.

Studies on transmission

The virus is readily sap transmissible (3, 6); mechanical transmission is one way in which it differs from the African cassava mosaic virus (18). CCMV does not have a known insect vector whereas ACMV does (6). In studies to identify a vector, results have been negative with the whiteflies *Bemisia tabaci* (6,8), *B. tuberculata* (6), *Aleurothrixus aepim* (6,8), *Trialeurodes variabilis* (6). Similar results were obtained with the thrips *Scirtothrips manihotis* (6,8) and with the mites *Mononychus bondari* (6), *Tetranychus urticae* (6) and *T. telarius* (8). CCMV is not transmitted by sexual seed (6), but it is efficiently disseminated in vegetative cuttings from diseased plants (6,7). It is also readily transmissible by grafting (3).

Purification of the virus

Properties of particles

There is no information about the sedimentation coefficient, molecular weight, diffusion coefficient, isoelectric point, electrophoretic mobility, absorbance at 260 nm or the ratio 260/280.

The CCMV particles are flexuous filaments ca. 500 nm in length and ca. 15 nm diameter that do not show an internal channel (6, 8, 12, 17). There is no information on particle composition.

Relation to cells and tissues

CCMV is found in the cytoplasm of practically all cell types, except tracheids and sieve tubes (12, 17). Virus inclusions of varied size and shape, consisting of masses of virus particles more or less parallel but without a definite arrangement are common (12, 17). They have also been observed in *E. prunifolia, C. quinoa, C. amaranticolor, M. parviflora* and *D. stramonium* (26). It seems possible to use the presence of these inclusions for diagnosing the disease with the light microscope (8).

Serology

CCMV is active serologically, and using a partially purified preparation it was possible to obtain antisera that reacted with infected sap from *E. prunifolia, M. utilissima,* and *Chenopodium* spp., as well as with purified preparations, but not with sap from healthy plants (17, 25).

CCMV is considered as one of the components of the potato virus X group, but it does not react with antiserum against that virus (6, 17).

Control

The disease is easily controlled when there is early roguing of diseased plants and care is taken in selecting virus-free plants for propagation (3, 4, 8).

Attempts to free virus-infected cuttings by heat therapy were unsuccessful since the temperatures that permitted cutting survival were ineffective (5, 7).

Cassava leaf vein mosaic disease (LVMD)

Cassava leaf vein mosaic disease, also known as cassava vein mosaic or veinal mottle virus, has been registered since 1940 (3). The disease is characterized by the development of veinal mosaic symptoms that are not generally seen in very young leaves. The chlorotic areas may be limited to the veins or invade the leaf parenchyma near the veins. Leaves with symptoms have the lobes generally curled downwards (6, 8, 19) (Fig. 2).

Geographic distribution

The disease produced by LVMV has been recorded in the states of Rio de Janeiro, São Paulo,

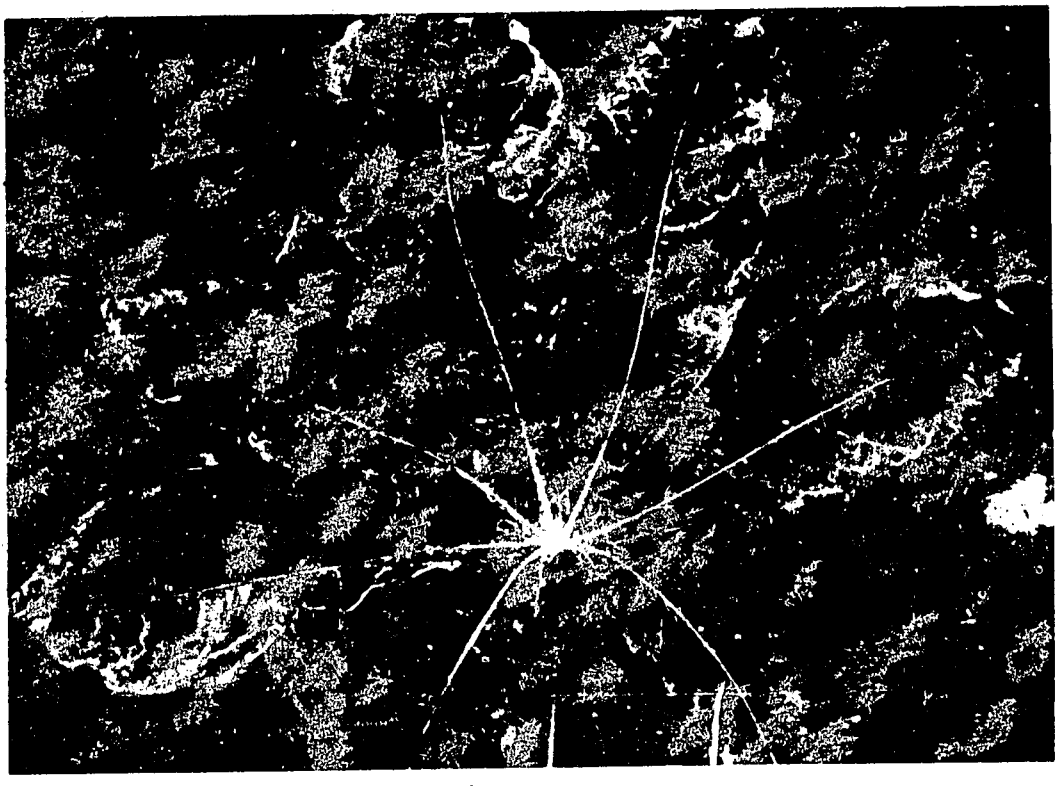

Figure 2. Symptoms of leaf vein mosaic virus in cassava: yellowing of veins and leaf curling.

Pernambuco, Mato Grosso and Rio Grande in Brasil, mostly in collections of cassava cultivars in experimental stations, but rarely in commercial cassava plantions (6). It has also been registered in Venezuela (19).

Economic importance

The disease is considered of little economic importance (6, 8); but there is no reliable data to determine losses in individual infected plants (18).

Pathogenicity

Host range and symptomatology

The virus has been found naturally only in *Manihot esculenta* (6). In transmission tests with many species of Cruciferae and other families, symptoms of infection were observed only in *Datura stramonium* L. (6, 8).

Properties of infectivity

There is no information on thermal inactivation point, dilution end point or longevity in vitro. It has not been purified, nor is there complete data on the properties of its particles. LVMV has isometric particles about 50 mm in diameter. It can be observed in leaf dip preparations and ultrathin sections (13).

Studies on transmission

The virus is transmitted mechanically by sap inoculation, but this is difficult to do (6). LVMV does not have a known vector (3, 6). Studies with *Myzus persicae* and other species of aphids gave negative results (6). There is no information regarding virus transmission by sexual seed. It is disseminated by cuttings from infected plants and can, on occasion, be obtained from infected cuttings (6, 8). The virus is readily transmissible by grafting (6).

Purification of the virus

Relation with cells and tissues

LCMV occurs in the cytoplasm of infected cells dispersed in certain areas rich in ribosomes but poor in other cytoplasmic organelles (13).

Serology

The virus is not related to cauliflower mosaic virus, which it resembles morphologically (6).

Control

The disease is easily controlled by the use of healthy cuttings, which can be obtained through a certification program, the establishment of germplasm banks and quarentine measures (3-4,6,8). Heat treatment of cuttings was not a satisfactory procedure for obtaining virus-free plants (5).

Cassava latent virus

There are no symptoms of disease in infected cassava plants (6). Its distribution is unknown but may be widespread (18). No information is available on yield losses.

Properties of particles

The cassava latent virus has bacilliform particles 280 to 300 nm in length and 80 nm in diameter (6,8). The particles are present in the perinuclear space of cells in parenchymatous tissues of infected cassava plants (6).

Control

As there is no information on this virus as a disease agent, nothing has been done regarding its control.

Cassava witches-broom

Cassava witches'-broom, also known as "superbrotamento" or "envassouramento" has been described since 1939 in Minas Gerais, (20, 22) and in São Paulo, Brazil, in 1941 (9-10). It was first considered a virus disease (9-10, 22, 24); but later it was determined that it is produced by a mycoplasmalike organism (6, 14).

The disease is characterized by stunting of the infected plant and proliferation of shoots, especially near the apex, so the plant acquires a bushy appearance (Fig. 3). Leaf symptoms consist of slight vein clearing, yellowing and reduction in size. Roots become more numerous but are of poor quality and of no commercial value (6, 20, 24). There is excessive budding in cuttings taken from infected plants (Fig. 4).

Geographic distribution

It has been reported in Minas Gerais, São Paulo and Pernambuco in Brazil (8, 20); Mexico (16), Venezuela (18, 20) and may possibly be present in other parts of Brazil (6)

Economic importance

The disease is considered of little economic importance (8), but it can cause heavy losses (6, 18). It appears suddenly and after one or two years disappears. The Pernambuco type can cause death of plants produced from infected cuttings (6).

Pathogenicity

Host range

The disease has been recorded only in *M. esculenta* and *M. glaziovii* (18, 20, 24).

Strains

Costa and Kitajima (6) indicated that it is possible to differentiate three types of witches'-broom in Brazil: (a) The old type observed in São Paulo; (b) the Pernambuco type, which induces a less severe type of witches'-broom, but with strong leaf vein clearing and yellowing. Stunting is severer and there is death of shoots coming from infected cuttings (6); and (c) the Santa Barbara type, characterized by less stunting of the plant than type (b) and milder witches'-broom symptoms than type (a) (6). They have not been compared under the same conditions because of the possible introduction of new disease agents in areas where they may become a problem (6).

Properties of infectivity

The cassava mycoplasmas are morphologically indistinguishable from other plant-infecting mycoplasmas (6).

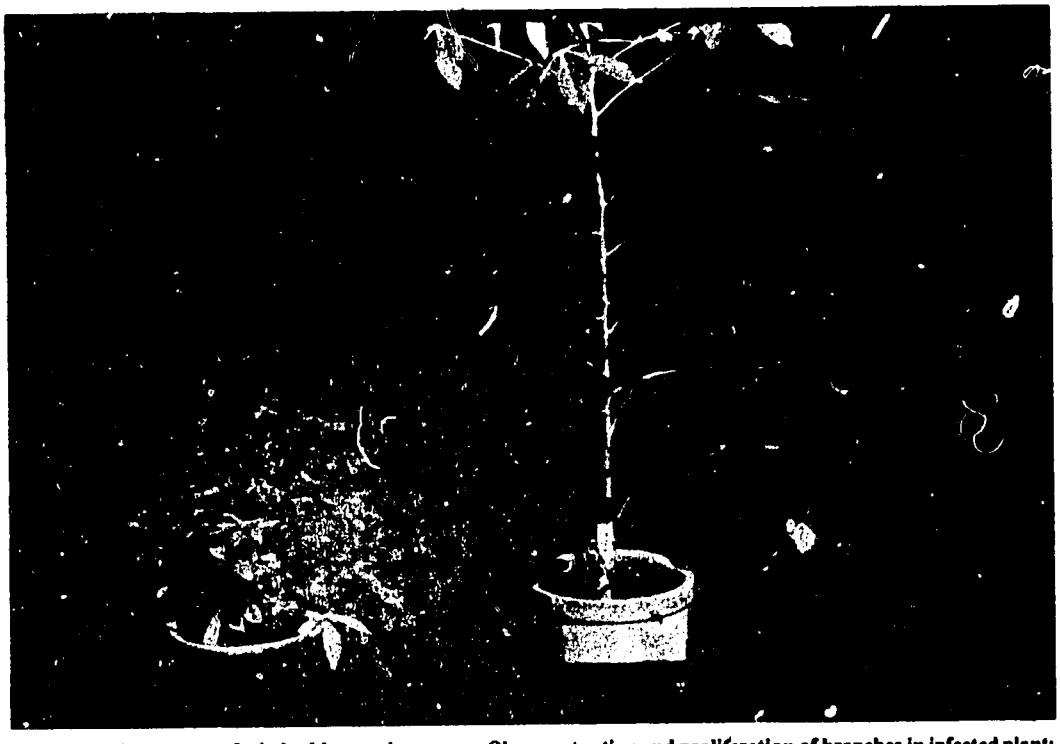

Figure 3. Symptoms of witches'-broom in cassava. Observe stunting and proliferation of branches in infected plant; shoots have small leaves and short internodes.

Relation with cells and tissues

The mycoplasmalike organisms in cassava occur mostly inside the sieve tubes of infected plants, but some of them might be present in the parenchyma cells adiacent to the sieve tubes (6, 14-15).

Figure 4. Symptoms of witches'-broom: proliferation of shoots in cuttings taken from infected plants.

Studies on transmission

There is no mechanical transmission (20, 24), nor are there any known vectors (6, 20). Experiments on vector transmission using the whiteflies *A. aepim, B. tuberculata, T. variabilis* or the thrips *S. manihotis* gave negative results (8). There is no evidence of transmission by sexual seed, but the pathogen is perpetuated in cuttings from infected plants (20-21, 24). It is also transmitted by grafting, but only when it is carried out in the stem of a young growing plant and not on a mature one (6, 21, 24). It takes twice as long for the symptoms to develop when *M. esculenta* is grafted on *M. glaziovii* (24).

Control

The disease has been controlled by early eradication of diseased plants (6, 20), the use of healthy stock (9, 10, 18, 22) and a fallow rotation

Figure 5. Symptoms of cassava frog skin disease. There is no development of swollen roots of commercial value.

period of six months to one year (6). It has been possible to free plants from the disease agent by heat therapy at 50°C for one hour or a week at 38°C. The procedure is expensive and difficult because the treated cuttings germinate poorly (5, 6). The use of tetracycline treatments has not been promising (6).

Frog skin disease

The frog skin disease was reported in southwestern Colombia in 1971 (Lozano and Castaño, personal communication). It is characterized by the development of few or no swollen roots. Infected plants have no symptoms in the aerial part (Fig. 5).

Geographic distribution

The disease has been observed only in Colombia, in the area where it was first detected (Lozano and Castaño, personal communication).

Economic importance

The yield of infected plants is very low and of little commercial value; losses as high as 90 percent are common. All 382 cultivars cultivated in an infected area were affected after three years' continuous cultivation (Lozano and Castaño, personal communication).

Pathogenicity

Host range

There is no information about other host plants for the disease agent.

Properties of infectivity

There is no information on the etiology of the disease agent, its properties and relationships with cells and tissues.

Studies on transmission

There is some evidence that the disease agent is being disseminated in the field when infested tools are used to cut healthy plants. (Lozano and Castaño, personal communication). There is no information about transmission of the disease by sexual seed. All cuttings taken from infected plants produce diseased plants (1; Lozano and Castaño, personal communication). The disease agent is readily transmitted by grafting (Lozano and Castaño, personal communication).

Control

Frog skin disease is controlled by using healthy plants for propagation (Lozano and Castaño, personal communication).

Areas requiring research

Taking a look at our knowledge about the virus and mycoplasmalike diseases in the Americas, it is evident that although some of them have been known for almost 40 years, more information is required on the properties of the disease agents, their means of dissemination, and the conditions that might be favorable for an epidemic.

It is necessary to develop quick and accurate diagnostic procedures, establish seed certification projects and quarantine measures to prevent the dissemination of the diseases already present in the Americas and to prevent the introduction of those found in other areas.

Other host plants that might have an important role in the epidemiology of these diseases should be identified. The possible existence of strains of these viruses and possible differences between the different types of mycoplasmalike organisms should be studied. At the same time, it will be necessary to review their economic importance and geographic distribution.

It would also be worthwile to try to use the meristem tip culture technique as a means to obtain get pathogen-free plants that can be used to regenerate some infected cultivars, as well as to have a germoplasm bank stored in test tubes.

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Superelongation: a *Sphaceloma* disease of cassava*

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Abstract

A new and serious disease of cassava was first reported to be causing serious epidemics in Colombia in 1972 and has since been found in Central America, Brazil and Venezuela. The causal organism was identified as a fungus of the species *Sphaceloma*, probably *S. manihoticola*. The disease results in extensive elongation of the internodes of infected plants and causes serious yield loss. Artificial inoculation of young cassava plants was achieved in a mist chamber, and free water was found to be necessary for conidial germination. Pathogen dissemination appears to be associated with wind-blown spores and, more extensively, with infected stem cuttings used for propagation. The pathogen also attacks *Manihot glaziovii*. Resistant germplasm within *M. esculenta* has been identified.

A new disease of cassava was reported by Lozano in 1972 (2) and by Lozano and Booth in 1973 (4) to be causing epidemics in various parts of Colombia. It was named the superelongation disease (superalargamiento in Spanish) of cassava because it was characterized by an extensive elongation of the internodes of infected plants. In various parts of Colombia, farmers have had to abandon cassava crops because of the disease. A fungus consistently isolated from infected plant material was proven to be the causal agent, but its identification was uncertain. The following investigation was undertaken to learn more about the etiology and epidemiology of the disease.

Materials and methods

The pathogen was isolated from sporulating cankers by macerating them in sterile water and streaking the resulting suspension onto acidified water agar. The cultures were incubated at room temperature until germinating conidia could be isolated and removed aseptically to petri dishes containing potato dextrose agar (PDA). Cultures were maintained in petri dishes at room temperature and transferred periodically at two-week intervals. Isolations were made from cassava

* Based on a portion of the doctoral thesis of the senior author conducted at CIAT, Cali, Colombia

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and from *Manihot gleziovii* material from widely scattered areas of Colombia and Costa Rica.

Conidial-mycelial suspensions containing 1 x 10^6 conidia/ml were prepared by homogenizing entire fungal cultures with distilled water in a Waring blender. The suspensions were sprayed upon young cassava plants with a piston-action hand atomizer. Inoculated plants were incubated in a mist chamber for periods ranging from 8 to 24 h at a temperature range of 24 to 29°C.

To test the effect of moisture on conidial germination, drops of a conidial suspension (5.3 x 10^6 conidia/ml) were placed onto three microscope slides. Two of these slides were air dried, and then one of these was remoistened with a drop of sterile distilled water. All three slides were placed into a moist chamber at 100% RH for 19 h at 25°C. The percentage of conidial germination was recorded for three replicates of this test.

The identification of the causal agent was based upon observation of symptoms on infected cassava, colony characteristics on artificial media, and morphology of conidia and conidiophores. Infected cassava plants were observed at various stages of disease development in naturally infested fields and in artificially inoculated plants. Fifteen isolates of the pathogen obtained from different regions of Colombia and one from Costa Rica, were grown and observed on PDA containing 0.8% yeast extract. Riddell mounts (7) were prepared to observe single conidiophores and to determine the manner of conidial production.

The critical temperatures for the pathogen's growth were determined by transferring small pieces of fungal tissue (2 mm diameter) to PDA and placing the cultures in incubation chambers at 6, 9, 15, 18, 21, 24, 27, 30, 33 and 36°C (±0.5°C) for 30 days. Colony growth was determined by averaging the two largest perpendicular diameters of each colony, and two or more colonies were measured at each temperature.

To determine the mode of ingress of the pathogen into host tissue, drops of a conidial suspension were placed onto cassava leaves in petri dish moist chambers and were incubated at room temperature. After periods ranging from 12 to 60 h, inoculated leaf samples were removed and treated with the staining method reported by Latch and Hanson (3).

Observations on the dissemination of the pathogen were made at various stages during a naturally occurring epiphytotic. Sources of primary inoculum were identified and the pattern of disease spread from these sources was observed. Observations were also made on the spread of the disease from an artificially inoculated plot of cassava to an adjacent uninoculated plot 30 m distant.

Results

The disease occurs primarily on the younger portions of the plant. It is characterized by an exaggerated elongation of the internodes of young stems, by distortion and leaf curl of young leaves, and by canker formation on infected stems, petioles, and leaf midribs and main veins (Fig. 1a-b). The initial symptoms appear as small, puckered, slightly chlorotic spots on the laminae of young, fully expanded leaves. These spots soon become necrotic and take on a khaki brown to ash white color. Often a narrow, slightly chlorotic halo surrounds the older spots. As the spots age, they expand slightly (1-3 mm in diameter) and sometimes form a distinct, narrow dark brown margin. With fully advanced spots, the centers become thin and lighter in color; they often disintegrate, giving the leaf a shot-hole appearance (Fig. 1c). During severe infection, the leaves may become completely deformed and necrotic, resulting in premature leaf drop (Fig. 1b).

The inoculation method using a mist chamber proved satisfactory for obtaining uniform infection. Very little infection occurred after 8 h of incubation in the chamber, and severity of infection increased progressively up to 24 h of mist. Disease symptoms appeared 5 to 6 days after inoculation under these conditions. The pathogen obtained ingress by direct penetration as observed on the stained leaf sections.

Free water was necessary for conidial germination. Virtually no germination occurred at 100% RH unless free water was present. The optimum temperature for rapidity and percentage of conidial germination over a 24-h period was 28.5°C.

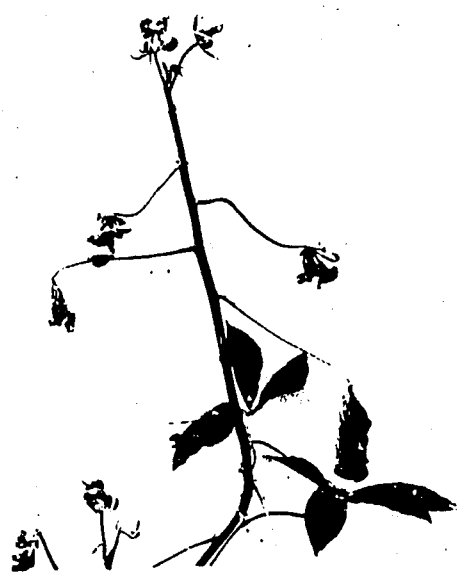

Figure 1. (a) Leaf symptoms of the superelongation disease on cassava showing leaf spots, cankers on the midribs and main veins, and ragged appearance of entire leaf. (b) Terminal portion of infected plant showing characteristic elongation of internodes, leaf deformation and premature leaf drop. (c) Conidia and hyphae of the superelongation pathogen (x 1400).

Colonies grown from spores streaked onto agar media consist of small, slow-growing, raised, yeastlike colonies with deeply convoluted surfaces. The colony consists of pseudoparenchyma, often with a gummy or tenacious consistency. On PDA the colonies are usually various shades of light orange, but the color can range from a light orange to a light brown.

The conidia from PDA cultures are unicellular and small, 3.3. to 6.8 x 1.8 to 4.9 µ, with average dimensions of 5.3 x 2.7 µ. They are generally ovoid to oblong-elliptical, hyaline and refringent under the light microscope. When stained, the conidia often show two polar guttules (Fig. 1c). Conidia germinate by budding or by germ tubes and usually become greatly swollen before germination.

From the Riddell mounts of the fungus, it was observed that the conidiophores are short, usually unicellular, more or less cylindrical structures, tapering slightly at the apex. Numerous conidiophores are borne upon well-developed hyaline to yellowish pseudoparenchyma-like stromata. The conidiophores are phialides, producing phialospores (conidia) acrogenously.

Optimum temperature for fungal growth in vitro was 24°C, with minimum and maximum temperatures at 6 and 36°C, respectively.

The disease appears to be disseminated over long distances by means of infected cassava stem cuttings. In the very early stages of an epiphytotic, four or five infected stem cuttings were determined to be the sources of inoculum. The spread of the disease from these sources of inoculum did not show a plant-to-adjacent-plant pattern but showed initial stages of infection occurring throughout the field. This pattern of dissemination was observed throughout the course of two epiphytotics in widely separated areas of Colombia. These observations suggest the probable involvement of wind-blown spores in the dissemination of the pathogen over relatively short distances.

Discussion

The first definite report of superelongation disease was made by Lozano in 1972 (2). Since then, the disease has been recognized as causing serious epiphytotics in numerous areas of Colombia, Central America, Venezuela and Brazil. Preliminary yield trials have demonstrated losses up to 80 percent due to the disease (6), and in a number of cases farmers have completely abandoned their cassava crops due to total loss.

The pathogen is of the genus *Sphaceloma*. In 1950 Bitancourt and Jenkins (1) named a new species of fungus *Sphaceloma manihoticola*, found attacking *M. esculenta* in the Dominican Republic and Guatemala and *M. glaziovii* in Brazil and Nicaragua. Their description of the fungus and its symptoms on its hosts is superficial, but there appear to be many similarities in symptomology with the superelongation disease. It seems reasonable that the superelongation pathogen is actually the same fungus reported by Jenkins and Bitancourt as *S. manihoticola*. Confirmation of this hypothesis, however, is almost impossible because Bitancourt and Jenkins failed to find and describe spores for taxonomic purposes and made no mention of the elongation of internodes in their discussion of symptoms. Nevertheless, since they primarily used dried plant material sent to them by others to describe the new species, it is not unreasonable to suspect that they never had an opportunity to observe the possible elongated appearance of the infected cassava plants. Also, the inability to find spores on dried plant material supports experiences encountered in the present study.

Considering the above, it is recommended that the same *Sphaceloma manihoticola* be used for the superelongation pathogen until further evidence be found that would indicate clearly that, in fact, more than one species of *Sphaceloma* infects *M. esculenta* and *M. glaziovii* naturally.

A number of good sources of resistance to the disease have been found, some of which are agronomically acceptable cultivars. Only uninfected cassava cuttings should be used in planting. If the disease does become established, burning of infected plant debris is recommended.

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The Cercospora leaf diseases of cassava

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Abstract

A review is presented on the leaf diseases of cassava caused by *Cercospora* spp., with the purpose of determining the present state of knowledge on these diseases, as well as on-going research in this area. The following aspects of brown leaf spot *(C. henningsii)*, white leaf spot *(C. caribaea)*, blight leaf spot *(C. vicosae)* and dark leaf spot *(C. manihobae)* are discussed: geographic distribution, host range, etiology, epidemiology symptomatology, economic importance and control measures including exclusion, eradication, chemical protection and varietal resistance (HCN content, anthocyanins and genetic mechanisms). Greenhouse and field-screening techniques for evaluating resistance are also dealt with.

Introduction

This review of the Cercospora leaf diseases of cassava was made with the following objectives in mind: (a) to determine the present state of knowledge on these diseases, (b) to discuss on-going work and (c) to indicate areas needing further study. The Cercospora leaf diseases have long suffered from neglect by plant pathologists (6), apparently because they were considered unimportant. In addition, cassava was also thought of as a low-status crop, so little attention was given to it by agricultural scientists.

Most of the early literature on these diseases was essentially mycological in nature or gave merely causal reports of their incidence in different parts of the world; very few were original research reports. Some of the early detailed accounts of these diseases were those by Ciferri (14-15) in 1933 and 1940, Viegas (44) in 1941, Viennet Bourgin and Grimaldi (46) in 1950 and Chevaugeon (12) in 1956. Other general references available are those of Bouriquet (2), Powell (32), Arene (1) and Lozano and Booth (26).

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The time between the first description of the fungus in East Africa and Brazil is very short. It is likely that the disease had its origin in Brazil, the probable home of cassava; and from there it could have been distributed to different parts of the world by means of vegetative cassava material.

These diseases are essentially confined to the foliage where they cause spots or blight (13, 35, 44, 46). *Cercospora henningsii* incites brown leaf spot (35); *C. caribaea*, white leaf spot (35); *C. vicosae*, blight leaf spot, also described as difuse leaf spot (13, 26, 29); and *C. manihobae*, dark leaf spot (13, 45).

History and geographical distribution

Brown leaf spot

Of the Cercospora diseases affecting cassava, brown leaf spot has the widest geographical distribution. Where and when the disease originated is not documented; the first report coincides with that of the description of the fungus in 1895 from cassava leaves collected in Tanzania (22). In the same year Ellis and Everhart (18) described the fungus in Florida and in 1902 Hennings (23) reported it from Pará, Brazil. In 1905 the pathogen was described on Ceará rubber in Ceylon (Sri Lanka) (31), and by 1925 Van Overeem (43) stated that the disease was found in all tropical regions of the world where cassava was grown.

White leaf spot

C. caribaea was described by Chupp and Ciferri (29) from material collected by Muller in 1929 from the Minas Gerais region, Brazil (13). This was the same fungus as the one found in material collected from British Guyana (Guyana) by Stevens in 1925 (13). The disease was also reported in other Latin American countries and the Caribbean Islands (4-5, 13). Deighton (17) first reported the disease in Africa in 1936.

Blight leaf spot

C. vicosae was first described in 1935 by Muller and Chupp (29) from material collected from Minas Gerais, Brazil in 1933 (13). The disease has also been reported from Colombia (5, 7). It appears to be confined to Latin America at present (26).

Dark leaf spot

C. manihobae was first described in 1945 by Viegas (44) from material collected from Campinas and São Paulo, Brazil (13). There is no report of the disease from any other region of the world.

Host range

According to Chupp (13) the Cercosporae are remarkably limited in their host range, which also appears to be true of the *Cercospora* spp. found on cassava. Cassava *(Manihot esculenta* Crantz) is the most important suscept of these fungi. Other suscepts reported for *C. henningsii* are Ceará rubber *(M. glaziovii)* (31), *M. piauhyensis* (44), *M. carthagenesis* (26) and *Ipomoea batatas* (sweet potatoes), the last by artificial inoculation (26,32). However, Chupp (13) states that the results of cross inoculation under high humidity conditions in the laboratory are not acceptable for the Cercosporae. For this reason *Ipomoea batatas* should probably not be included in the list of suscepts.

C. caribaea, *C. vicosae* and *C. manihobae* appear to be restricted to *M. esculenta* (26, 32, 44-45). No extensive search has been made for suscepts, however (1).

Etiology

Morphology, taxonomy and nomenclature

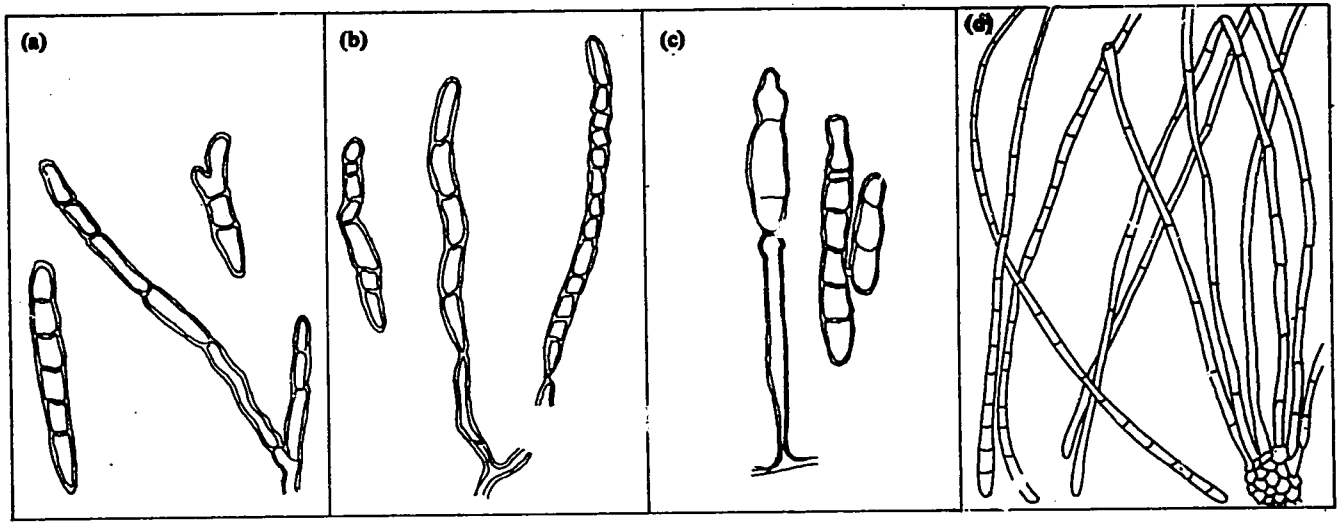
There has been a great deal of confusion and controversy in this regard since the first description of the pathogen causing brown leaf spot. This aspect has been reviewed by Ciferri (15), Viegas (44-45) and Chupp (13).

Chupp (13) recognizes four *Cercospora* spp. on *M. esculenta* (Fig. 1). The following is a modification of his key by Powell (33).

Cercosporae on *Manihot*

A. Conidia colored

B. Leaf spots distinct; fruiting not effuse; stromata 20-40 µm; fasciles dense; conidiophores pale in color, 3-5 x 10-50 (100) µm; conidia cylindric, 4-7 x 30-85 µm. *Manihot* spp. *C. henningsii* Allesch.



Source: a-c, Teri (41); d, Viegas (45)

Figure 1. Conidiophores and phragmospores of (a) *C. henningsii*, (b) *C. vicosae*, (c) *C. caribaea* and (d) *C. manihobae*.

BB. Leaf spots indistinct; fruiting effuse; stromata lacking; fascicles sometimes coremeoid; conidiophores dark reddish brown, 4-6 x 50-150 µm; conidia cylindro-obclavate, 4-6 x 25-100 µm.
Manihot sp. *C. vicosae* Muller & Chupp

AA. Conidia hyaline or rarely subhyaline

B. Conidia hyaline, acircular, 3.5-5 x 80-270 µm, leaf spots indistinct to sometimes distinct, dark to black; conidiophores pale to medium in color, 4-6 x 70-1000 µm.
M. esculenta Crantz *C. manihobae* Viegas

BB. Conidia hyaline to subhyaline, obclavatecylindric, 4-8 x 20-90 um; leaf spots distinct, snow-white; conidiophores medium dark, 3-5 x 50-200 µm.
M. esculenta Crantz *C. cariabaea* Chupp & Ciferri

No Latin descriptions are available for *C. caribaea* and *C. vicosae*. These fungi belong to the Sympodulosporae of the dematiaceous hyphomycetes and share the characteristics common to the Cercosporae (13).

Ascosporic states. The perfect state of *C. henningsii* was described as *Mycosphaerella manihotis* Ghesquire & Henrad,von Sydow in 1924 (20), which was later given as *Mycosphaerella (Sphaerella) manihotis* (Sydow) Ghesq. (19). Powell (33) suggests that a new name be given to the fungus since the present one is a later homonym of the 1901 Sydow name. He points out that the genetic connection between the perfect and imperfect states has not been clearly proven. It has been stated that most Cercosporae generally have a *Mycosphaerella* perfect state although no proof is a available of the genetic connections (13, 39). The ascosporic states of the other species have not been reported.

Proof of pathogenicity

The only available reports specifically on proof of pathogenicity are those of Ciferri (14) for brown leaf spot and Ramkrishnan et al.(34) for *C. henningsii* on Ceara rubber.

Primary and secondary cycles

This has been reviewed by Arene (1), Ciferri (15), Lozano and Booth (26), Powell (32) and Viegas (44) The pathogens appear to have similar development cycles (39). The fungi overseason on old fallen leaves or on old lesions on leaves still on plants. Sporulation is profuse under favorable conditions. Conidia are carried by wind or rain splash to infection courts where infection and disease are initiated.

Mature primary lesions have conidiophores that emerge through open stomata. Under moist, humid conditions, conidia are produced profusely. These conidia are blown by wind or carried by rain splash to new infection courts, becoming the source of inoculum for secondary cycles. Secondary cycles are repeated throughout the rainy season (1, 26, 32).

Epidemiology

Relative humidity, temperature, plant age and soil fertility appear to be the most important factors in the epidemiology of the diseases (1, 12, 14, 26, 32, 44).

Relative humidity

The Cercospora diseases are prevalent during the rainy season with an overseasoning period during the dry periods of the year (1, 26, 32). Relative humidity and moisture have also been demonstrated to have an effect on spore germination, disease development, sporulation of the pathogens (14), and the relative distribution of the different species (26).

C. henningsii has been reported to have germination of conidia at relative humidities below saturation point while *C. caribaea* conidia need to be immersed in water for normal germination (32 33). *C. henningsii* has also been reported to sporulate at lower relative humidities than *C. caribaea*. Sporulation for *C. henningsii* occurs at relative humidities of between 50 to 90 percent while those of *C. caribaea* vary between 65 and 100 percent (12, 32). For this seasons, *C. caribaea* has been reported in the more humid regions, giving way to *C. henningsii* in the drier areas (12, 26, 32).

Temperature

C. henningsii has been reported to be more thermophilic than *C. caribaea*. It has an optimum temperature of 39°C for spore germination, with a maximum of 43°C, while *C. caribaea* has a lower optimum temperature of 33°C with a maximum of 35°C for spore germination (12, 14, 26, 32). *C. vicosae* has been reported to be prevalent in warm cassava areas where *C. henningsii* is also prevalent (26).

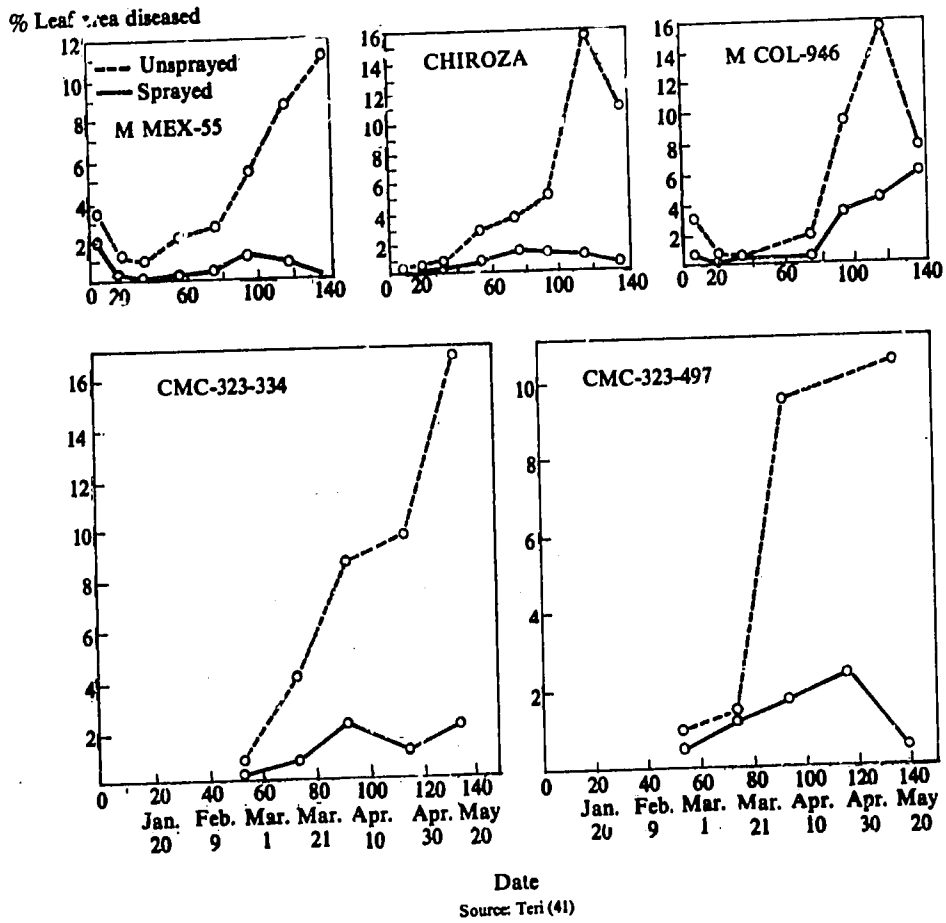
Plant age

It has been generally observed that the older, lower leaves are more susceptible than the younger, upper ones. Chevaugeon (13) showed that leaves 5 to 15 days old were virtually immune to the disease, becoming susceptible only after 25 days. He also showed that plants 3 to 5 months old were more resistant than those that were 14 to 16 months old. However, Lozano and Booth (26) have stated that very susceptible cassava varieties and other *Manihot* spp. can be uniformly infected.

Soil fertility and plant nutrition

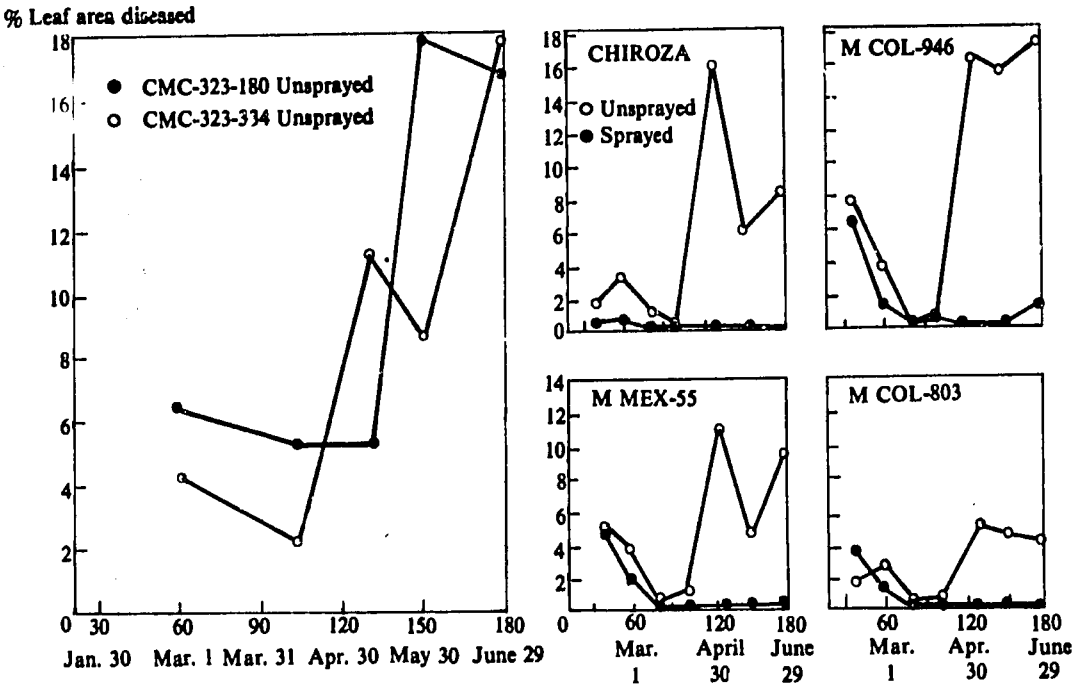
Viennot-Bourgin and Grimaldi (46) observed that plants hardened by poor growing conditions were more resistant than those growing under favorable conditions. According to Chevaugeon (13), soil fertility had no effect on the diseases.

The progress of disease with time on a new plantation is shown in figures 2 and 3 (41). The diseases are typical compound interest diseases



Source: Teri (41)

Figure 2. Progress of brown leaf spot in cassava plots; 20 corresponds to date when plants were 113 days old.



Source: Teri (41)

Figure 3. Progress of blight leaf spot in cassava plots; 60 corresponds to date when plants were 125 days old.

with a long lag stage, a sharp logarithmic stage and a postlogarithmic stage, which can also be long, depending on when the crop is harvested.

Rainfall, relative humidity and plant age seem to be the most important epidemiological factors in areas where the diseases are prevalent. Figure 2 shows declines in the epidemics that were brought about by droughts (41).

Symptoms and signs

The symptoms and signs of these diseases have been described by several authors (12-13, 21, 27, 44, 45).

Brown leaf spot

General symptoms: Diseased plants exhibit normal growth. Only Castaño (5) has mentioned dieback and death of diseased plants. The disease appears to be confined to the foliage; the older leaves of the plant are more affected than the younger ones. Premature defoliation is a general effect of the disease (Figs. 4 and 5). The spots are found on both sides of the leaf: on the upper surface they are uniformly brown within a darker border; on the lower surface they have a grayish cast due to the presence of conodiophores and conidia. Lesions are sharply separated from healthy tissue by a narrow brownish black ring ranging from 0.3 to 0.5 mm in width. A yellowish halo may be found outside this ring on very susceptible varieties under extremely humid conditions. The circular lesions are delimited by major veins and are angular or irregular in shape (Fig. 6). The small veins within lesions are an intense black. The necrotic tissue in the center of lesions may fall, giving a shot-hole effect.

As regards histological symptoms, a toxin is produced by the advancing mycelium of the fungus. As a result, cells lose their plasticity, their cytoplasm becomes plasmolytic and is oxidized to a yellowish brown color. Hyphae amass in the intercellular spaces beneath the stomata, forming stromata. Cells maintain normal arrangement, except that the epidermis is usually collapsed or ruptured (32).

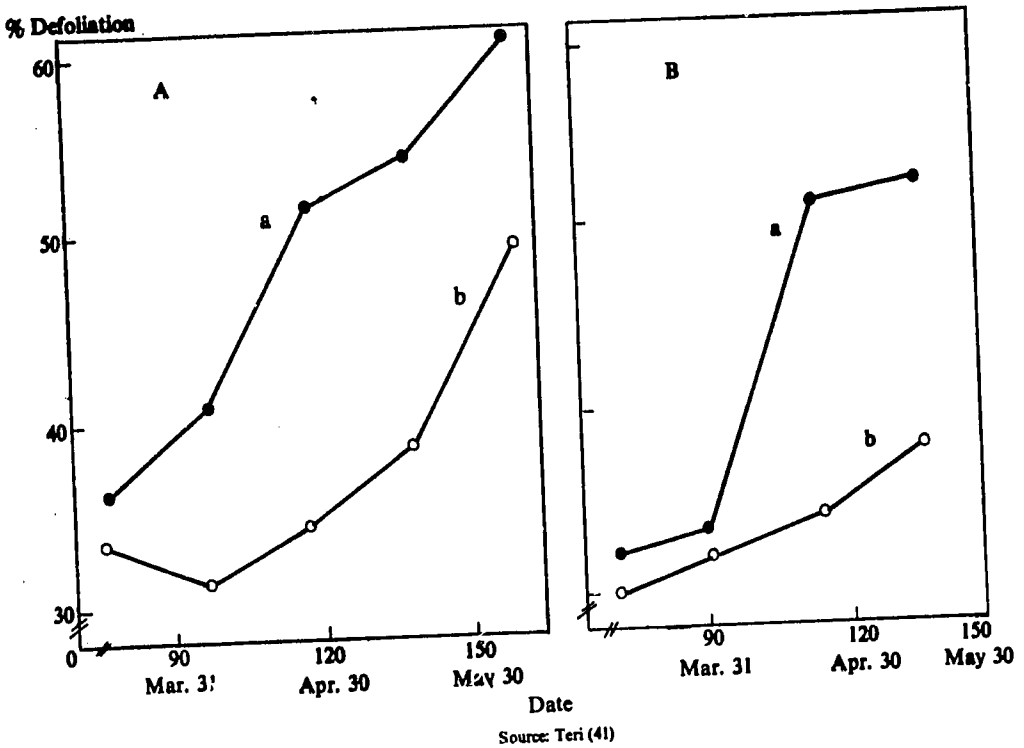


Figure 4. Defoliation in cassava varieties (A) and hybrids (B), unsprayed (a) and sprayed (b), to control brown leaf spot; 90 corresponds to date when plants were 183 days old.

White leaf spot

The general symptoms are similar to those of brown leaf spot. Lesions on leaves manifest themselves first as small hydrotic areas followed by yellow discoloration. The lesions soon become reddish brown and then bleached, leaving the upper surface white and translucent (Fig. 6). The lesions are bordered by a diffuse, irregular, violet-brown ring, surrounded by a yellow halo. Mature lesions reach a size of 1.0 to 5.0 mm in diameter.

C. caribaea may also produce a toxin that kills cells in advance of the growing mycelium. There is a general collapse of the cells of the spongy and palisade parenchyma in the lesion area. The lesions are sunken on both sides of the leaf, reducing the thickness of the leaf blade to about half the normal.

The centers of the spots, especially on the under-surface of the leaf, have a velvety appearance due to the fruiting bodies of the pathogen (32).

Blight leaf spot

The general symptoms are similar to those of brown and white leaf spots. Plants grow normally, and lesions are concentrated on the basal leaves. Premature leaf fall is also characteristic.

Symptoms on foliage also begin as discolored hydrotic areas on the leaf surface; these areas increase rapidly in size, becoming necrotic. The necrotic areas have diffuse borders and may cover up to 20 percent or more of the leaf lobe area (Fig. 7). The upper surface of the blighted area is uniformly brown; but on the lower surface, especially in the centers of the affected areas, there is a grayish cast due to the fruiting bodies of the pathogen. Detailed histological studies have not been made.

Dark leaf spot

The symptoms caused by *C. manihobae* consist of distinct to indistinct subcircular leaf spots that

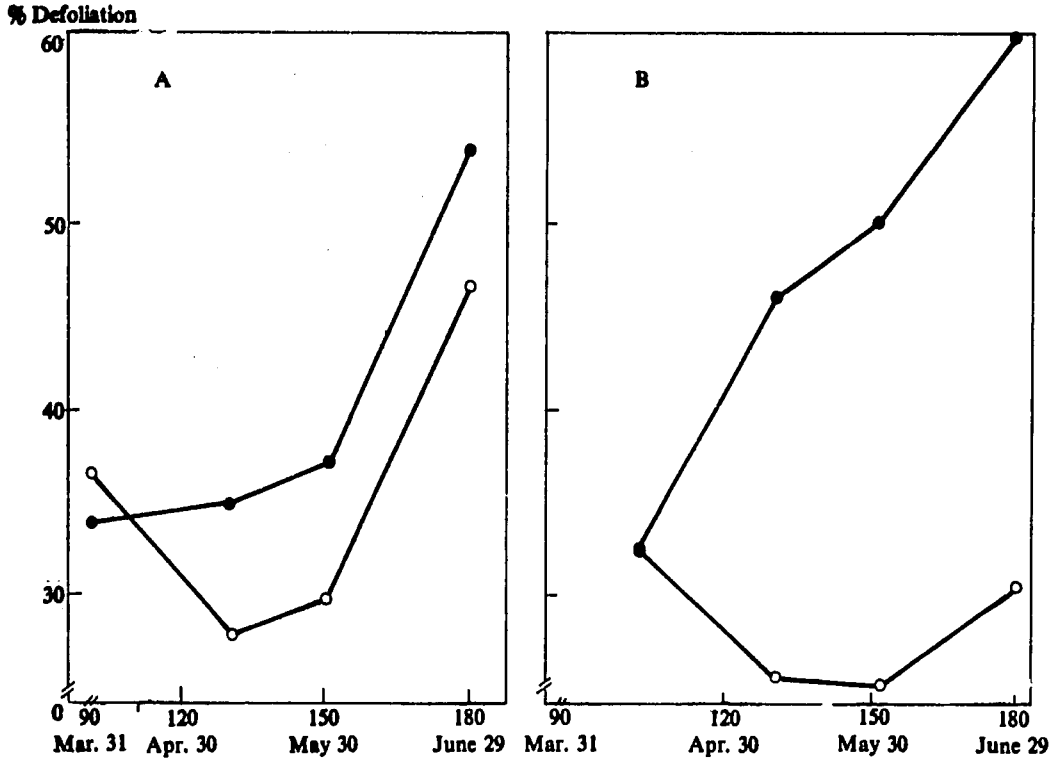


Figure 5. Defoliation in cassava varieties (A) and hybrids (B), sprayed (o) and unsprayed (•) to control blight leaf spot; 120 corresponds to date when plants were 185 days old.

are dark in color. Elongated lesions also occur on he petioles (13,45).

Economic importance

The Cercospora leaf diseases of cassava have never been reported to kill infected plants; rather, diseased plants continue to grow, giving reasonable yields. Apparently because of this, the diseases are not considered to be of economic importance (2, 4, 14, 30). On the other hand, brown leaf spot has been reported as one of the most important leaf diseases of cassava (3, 36). It is probable that the slash and burn agriculture of the tropics, where cassava was grown in small backyard plots with other crops, restricted conditions for severe epidemics, or the effects of diseases under such sutuations could have gone unnoticed (24-25, 35).

The spots and blight result in loss of leaf area for photosynthesis. Premature defoliation also results in the loss of leaves available for photosynthesis. The fungi are also known to produce toxins (9). These factors most likely have a detrimental effect on yield; however, the extent of losses due to *Cercospora* spp. has never been determined (1).

The first (1915) to point out that these diseases could become important when cassava was grown in intensive monocultures, often with only one variety, was Rorer (35) in Trinidad. He was also the first to attempt an experiment to determine the importance of these diseases. Unfortunately, his results were apparently never published.

For the purpose of guiding future work on these diseases, it is necessary first and foremost to establish their economic importance. With respect to brown leaf spot in Africa, this is complicated by the presence of African cassava mosaic disease in almost all cultivars (42).

Recent assessments of yield reductions

Using the susceptible variety Llanera at CIAT, a weekly spray of fungicide to control brown leaf

Figure 6. (a). Brown leaf spot symptoms (large lesions) and (b) white leaf spot symptoms (smaller, white lesions).

Figure 7. Blight leaf spot symptoms

spot and leaf blight increased yields by 14 percent (Table 1). Teri (41) carried out experiments at two locations in Colombia to determine the separate effects of brown leaf spot and leaf blight on yield, using five varieties and four hybrids, ranging from highly resistant to susceptible. In addition a fungicide was used in a split plot design to have sprayed and unsprayed plots. The results are summarized in figures 1 and 2; a general picture of the epidemics, is also given in tables 2, 3 and 4. The increase in fresh root yield of the susceptible cultivars resulting from disease control ranged from 10 to 23 percent for brown leaf spot and from 12 to 30 percent for blight leaf spot. There were also apparent increases in root starch content and yield (Table 3). The importance of these diseases in reducing yield and quality is indicated by these results; further work should be done to establish this conclusively. The resistant cultivars showed insignificant effects from spraying. The variety Chiroza was interesting in that the differences in disease between sprayed and unsprayed plots were most striking, yet differences in yield were quite small. It appears to be an example of a variety tolerant to both diseases. Cock (16) states that root dry weight decreases after a leaf area index (LAI) of about 3 is reached. This could account for tolerance in cultivars with high LAIs since defoliation is not detrimental.

There can be other indirect losses from the Cercospora leaf diseases. Thurston (personal communication) has suggested that weed problems may increase due to severe defoliation which leaves open canopies in large plantations, allowing light penetration which results in more vigorous weed growth. Susceptibility to other diseases may also be enhanced.

Preventive and control measures

Little has been done with regard to developing control measures for these diseases, perhaps because of the two historical reasons cited earlier; i.e., they were essentially of mycological interest and were considered of insufficient economic importance to justify control measures.

Table 1. **Yield of cassava (var. Llanera) according to the frequency of application of either mancozeb, Vitigran, benomyl and Macuprax plus sticker (Triton or Tween 20).**

Frequency of application	Yield (t/ha)
Every week	33.1a*
Every 2 weeks	28.1b
Every 3 weeks	29.2b
Control	28.5b

Source: CIAT Annual Report 1976 (11)

* Numbers followed by different letters not significantly different (P=0.05).

Table 2. Fresh root yield of cassava varieties and hybrids attacked by brown leaf spot.

Variety or hybrid	Reaction*	Yield (t/ha)			Increase (%)
		Sprayed	Unsprayed	Increase	
Varieties					
M. Mex 55	S	27.96	23.79	4.17	14.91
M. Col 946	S	29.70	26.65	3.05	10.27
Chiroza	T	29.13	29.57	-0.44	-1.51
M. Mex 59	R	32.72	32.95	-0.23	0.70
Hybrids					
CMC-323-334	S	31.89	26.73	5.16	16.18
CMC-323-497	S	23.21	17.83	5.38	23.28
CMC-323-178	R	22.33	20.70	1.63	7.30
CMC-323-492	R	15.58	15.70	-0.12	-0.77

* S = susceptible, R = resistant, T = tolerant

Exclusion

Nothing has been mentioned about this control measure in the literature, but it appears that exclusion can be important in preventing further distribution of the more restricted and hitherto rather obscure species, *C. vicosae* and *C. manihobae*. Although the importance of these pathogens has not been established, it is recognized that they are likely to become more important as cassava production increases (25).

Eradication

One eradicative measure suggested (32) is to rake and burn fallen cassava leaves frequently during

Table 3. Fresh root yield of cassava lines attacked by blight leaf sp

Variety or hybrid	Reaction*	Yield (t/ha)			Increase (%)
		Sprayed	Unsprayed	Increase	
Varieties					
M. Mex 55	S	23.36	19.74	3.62	15.50
M. Col 946	S	16.24	14.21	2.03	12.50
M. Col 803	S	20.83	14.86	5.97	28.66
M. Mex 59	R	24.90	24.28	0.62	2.55
Chiroza	T	15.13	14.80	0.33	2.18
Hybrids					
CMC-323-180	S	35.40	24.65	10.75	30.36
CMC-323-334	S	34.40	25.43	8.95	26.08
CMC-323-487	R	27.30	27.14	0.16	0.59
CMC-323-497	R	28.20	28.90	-0.70	-2.48

* S = susceptible, T = tolerant, R = resistant

Table 4. **Percentage of root starch content of cassava varieties attacked by blight leaf spot.**

Variety	Reaction*	Root starch content** Sprayed	Unsprayed	Increase (%)
M. Mex 55	S	69.3	65.7	3.6
M. Col 803	S	70.8	62.6	8.2
M. Mex 59	R	74.8	73.1	1.7
Chiroza	T	66.8	65.8	1.0

* S = susceptible, T = tolerant, R = resistant

** Starch content on dry weight basis

the dry season in-order to eliminate the source of primary inoculum. Plants can also be cut back to six inches during the dry season and the debris burned (32). The best measure is considered to be a three- to five- year rotation with other crops (32).

Protection

Several fungicides have been shown to give effective control of the diseases (1, 22, 26, 32, 41); however, because of economic considerations, Arene (1) considers that the only worthwhile use of fungicides is for producing clean planting material in multiplication nurseries where certified disease-free materials are maintained. Growing plants at wide spacings and frequent weedings have also been suggested as protective measures (32). The nature of *Cercospora* epidemiology (Figs. 1, 2) suggests that severe epidemics can be avoided by programmed planting so that plants reach their most susceptible stage during the dry season.

Resistance

Although this has been suggested as the most practical means for controlling these diseases (1, 26, 32), much more research is required.

HCN content and resistance

It has been suggested that cassava clones with high HCN content should be more resistant to the Cercospora diseases (40), but both bitter and sweet cassavas, which are known to differ in their HCN content, have been found to be equally susceptible (8, 14). No relationship between HCN content and susceptibility to *C. henningsii* was found in work at CIAT (9). The most susceptible CIAT clones (M. Colombia 9 and M. Ecuador 111), contained as much HCN as the most resistant ones (M. Colombia 84, 465 and 706). Sadasivam and Prasad (37) reported lower HCN content in diseased leaves than in healthy ones, and Sadasivam (36) has suggested a case of cyanide tolerance. It is possible that cyanide tolerance or detoxification plays a role in the disease mechanisms involving these pathogens; however, little has been reported on this subject relative to cassava.

Anthocyanin pigments and resistance

Ciferri (14) reported that anthocyanin pigments from bud leaves had an inhibitory effect on the germination of *C. henningsii* conidia. He also reported that cassava clones with violet, bluish or brownish young leaves were more resistant than those with green or yellowish green bud leaves. No other report is available on this.

Availability of resistance within *M. esculenta*

Differences in the reaction of different cassava clones to *Cercospora* spp. have been demonstrated (1,8-12,15,44). Screening of CIAT germplasm has identified a number of clones with resistance (Table 5), so it may not be necessary to go outside *M. esculenta* for sources of resistance. Resistance seems to be independent, with most clones being resistant to *C. henningsii* and *C. caribaea;* there is considerably lower resistance to *C. vicosae*. Of the clones screened in 1975, 8 and 56 percent, respectively, were classified as resistant and tolerant to both *C. henningsii* and *C. vicosae* (10-11).

Screening of over 2000 CIAT cassava clones identified over 58 percent as resistant and 27 percent tolerant to brown leaf spot. It has been

Table 5. **Resistance to Cercospora leaf diseases within the CIAT cassava germplasm collection***

Disease	No. of clones evaluated	Resistant	Tolerant	Susceptible	Resistant (%)
Brown leaf spot	2061**	1192	555	314	57.8
Blight leaf spot	2061**	221	1134	706	10.7
Brown leaf spot	1344***	616	210	518	45.8
Blight leaf spot	1344***	53	208	1083	3.9
White leaf spot	413***	141	154	118	34.1

* Adapted from CIAT Annual Reports (10-11)
** 1975
*** 1976

suggested that resistance to all Cercospora spp. may be combined in just one cultivar (10).

Physiological studies indicate that there is a maximum leaf area index (LAI) of about 3, above which yields decrease. Apparently, the cultivars tolerant to the disease probably have high LAIs and defoliation from leaf diseases does not reduce the LAIs below the critical values.

Nevertheless, more extensive evaluations of the importance of these diseases should be done, and including screening for resistance in breeding programs is recommended as a worthwhile foresight.

Genetic mechanisms of resistance

Although CIAT (10) has data on the reaction of 7321 F_1 clones obtained from different crosses, no genetic conclusions have yet been drawn. An understanding of the genetic mechanisms controlling resistance would definitely facilitate breeding for resistance to these diseases.

Screening techniques

For good results in breeding for resistance, it is some techniques to increase sporulation (28,38) which, perhaps, can be adopted for the *Cercospora* spp. on cassava.

At CIAT (9, 47) satisfactory sporulation of *C. henningsii* was obtained by spraying mycelial suspensions of the fungus in culture on sterilized cassava leaves of susceptible varieties on water agar and incubating for 12 to 15 days at 24 to 28°C. A spore suspension of 2-3 x 10^4 conidia/ml was sprayed on two-month-old plants. These plants were incubated for 45 days, during which three additional inoculations were made. Disease evaluation were made 15 days after the last inoculation.

Field screening

Humid zones with records of severe disease from year to year are ideal places for field screening. Such zones have been identified in Colombia (10), where the cassava screening material is grown in the field. Natural infection takes place and disease assessment is made when the plants are 7 to 8 months old.

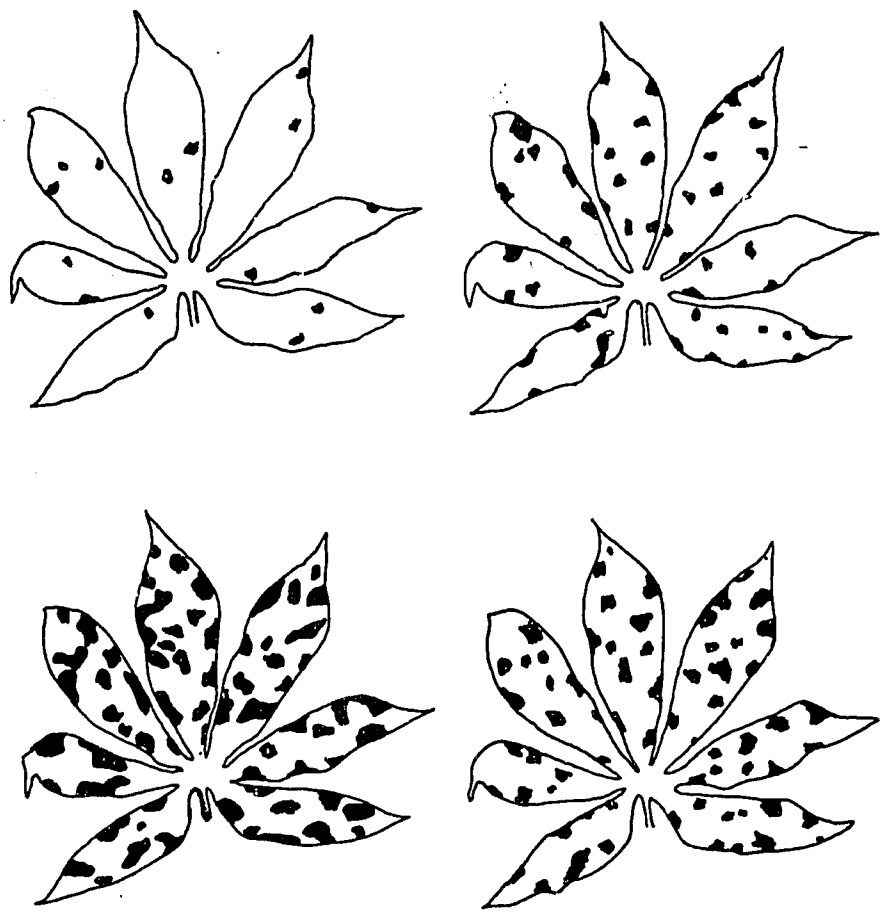
It is generally agreed that artificial infections are more reliable from year to year than natural

Disease rating for evaluating resistance

Ciferri (14) appears to have been the first to report on the grading of cassava clones for resistance to *C. henningsii*, based on density and distribution of lesions (number and area per leaf). Degree of defoliation or leaf retention (9, 41) have also been used to rate disease severity.

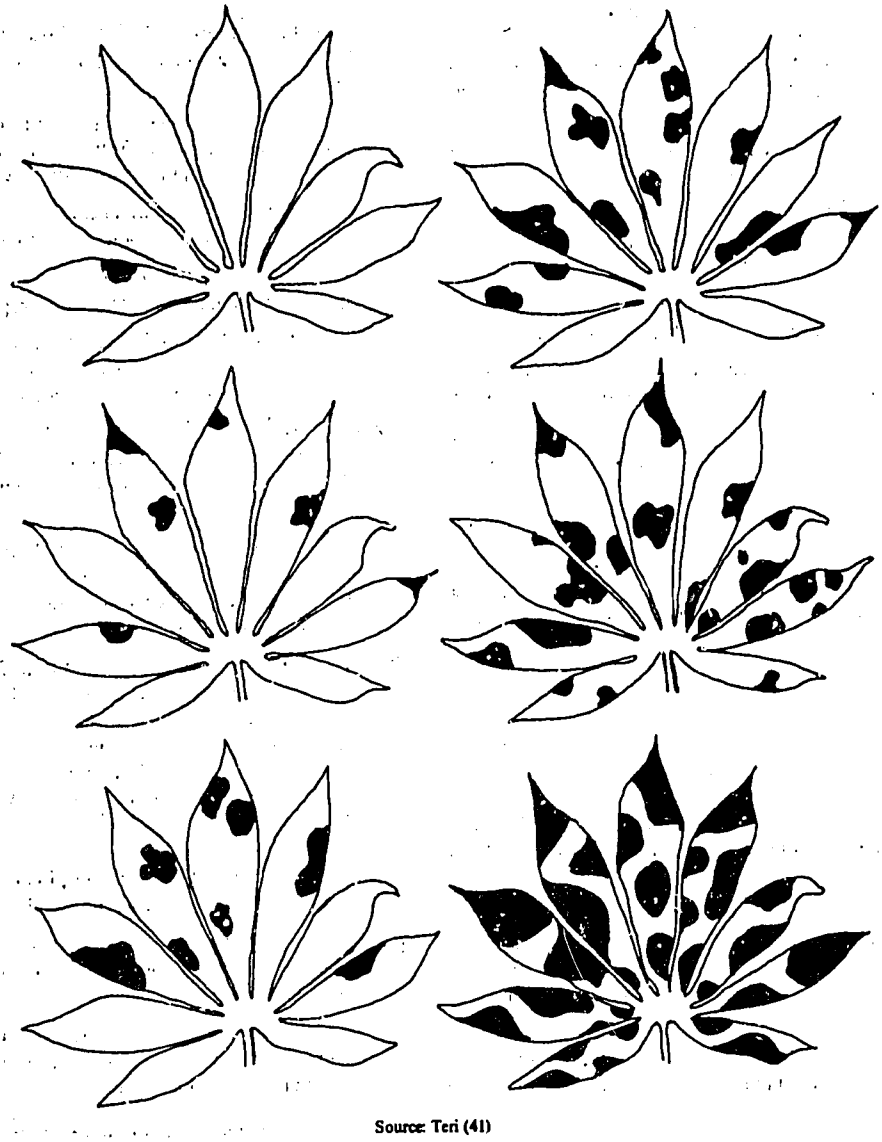
Figures 8 and 9 show keys (41) developed for the assessment of the intensity of brown leaf spot and leaf blight, respectively, while figures 1 and 2 show disease progress curves obtained on the basis of these keys.

The usefulness of these keys in assessment of disease severity and yield loss, as well as in screening for resistance, needs to be tested further. A mutually agreed system of screening for resistance should be developed whereby it would be possible to compare results from one area to another. The terms resistance, tolerance and susceptibility also need to be defined more clearly.



Source: Teri (41)

Figure 8. Area diagram key for assessment of brown leaf spot.



Source: Teri (41)

Figure 9. Area diagram key for the assessment of blight leaf spot.

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Concentric-ring leaf spot (*Phoma* sp.) of cassava

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Abstract

Concentric-ring leaf spot (*Phoma* sp.) is found attacking cassava in cooler areas and in the subtropics during the rainy season. A severe attack causes defoliation and dieback, resulting in heavy yield losses. Aspects of symptomatology, etiology; economic losses and varietal resistance are discussed. Results are given of trials conducted by CIAT evaluating more than 1000 cultivars for resistance to *Phoma* sp.; only 1.7% were found to be resistant and 12.9%, tolerant. The most effective control method is using resistant cultivars.

Concentric-ring leaf spot (*Phoma* sp.), also known as Phoma or Phyllosticta leaf spot, is found in the cooler cassava-growing areas and in the subtropical areas during the rainy season. The disease has been reported from Taiwan in 1909 (10), the Philippines in 1913 (12), tropical Africa in 1915 (14), Brazil in 1943 (13), India in 1968 (6) and Colombia in 1972 (1). The disease occurs on *Manthot esculenta (M. utilissima)* (10, 13), *M. heptaphylla, M. dichotoma* (8,13) and *M. aipi* (11,13). It has also been reported on *Morus alba* in Taiwan (10).

Symptomatology

Large brown leaf spots without definite margins are characteristic of this disease on cassava. The lesions are usually found at the tips or edges of leaf lobes or along the midrib or main veins. Concentric rings formed by brown pycnidia are evident on the upper surface of lesions; in old lesions, however, the rings are often obscure because the mature pycnidia are washed off by rain drops. On the lower surface, the lesions are uniformly brown because only a few pycnidia are formed; but the veins and veinlets around the lesion become necrosed, forming black strings that radiate outwards. When relative humidity is high, a grayish brown hyphal weft may cover the lesions. As lesions expand, the disease causes a leaf blight; the whole leaf and petiole turn dark brown and finally necrose. At this stage the wilted leaves drop, causing extensive defoliation in some cases. When infection is severe, the fungus also attacks young shoots, causing dieback. Diseased stems turn brown and are frequently covered with pycnidia.

Young leaves, fully expanded mature leaves and green stem parts have been found with severe

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disease symptoms. The older lower leaves appear to be more resistant.

Pathogen

The causal agent of the disease was reported to be caused by several *Phyllosticta* spp. (1,8, 10,12-14). Vincens (14) first described the causal agent as *Haplographium manihoticola* Vincens in 1915, but the pathogenicity of this fungus was later questioned by Viegas in 1943 (13). *Phyllosticta manihoticola* Sydow (10,12), *P. manihot* Sacc. (9) and *P. manihobae* Viegas (13) have all since been reported as pathogenic on cassava. Sawada (10) discriminated *Phyllosticta manihoticola* and *Phoma manihotina* based on the fact that *P. manihoticola* grows on the undersurface of the leaves and its conidia contain one oil drop; otherwise, symptoms induced on leaves and petioles are alike. As mentioned by Lozano and Booth (7), since the full definition and taxonomic validity of the reported species have not been fully determined, the possibility remains that they could be synonyms belonging to a single *Phoma* sp. A full taxonomic study of a wide range of pathogenic isolates is urgently needed to clarify this point.

The causal fungus produces numerous epidermal pycnidia which are dark brown, globose, found singly or in small clusters on the infected leaves and stems. The pycnidia are 78-180 µm in diameter; the ostiole, 15-28 µm. The conidiophores are short and hyaline, 3.5 µm (2.6-4.4) in width and 4.9 µm (3.1-6.2) in length as reported from Colombia (7). However, conidia size was recorded as 6-6.5 x 7-13 µm by Sawada in Taiwan (10).

Sporulation on artificial media is usually meager, but on lima bean agar mixture, it was profuse, forming a concentric pattern with 1.5 x 10^6 conidia per pycnidium at 20°C. Growth of the fungus was also optimal at 20°C (3).

Etiology

Disease occurrence is correlated with conditions permitting spore germination. Maximum spore germination has been observed between 20 and 25°C; successful artificial inoculation occurred only at temperatures at and below 25°C. Effects of temperature on spore germination have been studied (2). Spores did not germinate at 30°C, germinated well at 28 and 26°C; but at 26°C and above, no infection was obtained 10 days after inoculation. Lesions were bigger when the plants were maintained at 25°C than when they were kept at 15 and 20°C.

The concentrations of spores affects their germination (2). Percentage of germination was over 90 when spore concentration was adjusted between 2 x 10^4 to 7 x 10^2. At a higher concentration, (9 x 10^4), the germination rate dropped to half. On the artificial inoculation, the

Table 1. **Average yield (at 15 months) of 1139 cassava cultivars grouped according to their reaction to *Phoma* sp.**

Disease reaction	Av yield (kg/plant)	% yield related to regional yield
Regional yield	1.2	100a*
Resistant	2.3	190b
Tolerant	1.0	80a
Susceptible	0.5	40b

Source: Centro Internacional de Agricultura Tropical (5)

* Numbers followed by the same letter were not significant at the 0.01 level (F test).

Table 2. **Total plant weight of cultivars resistant (R), tolerant (T) and susceptible (S) to *Phoma* sp., 15 months after planting.**

	Disease reaction	% of defoliation	Total weight* (t/ha)
CMC-92	R	20	54.4
M Col 340	R	25	34.3
M Col 230	R	22	19.1
M Col 276	R	18	29.4
M Col 80	R	24	25.7
M Col 233	R	22	23.3
M Col 291	R	21	15.9
M Col 2	R	17	15.1
M Col 307	T	53	13.0
CMC-39	T	58	12.4
Valluna	S	98	3.6
M Col 22	S	100	0.17

Source: Centro Internacional de Agricultura Tropical (4)

* Total plant weight was calculated from 3 randomized plots of 9 plants/plot; borders were eliminated.

Table 3. Field evaluation of resistance of F_1 crosses to *Phoma* sp. from cultivars with different degrees of resistance.

Pollination system	No. of F_1 seedlings	Disease rating* R	T	S
Self-pollinated				
R	26	1(3.8)**	15(57.7)	10(38.5)
Open	52	0	6(11.5)	46(88.5)
Control pollinated				
S x S	81	0	2(2.5)	79(87.5)
R x R	41	2(4.9)	31(75.6)	8(19.5)

Source: Centro Internacional de Agricultura Tropical (5)

* R = Resistant; T = Tolerant; S = Susceptible

** Percentage related to total number of lines tested per cross type

number of lesions on leaves was also affected by spore concentration. The most suitable concentration was between 4 x 10^4 and 8 x 10^3; the number of lesions decreased at all higher and lower concentrations (2).

Economic losses

The disease affects root yield as shown in trials conducted at CIAT in Colombia. The yield of more than 348 cultivars was determined 15 months after planting. A group of 235 cultivars was harvested at the end of the rainy season and another group of 113 immediately after the dry season. Of the first

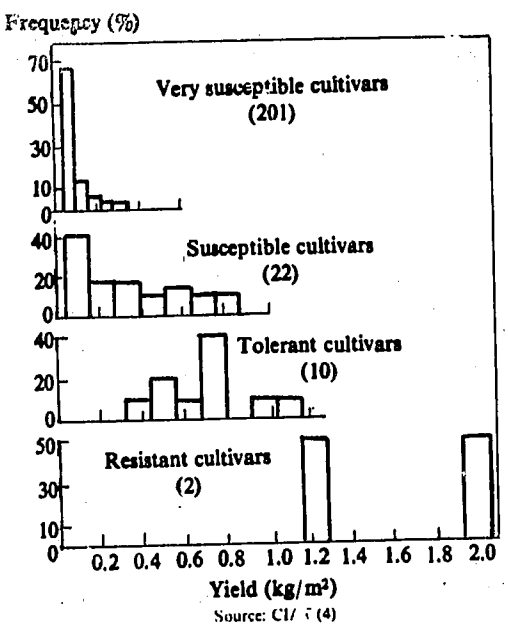

Figure 1. Yield of 235 cultivars grouped according to their reaction to *Phoma* sp. Cultivars were harvested 15 months after planting at the end of the rainy season.

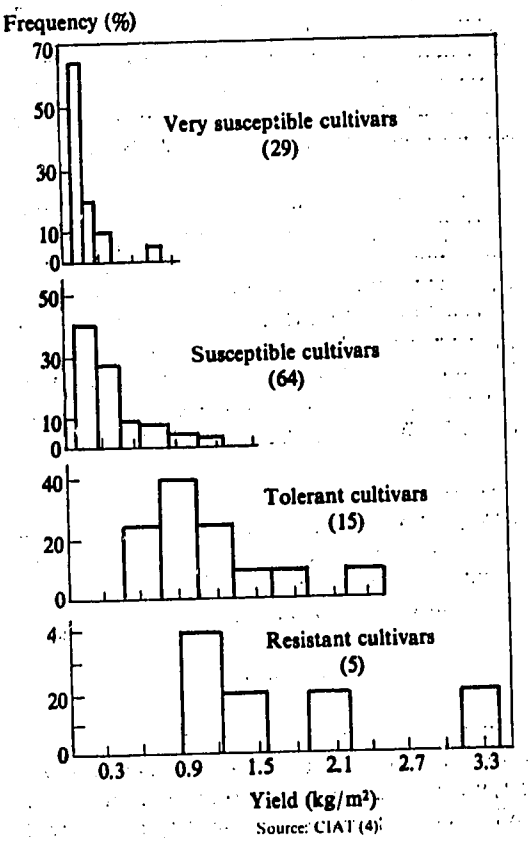

Figure 2. Yield of 113 cultivars grouped according to their reaction to *Phoma* sp. Cultivars were harvested 15 months after planting at the end of the dry season.

group, 100 percent of the very susceptible and 84 percent of the susceptible cultivars yielded less than the regional average (6 t/ha). In contrast, 70 and 100 percent of the tolerant and resistant cultivars, respectively, produced more than the regional average. Of the second group, 93 and 68 percent of the very susceptible and susceptible cultivars, respectively, yielded less than 6 t/ha; whereas 92 and 100 percent of the tolerant and resistant cultivars yielded more (Figs. 1 and 2) (4).

An evaluation of 1139 cultivars at CIAT showed that 1.7, 85:4 and 12.9 percent, respectively, were resistant, susceptible and tolerant. Yields obtained at 15 months after planting were 190 percent for the resistant cultivars but only 40 percent for the susceptible ones, in comparison with the regional average (Table 1) (4).

To increase yield in areas where concentric-ring leaf spot is severe and endemic, it is necessary to incorporate resistance to this disease in high-yielding cultivars as shown in Table 2 (5). The mechanism of inheritability of resistance to this disease is still unknown. Preliminary studies show it is quite low (Table 3) (5).

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A review of root rot diseases in cassava

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Abstract

Diseases of young, swollen and harvested roots are reviewed. Pathogenic rots and some physiological disorders are discussed. The need for further research on all aspects of these diseases, particularly the role of microorganisms in causing early root damage, the nature of primary root deterioration and the development of integrated control systems appropriate for the various production and utilization situations, is stressed.

Introduction

Although it is possible to list (Table 1) many microorganisms, both fungi and bacteria, that have been recorded isolated from damaged cassava roots (*Manihot esculenta* Crantz), their importance in causing root diseases remains poorly understood in most cases. More is known about diseases of aerial portions of the cassava plant than about root rot problems, possibly because the roots are normally inspected only at harvest and because root rots do not generally occur on an epidemic scale but are encountered in isolated patches. However, certain root rots have been known to cause losses in excess of 80 percent of potential production. Cassava roots deteriorate rapidly after harvesting and are often unfit for food or industrial purposes within 3 to 7 days. Traditional methods of preventing this problem include delayed harvesting or in-ground storage and immediate processing into numerous forms of dried products which have a longer storage life.

I. Diseases of young roots

A. Root necrosis

The influence of the early growth period on final root yield is becoming more apparent. Storage root number is generally determined early in the plant growth cycle and Hunt et al. (47) suggest that competition by weeds and attack by root rot organisms during this period could, by reducing the number of storage roots available, seriously reduce yield potential. They further suggest that because of the competitive nature of root/top growth correlations that such reductions may not be reflected in the visual appearance of the crop and that growth may appear vigorous. Fungi such as *Sclerotium* sp., *Sclerotinia* sp. *Pythium* sp. and *Fusarium* sp. have been isolated from young rooted cuttings which showed damping-off symptoms during propagation experiments (25). *Phytophthora drechsleri* is capable of causing severe root necrosis resulting in wilt and leaf drop in rooted shoot tip cuttings (65). What have previously been considered as mild infestions of

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Table 1. **Microorganisms isolated from damaged cassava roots.**

Organism	Disease	Reference *
Bacillus sp.	Minor wet rot Postharvest secondary deterioration	II.B.2. III.B.
Corynebacterium manihot	Root fermentation	(2,31)
Armillariella (Armillaria) mellea	Young root necrosis Minor dry rot	I.A. II. B.2
Aspergillus spp.	Postharvest secondary deterioration	III.B.
Circinella sp.	Postharvest decay	(48)
Clitocybe tabescens	Root rot	(9)
Cylindrocarpon candidum	Postharvest secondary deterioration	III.B.
Diplodia manihotis	Root rot	(21, 33, 67)
Erwinia sp.	Minor wet rot Young root necrosis	II. B.2. I. A.
Fusarium spp.	Minor wet rot	II.B.2.
Ganoderma pseudoferrum	Red root rot	(29)
Geotricum candida	Root fermentation	(2, 31)
Helicobasidium compactum	Minor dry rot	II. A. 3.
Lasiodiplodia theobromae	Postharvest secondary deterioration	III. B.
Mucor sp.	Postharvest decay	(21)
Penicillium spp.	Postharvest decay	(21, 45, 48)
Pheolus manihotis	Root rot	(9, 19)
Phytophthora spp.	Young root necrosis Wet rot	I. A. II. B. 1.
Pythium sp.	Young root necrosis Minor wet rot	I. A. II. B. 2.
Rhizoctonia sp.	Root rot	(43, 80)
Rhizopus spp.	Postharvest secondary deterioration Young root necrosis	III. B. I. A.
Rigidoporous (Fomes) lignosus	White root	II. A. 1.

Cont.

Table 1 cont.

	Root rot diseases	
Rosellinia spp.	Black rot	II. A. 2.
Sclerotinia sp.	Young root necrosis	I.A.
Sclerotium rolfsii	Young root necrosis	I.A.
	Minor dry rot	II. A. 3.
Sphaceloma manihoticola	Minor root rot	(13)
Sphaerostilbe repens	Root rot	(29-30, 79)
Syncephalastrum sp.	Postharvest decay	(48)
Trichoderma sp.	Postharvest secondary deterioration	III. B.
Xanthomonas manihotis	Cassava bacteria blight and minor dry rot	II. A. 3.
Unknown	Frog skin disease	I. B.
Physiological	Postharvest primary deterioration	III. A.
Physiological	Hollow heart or core rot	II. C. I.
Physiological	Abnormal root/stem thickening	II. C. 2.
Physiological	Root greening	II. C. 3.

* Refers to indicated section in this manuscript or literature where the particular organism and disease are discussed fully.

young roots by such fungi as *Rigidoporous lignosus* and *Armillariella mellea* should be reconsidered.

The role of root pathogens in causing establishment losses must not be ignored. These may be caused by infected cuttings as well as soil-borne organisms that attack either young shoots or roots or cause dieback of the cuttings themselves. Losses as high as 20 percent in establishment during the first two months after planting have been recorded even when good-quality cuttings have been planted in well-prepared and managed soils (27). Complete loss may occur when poor-quality cuttings are used or when they are planted under conditions unconducive to rapid plant establishment and growth such as drought or periods of excessive rainfall and water-logged soils. Such losses are frequently associated with several facultative parasites or even saprophytes including species of *Phytophthora, Pythium, Fusarium, Sclerotinia, Sclerotium, Rigidoporous, Rhizoctonia* and *Rhizopus,* which cause root rot, damping-off, or growth retardation. Fungicide treatments of cuttings can reduce establishment losses (26-27), but further studies are required to determine the importance of the various organisms, their major sources of inoculum and appropriate control measures.

B. "Frog skin" root disease

This unusual disease, which causes abnormal thickening of roots yet allows near normal top growth, has recently been reported to cause yield reductions of 90 percent in Colombia (27). Commonly, whole root systems are affected but sometimes only some of the roots show symptoms while others continue to grow and thicken normally. The epidermis of diseased roots becomes suberized, and there is often excessive accumulation of cork, which gives the roots a cracked and wrinkled appearance. Internally, diseased roots appear normal. The disease appears to affect the normal deposition and storage of carbohydrates in the roots so that plants produce fewer and frequently distorted swollen roots. The causal organism of frog skin disease remains

unknown, but studies at CIAT (28) have shown that the disease is not soil borne but is transmitted in symptomless cuttings taken fron infected plants. Furthermore, the disease is transmitted by grafting, in rooted shoot cuttings taken from infected plants, and to a limited extent by infested cutting knives (Lozano, personal communication). The disease may be eradicated by using healthy planting material (28).

II. Preharvest diseases of storage roots

A. Dry rots

1. White root or white thread disease is the most widespread and serious root rot of cassava in Africa (34, 51, 78) and Asia (29, 52). Although the disease is known in Latin America, it is not of major importance except in Brazil and Mexico (54). It is most common where cassava is planted immediately following jungle or susceptible plantation crop clearance. In Malaysia it is particularly prevalent in areas previously planted to rubber, an alternate host, and it is a major cause of yield loss.

White root is caused by a basidiomycete fungus *Rigidoporous (Fomes) lignosus*. Few detailed studies have been conducted on this disease on cassava, and much of the information is taken from research of a similar disease caused by this fungus on rubber trees (7,81).

The disease obtains its name from and is recognized by the presence of white cottonlike mycelial threads coating part or all of the exterior of infected storage roots and stem bases. Infected swollen roots and stem bases also commonly have a white, yellowish or even darker network of rhizomorphs on or just beneath their bark. Where infection is not severe, the internal root tissues remain undamaged and the roots are usable for both food and industrial purposes. As infection becomes severer, the outer tissues of swollen infected roots crack and develop a light- to dark-brown dry rot which increases in depth with increasing severity of attack until finally whole roots are completely destroyed. In dry soil roots become mummified and frequently have a characteristic wood rotting odor. In wet soils the infected tissues are usually invaded by a wide range of soil microorganisms that reduce roots to a semiliquid mass but in which white or light brown rhizomorphs of *R. lignosus* can still be seen. The fungus frequently attacks only the older and larger swollen roots, leaving the younger and smaller roots healthy. Typically, plants at harvest time show no marked aerial symptoms; however, if the infection is severe, wilting will occur. The presence of white root disease on large roots is taken as a sign of "maturity" in parts of Africa (1,50). Occasionally, in those situations where the inoculum potential has become very high, roots of young plants are infected. In severe cases, the roots are killed; this results in sudden wilting, defoliation and death of the plants.

Rigdoporus lignosus is generally regarded as a poor competitive saprophyte and is unable to spread any great distance through soil. Thus root infections generally occur by the host's roots growing into contact with previously colonized inoculum sources rather than by spread of fungal rhizomorphs through the soil. This is why the disease commonly occurs in patches representing sites of previously infected roots of alternate hosts.

Control measures should concentrate on management practices selected to eliminate or minimize the level of inoculum in the soil. Where cassava is planted following jungle or plantation crops, care should be taken to remove and burn all roots that could act as inoculum sources. Where the disease is observed in cassava, the infected area should be marked, the plant debris removed and burned; and if possible, the area should be avoided in subsequent plantings.

Where serious outbreaks of white root disease have occurred, it can usually be traced to a poor understanding of the disease by the grower and a failure to implement these simple control practices. For example, serious losses were observed on a new plantation in West Malaysia situated on very sandy soil, where cassava was planted following incomplete manual jungle clearing. In the first crop of cassava, localized patches of plants infected with white root occurred. Because of a lack of knowledge of the disease and a desire to increase soil organic matter, all the plant debris of this crop was returned to the soil. Considerable death and stunting of young plants caused by *R. lignosus* occurred over an extensive area in the subsequent cassava crop as a result of inoculum build-up and spread.

In the cultivation of rubber isolation trenches (aprox. 0.3m wide and 0.6m deep) are sometimes used as an emergency measure to prevent the spread of the fungus from infected to healthy trees. Root trimming and chemical collar dressing with 20% Quintozene are also recommended control measures but appear to have little application to the shorter lived cassava crop. During the replanting of rubber, it is sometimes suggested that known infected areas should first be "mapped" by using other shorter term susceptible crops like cassava so that areas with a heavy inoculum can be avoided (4). Mixed creeping legumes or crops such as peanuts or soybeans are frequently recommended as cover and intercrops in young rubber plantations, not only with the hope of improving soil fertility and preventing soil erosion but also because *R. lignosus* attacks their roots which rapidly rot away in the soil and so reduce the inoculum available for colonization of the tree roots (5). Such a practice could be useful to reduce inoculum in known infected areas prior to the planting of cassava. Care should be taken to avoid using infected cassava plants, particularly their basal portions, for planting material.

2. Black rot or Rosellinia root rot appears to be predominantly confined to South America (24, 32, 35, 56, 68, 70, 84) although it has also been reported in the Congo (78), Jamaica (61) and Madagascar (73). It is most common where cassava is grown following a forest or woody crop such as coffee, grapes or rubber in wet, high organic matter soils that contain decaying stumps or large roots harboring the causal agent. It may cause serious losses after continuous cassava cultivation.

Black rot is reported as caused by *Rosellinia necatrix* (24), *R. bunodes* (63, 68, 84) or simply *Rosellinia* sp. (61, 73). The disease is called black rot because of the characteristic black discolorations and cankers on the large swollen roots and stem bases. Initially, white fungal rhizomorphs, which later turn black, cover root surfaces. Internally, the infected tissues of swollen roots become slightly discolored and rubbery in texture; they exude a watery liquid when squeezed. As infection progresses, black mycetial strands penetrate into and grow throughout the tissues, and small cavities containing whitish mycelium may be formed in the root flesh. When infection is very severe, all roots become infected; and wilting, leaf yellowing and defoliation may occur. There are no reports that young plants are attacked, and the disease is usually observed slightly before or at harvest time.

For control of this disease, all debris from infected plants should be removed and burned. Where the disease is widespread, it is advisable to rotate cassava with a nonsusceptible crop or with a susceptible herbaceous crop with less woody and less persistent root systems. In areas where the disease is known to have been present on alternate host crops, a cereal or cover crop should be planted prior to cassava so as to reduce the inoculum level present in the soil. In the growing of cassava, care should be taken to select planting material from healthy, noninfected plants.

3. Minor dry rots are recorded as caused by fungi such as *Sclerotium rolfsii* (25, 29, 32, 41, 64, 78, 82-83), *Armillariella mellea* (9, 25, 81) and *Helicobasidium compactum* (36). White mycelium of *S. rolfsii* can occasionally be seen as a coating on swollen storage roots at harvest time and is sometimes confused with the more serious white root disease caused by *Rigidoporous lignosus*. The mycelium may, however, penetrate the roots through wounds produced during cultural practices or by other diseases or pests and cause some tissue rotting which continues after harvesting. The role of *S. rolfsii* in causing root necrosis of young plants is discussed above. *A. mellea* and *H. compactum* have been found associated with a stem base and root rot of old cassava plants. Little information is available as to the occurrence, biology or importance of these minor cassava root rots.

Under environmental conditions conducive to the development of cassava bacterial blight (CBB) and following the infection of very young, susceptible cultivars, CBB can infect and cause slight damage to swollen storage roots (53,55). Infected roots show dry, necrotic, discolored vascular strands which render the roots less acceptable, particularly in those areas where they are consumed as a fresh vegetable. Rotting is restricted to the vascular strands and the symptoms resemble those of postharvest vascular streaking.

B. Wet rots

1. Phytophthora root rot is the most serious wet/soft rot and has been reported infecting

cassava plantations in both Africa (40, 77-78, 81) and Tropical America (42, 65, 80), where it has caused yield losses of up to 80 percent. The disease is most common in water-logged and poorly drained soils and is frequently found in basin valley sites and close to drainage ditches.

Three species of *Phytophthora* have been reported as causal agents of this disease: *P. drechsleri* in Brazil (3, 32, 42), Colombia (25, 65) and the Congo (22); *P. erythroseptica* in the Congo (40); and *P. cryptogea* in the Congo and Zaire (77-78, 81). All three species are well known causal agents of root rots in other crop plants, but whether or not they are all responsible for cassava root rots needs to be confirmed. Following the identification of *P. drechsleri* as a causal agent of a serious root rot of forest trees and other agricultural crops in Australia (71), it was suggested (44) that failure to recognize the significance of this organism, despite its widespread occurrence, possibly stems from the fact that it bears a superficial morphological resemblance to other *Phytophthora* spp. and that many *Phytophthora* spp. tend to induce similar disease symptoms. Pratt (personal communication) suggests that species synonomy may exist. Such considerations need to be borne in mind in future studies of the causal organism of this soft rot disease.

Diseased swollen roots are discolored light brown and decompose very rapidly, leaving a foul-smelling watery mass. Similarly, when partially rotted, the roots excude a foul-smelling liquid. From sites of initial infection the dizease spreads very rapidly throughout the roots, frequently rotting the centers first. This rapid breakdown of the roots results in sudden wilting, some leaf drop and in severe cases plant death. The capability of *Phytophthora* spp. to cause necrosis of roots of young plants is well established (54, 65).

Control of this disease can be achieved by agronomic practices aimed at avoiding soil water logging. Cassava should not be grown in areas known to flood. Heavy soils should be well drained, and in areas or periods when heavy rainfall is expected, planting should be done in large, well-formed ridges. Excessive irrigation, particularly on heavy soils, should be avoided, and cassava should not be planted too close to large drainage channels. By following these simple control recommendations, the incidence and losses caused by this disease in Colombia have been greatly reduced. There are indications that varieties differ in their reaction to infection by *Phytophthora* spp. (3, 40, 65).

2. Minor wet rots. Species of *Pythium* and *Fusarium* (25) and several soft rot bacteria such as *Bacillus* sp., *Erwinia* sp. and *Corynebacterium* sp. (54) have been isolated from roots with soft rot. Lozano and Booth (54) suggest that these organisms enter the roots through wounds induced by man during cultural operations, by animals or insects, or by disease-inducing fungi and that they are frequently accompanied by a wide range of soil microorganisms that serve to exaggerate the damage caused by primary root pathogens.

C. Physiological disorders

1. A condition similar to that of hollow heart in potatoes can be observed in older larger swollen roots of some cassava cultivars. It is more frequently observed in large roots harvested during periods of heavy rainfall following a drought period. Hollow cavities and water-soaked areas of cells containing little or no starch appear at the center of large roots; the formation of the cavities in severe cases causes fracturing of vascular tissues which may isolate the roots from the growing plant. In some cases, following the formation of internal cavities, a dry internal necrosis may spread throughout the cortical tissues and is described as core rot by Barat et al (11).

2. Following poor soil preparation, abnormal and irregular root thickening can occur. In the Philippines, for example, severe damage was observed where cassava had been planted with only surface soil preparation in fields where rice had been previously grown for many years. A hard pan several inches below the soil surface restricted normal root growth, and root swelling was confined to the surface roots. This physical root-sink limitation induced the plants to deposit starch elsewhere, and abnormal plants with poorly developed swollen roots and thick, enlarged, round stem bases were formed.

3. Following certain planting practices and in areas where heavy rainfall sometimes washes the soil away, swollen roots may become exposed to

the air and light. In addition to encouraging consumption by rats, this may result in a greening of the outer and cortical layers of the roots as observed in Malaysia. The importance of this greening from a nutritional or acceptance point of view is not known. It has not been reported to occur in stored roots exposed to light following harvesting.

III. Postharvest root rots

The very rapid postharvest deterioration of cassava roots, which usually prevents more than a few days' fresh storage, is poorly understood and until recently had received little scientific attention. Two distinct types of postharvest deterioration occur; namely, primary deterioration and secondary deterioration or microbial rotting. (10, 15-16).

A. Primary deterioration

Previously reported as vascular streaking, primary deterioration is usually the initial cause of loss of root acceptability. It is first manifest as fine blue-black or brownish discoloration of the root vascular tissues, which is more intensive near the periphery of roots. This discoloration later spreads, causing a more general brown discoloration and finally death and breakdown of root tissues. This deterioration usually commences at the sites of root damage inflicted during harvesting and handling operations (10, 15-16). Primary deterioration renders the roots completely unacceptable for human consumption, usually within 3 to 10 days of harvesting, and considerably lowers the quality of industrial products such as starch and animal feed.

Primary root deterioration is a physiological disorder, the exact nature of which is undetermined. This theory is supported by the fact that (a) no single microorganism has consistently been isolated from the margins of discolored tissues (10, 16, 69); (b) high concentrations of certain sterilants and fungicides do not necessarily inhibit the reaction (62, 69); (c) inoculation with microorganisms, such as *Pythium, Mucor, Rhizopus, Aspergillus, Fusarium, Cladosporium, Glomerella, Gloeosporium, Rhizoctonia, Botryodiplodia, Trichoderma, Penicillium, Bacillus, Xanthosoma, Erwinia* and *Agrobacterium*, which are often present on the surface of "healthy" roots or which can be frequently isolated from decayed root tissues (62, 65), may result in rotting of freshly harvested roots but vascular streaking symptoms are not consistently produced (69). The role of microorganisms in stimulating primary deterioration symptoms, at least under certain conditions, should not be completely ruled out, however. It has been suggested (16) that primary deterioration could be caused or stimulated by microbial activity at the sites of cell damage and perhaps encouraged by the increased moisture loss that occurs at these sites. The possible causal involvement of moisture loss gained support from work by Marriott et al. (59) who suggest that vascular streaking develops as a reaction to increased water loss and/or alternations in gaseous diffusion, resulting from wounding.

Primary deterioration is traditionally controlled by leaving the roots in the ground until required and once harvested, immediately utilizing or processing them into some form of dried and more durable product. This control measure can be practiced very successfully as cassava has no fixed specific maturity period. Nevertheless, susceptibility to pathogenic root rots increases when roots remain in the ground too long; and although the roots may continue to increase in size, they also become more fibrous and woody and their extractable starch content and palatability reportedly decline (46). This method of avoiding primary deterioration is only applicable in those regions where there is little pressure on agricultural land. It has, for example, been estimated (48) that in-ground storage occupies 750,000 ha of agricultural land globally, some of which could be used to produce additional crops. In situations where climate, land availability and cropping system permit, continuous cropping with short periods of in-ground storage to prevent postharvest primary deterioration is recommended.

Traditional postharvest methods for controlling primary deterioration for a few days include such simple techniques as reburial in moist soil, coating in mud, or placing under water. Except for the use of such high-cost systems as refrigeration (60, 75; Rojanaridpiched and Kawano, personal communication) and waxing (49), there are few recorded instances of successful long-term storage

of fresh roots (16). Recently, CIAT (26) and Booth (15-16) have shown that in addition to minimizing primary deterioration by selecting varieties least susceptible to mechanical injury and by reducing such injury by careful harvesting and handling, the wounds of damaged roots can be healed and the onset of primary deterioration prevented by a "curing" process. Curing is a process effective in reducing both moisture and pathogenic storage losses of other root and tuber crops such as potatoes, sweet potatoes and yams (14). It first involves suberization of the outermost cells near wounds; then deeper parenchymatous cells form a meristem or cork cambium, which produces a cork layer around the wound. This process has been observed in cassava roots kept for 4 to 9 days at a relative humidity of 80 to 85 percent and a temperature between 25 and 40°C (16). Marriott et al. (59) have suggested that control of vascular streaking is the result of storage under high humidity or low vapor pressure deficit conditions and that it is unlikely that the wound healing process itself is involved in the initial suppression of vascular streaking.

Successful storage of fresh roots for periods of weeks and even months has been achieved in various structures that maintain a high relative humidity and thus promote curing; i.e., field trenches (5, 12, 38) and more recently in experimental field clamps and storage boxes (15, 17). Field clamps are constructed by first placing a circular bed of straw or other similar material approximately 1.5 m in diameter and 150 mm thick, after compaction, on a suitable well-drained area of ground. The freshly harvested roots (300-500 kg) are heaped in a conical pile on this bed and covered first with straw and then with soil that is dug from around the circumference of the unit so as to form a drainage ditch. The exact thicknesses of straw and soil-covering layers and whether or not ventilators have to be provided needs to be determined for each location so that the internal clamp temperature is maintained below 40°C (15, 17). As an aid to the marketing of fresh roots, it has been found possible to delay primary deterioration and store roots successfully for 2 to 6 weeks by packing them with a moist material such as moist sawdust, soil, peat or coir dust in suitable containers such as wood, tin or cardboard boxes (15, 17, 58, 74). Using these two storage metods, it has been shown (18) that although there is a decline in root quality, fresh roots remain acceptable for both human consumption and for use fresh as an animal feed for at least an eignt-week period. It has also been shown possible to store fresh roots successfully in sealed polythene bags for at least four weeks (66).

Differences in varietal resistance to primary deterioration have been reported (15, 60, 69; Rojanaridpiched and Kawano, personal communication). In a detailed study of varietal reaction to root deterioration, Rojanaridpiched and Kawano found that out of 2312 lines of F_1 cassava hybrids examined, 49 (2.12%) showed very high levels of resistance to deterioration following open "storage" in the field for 14 days and that out of 232 cultivars examined 3 showed high levels of resistance. They also observed that the distribution of resistance among varieties was nearly normal. Resistant varieties showed symptoms of streaking near the sites of damage in some roots but it did not spread. Rojanaridpiched and Kawano (personal communication) showed that it is possible for the plant breeder to contribute significantly to reducing postharvest losses by selecting for resistance, which they also demonstrated could be transferred to high-yielding varieties. They found no correlation between root yield and root deterioration, but primary deterioration was positively correlated with root starch content and negatively correlated with root moisture. It might, therefore, be difficult to obtain a variety that has a high starch content and that is also resistant to deterioration. However, by keeping starch content at an acceptable level, a variety might be improved or developed with resistance to deterioration and a high starch yield per unit area achieved through high root yields. The role of root moisture loss in the development of primary deterioration requires further study.

Because of the production of free hydrocyanic acid at the sites of cell damage, it is possible to postulate that various cyanide compounds might be involved in the color development during vascular streaking. No correlation has, however, been found between varietal reaction to vascular streaking and root HCN content (16). This does not necessarily indicate that cyanide compounds are not involved, as the minimum level required to produce the colored reaction may have been present in all the varieties.

The use of various chemicals and gas storage atmospheres to prevent the onset of primary deterioration has been examined (16, 48, 57, 62). Numerous chemicals such as benomyl, benzoic acid, calcium hypochlorite, dicloran, ethyl alcohol, ethyl bromide, ethylene dibromide, formaldehyde, lactic acid, sodium chloride, sodium dithiocarbamate, sodium-o-phenyl phenate, sodium hypochlorite, and sodium sulfite have been reported to reduce postharvest spoilage in small, controlled experiments, particularly where root slices rather than whole roots were used (16, 62). No chemical treatments have been applied successfully on a large, practical scale to the storage of whole fresh roots. It has, however, been shown that surface waxing enables whole roots to be stored successfully for 30 days (20, 23, 49, 76). This process involves washing, drying and then dipping the roots in hot molten paraffin wax, after which they must be packed carefully to prevent damaging the wax coating. Buckle et al. (20) suggest that the success of the method is due to a reduction in moisture loss, a lowering of contamination by microorganisms, and a reduction in the availability of oxygen. Machinery that can process 1/2 and 10 tons daily has been developed (49). In Brazil (6, 37) and recently in Malaysia (Booth, unpublished data) it was shown that deterioration of freshly chipped cassava roots can be prevented by mixing them with commercial salt. They can be stored for considerable periods, even up to one year, and fed directly to animals. This treatment can also be used to maintain high-quality dried chips during periods of poor, slow sun drying (Booth, unpublished data). Passam and Noon (69) and Noon and Booth (62) reported control of vascular streaking when root slices were stored in gaseous atmospheres with reduced oxygen tension, suggesting that an oxidation reaction may be involved in the development of primary deterioration.

Control of root deterioration is also possible by keeping the roots refrigerated at 0 to 6°C (60, 75; Rojanaridpiched and Kawano, personal communication). Above 6°C roots deteriorate rapidly and frequently show signs of chilling injury (58, 60; Booth, unpublished data). In addition, roots removed from successful low-temperature storage deteriorate rapidly on return to ambient temperatures (58). At present it is unlikely that refrigeration could be used on an extensive scale for storing cassava roots, but it should be considered in certain situations and can be used successfully for storing small quantities of roots in the home.

B. Secondary deterioration

Secondary deterioration is usually caused by microbial rotting, though it may be due to fermentation and/or softening of root tissue. It is initially less important than primary deterioration as it generally occurs after the roots have already become unacceptable due to primary deterioration (15, 16). Occasionally, however, secondary deterioration may be the initial cause of loss of acceptability; and in these instances symptoms similar to those of vascular streaking frequently occur ahead of advancing rots. Majumder (57) reported two types of postharvest rot: an aerobic dry rot caused by *Rhizopus* sp. and an anaerobic soft rot caused by *Bacillus* spp., both causing root discoloration and increased acidity. Ekundayo and Daniel (39) report that tissue deterioration, due partly to wound infection by *Lasiodiplodia theobromae*, *Trichoderma harzianum*, *Cylindrocarpon candidum*, *Aspergillus niger* and *A. flavus*, was the main cause of storage loss in Nigeria. These pathogens penetrated through wounds and bruises inflicted during harvesting and handling but not through undamaged surfaces. Storage at high humidities encouraged fungal rotting; this was reduced by dipping roots in benomyl or thiabendazole suspensions. Noon and Booth (62) also found that *L. theobromae*, *A. flavus*, *T. harzianum* and *Fusarium solani* were capable of producing rotting following artificial wound inoculations.

Several of the control measures developed for reducing primary deterioration should also reduce secondary deterioration. For example, curing by the production of a wound periderm will, if conducted rapidly following root injury, prevent the entry of wound pathogens; storage at low temperatures will reduce the degree of rotting by most pathogens; and varieties should be selected for both minimal damage and resistance to post-harvest decay. Studies on the control of secondary root deterioration alone are difficult because of primary deterioration. Emphasis should thus be placed on selecting varieties and developing handling and control measures that will reduce losses caused by both forms of deterioration.

IV. Conclusions

Further research is clearly needed on cassava root rots (a) to obtain detailed figures on actual losses, (b) to determine more accurately their geographic distribution and importance in the many widely differing cassava-growing areas, and (c) to expand scientific knowledge of the etiology, epidemiology and control of the majority of these diseases.

Isolated figures exist on particular losses caused by individual root rots, but no information is available as to the frequency at which such losses occur or to the average loss caused by the various root rots in given areas over a given number of years. Although there is now considerable information on the various pre- and postharvest root rots, our knowledge is still very incomplete. Few detailed scientific studies have been conducted, and much of the information comes from observations alone. In particular, it is suggested that the effect of microorganisms in reducing potential plant yields by causing root damage and necrosis during early plant growth and the exact cause and biochemistry of primary deterioration warrant considerable attention.

Based on information currently available, it appears that many cassava root rots could best be reduced by utilizing integrated control measures. For example, the incidence of Phytophthora root rot can be reduced by good soil management, and varieties differing in their reaction to this disease have been found. A large number of techniques such as traditional in-ground storage, varietal resistance, low-temperature or high-humidity storage, and chemical treatments are all capable of reducing postharvest root losses; but there are few indications at present of how some of these individual techniques may best be combined to provide the most efficient systems for reducing losses in the widely differing production and utilization systems that exist.

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New developments in cassava storage

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Abstract

Cassava roots deteriorate rapidly after harvest. Deterioration is either physiological or microbial, but the former generally occurs within 48 h of harvesting. Experimental results show that physiological deterioration can be prevented either by pruning the plants 2-3 wk before harvest or by packing the roots in polyethylene-lined paper bags after harvest. Microbial deterioration can be prevented by dip-treating the roots with broad-spectrum fungicides such as Manzate.

Introduction

The cassava root is highly perishable, often showing cortical necrosis (physiological deterioration) as rapidly as 24 hours after harvest; five to seven days later, microbial rotting occurs (1).

Some progress has been made in searching for varietal resistance to both types of deterioration (Kawano, personal communication); nevertheless, resistance to physiological deterioration appears to be positively correlated with moisture content (4; Kawano, personal communication). Although this correlation is not particularly close, it does suggest that it may be difficult to breed for high dry matter content, a desirable character, and for resistance to physiological deterioration at the same time. Furthermore, most lines apparently resistant to this type of deterioration eventually suffer microbial deterioration after about ten days. It is a moot point whether resistance to deterioration for such a short period would resolve many of the problems associated with cassava perishability.

In their comprehensive review on cassava storage, Ingram and Humphries (5) mentioned various traditional methods such as packing in mud and structures similar to potato clamps used in Europe. Booth (1) refined the potato clamp method and developed a storage system using boxes filled with moistened sawdust. These systems are somewhat costly and difficult to manage and have not, up to the present, been adopted on a commercial scale. Oudit (6) suggested that fresh cassava could be stored for up to one month in polyethylene bags with no extra treatment.

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During visits to cassava-growing areas, the authors and other members of the CIAT Cassava Production Systems team observed that in many local markets the cassava roots were sold while still attached to the stem. The vendors claimed that the roots deteriorated much more slowly under these conditions than when removed from the stem.

Booth (1) showed that roots kept under conditions of high humidity "cured" and physiological deterioration was prevented; however, as temperature increased microbial deterioration occurred rapidly.

We have attempted to develop simple methods that may readily be adopted to control both physiological and microbial deterioration of the harvested roots. In the former case both maintenance of high humidity and leaving roots attached to the stems have been the basis, whereas in the latter case, use of protectants and sterilants were evaluated for preventing microbial rotting.

Material and methods

The symptomatological definition of the two reported types of deterioration in cassava roots (1) was determined by general observations on stored roots of different varieties. The severity of these two types of deterioration was evaluated by following Booth's scale of deterioration (3), considering 0 as healthy roots and 4 as the most affected.

Physiological deterioration

The control of physiological deterioration was investigated by (a) pruning the aboveground part of the plants before harvesting and (b) by using different packing systems.

Pruning

One-year-old plants of two varieties susceptible to physiological deterioration (M. Colombia 22 and M. Colombia 1802) were used in the first trial. Plants were pruned back to 20 cm aboveground and harvested 7, 14 and 21 days after pruning. Half of the roots were stored without the stem and the others with the stem section attached. Roots were stored in the field under an open-sided palm hut and readings taken every five days. Deterioration was determined on 20 roots/variety/time of storage. A second trial included six varieties (M. Colombia 45, M. Colombia 1807, CMC 29, CMC 92, M. Mexico 59 and Popayán), which in previous trials had showed different degrees of deterioration.

To determine the effects of temperature and humidity on deterioration, M. Colombia 22 was pruned 14 or 21 days before harvest. Roots were detached from the stems at harvest; half were sliced at both ends and half were left whole. These roots were stored at 35 and 45°C and 20, 40, 60 and 80 percent relative humidity for 0, 6, 12 and 24 hours. Deterioration was evaluated daily on 10 roots per treatment for 20 days.

Packing systems

Twenty fresh, recently harvested one-year-old M. Colombia 113 roots were packed in burlap sacks or bags made of paper, polyethylene-lined paper, or transparent polyethylene. Bags were stored in an open-sided palm hut, and every five days the root deterioration of 3 bags per treatment was recorded as previously. The same trial was later repeated with freshly harvested roots of Llanera and M. Mexico 23.

Microbial deterioration

To control microbial deterioration sodium hypochlorite and Manzate (manganese ethylene bisdithiocarbamate) were used to treat the roots; the former because of its sterilizing effect without leaving toxic residues and the latter because of its protectant effect with low reported toxicity (7), as well as its availability on the market. The combined products were suspended in water at increasing-decreasing concentrations of 5×10^2, 1×10^3, 2×10^3, 3×10^3 and 4×10^3 ppm a.i. of Manzate and 5×10^3, 1×10^4, 1.5×10^4, 2×10^4 and 2.5×10^4 ppm a.i. of sodium hypochloride. Roots were immersed in the suspension for 3 to 5 minutes before packing them in paper-lined polyethylene bags. Readings of deterioration were taken, as above, every five days.

In order to determine whether light had any effect on chemical degradation after treatment which would lead to microbial deterioration during storage, roots of Llanera, M. Colombia 113 and M. Mexico 23 were packed in transparent, red, green and black polyethylene and polyethylene-lined

paper bags after treating the roots with 3×10^3 ppm a.i. of Manzate and 1×10^4 ppm a.i. of sodium hypochloride. Readings were also taken as above every 5 days.

Results

Physiological deterioration is characterized by a dry brown to black necrosis, normally appearing in the form of rings around the periphery of the cortex. This deterioration appears within the first 48 hours after harvesting, depending on varietal susceptibility, and ends in dehydration. Microbial deterioration commonly initiates as vascular streaking, followed by soft rot, fermentation and maceration of the root tissues. This type of deterioration, which does not occur in any special order, is normally noticeable 5 to 8 days after harvesting, depending on the soil microbial flora able to metabolize cassava roots and on the intensity of damage to roots at harvest (Fig. 1).

Pruning

When plants were pruned before harvest, the percentage of deterioration decreased with the time from pruning to harvest up to 14 to 21 days; leaving more time between pruning and harvest had little effect. Roots left attached to the stem piece always deteriorated more slowly than those without the stem (Fig. 2). Varieties without any treatment differed in susceptibility to deterioration (Fig. 3); for example, M. Colombia 1807 and M. Colombia 22 were very susceptible whereas M. Colombia 1802 and M. Mexico 59 were moderately resistant. After 21 days of pruning, however, the first two varieties showed less deterioration when treated than the last two, which were more resistant without treatment. Hence the reaction of varieties to the pruning treatment varies and resistance without treatment is not related to resistance with treatment.

Damaged roots generally deteriorate more rapidly than undamaged roots (1); however, after the pruning treatment roots that were cut to simulate damage deteriorated at the same rate as undamaged controls even when held at low humidity to prevent curing. High or low relative humidities did not increase deterioration of roots taken from pruned plants (Fig. 4).

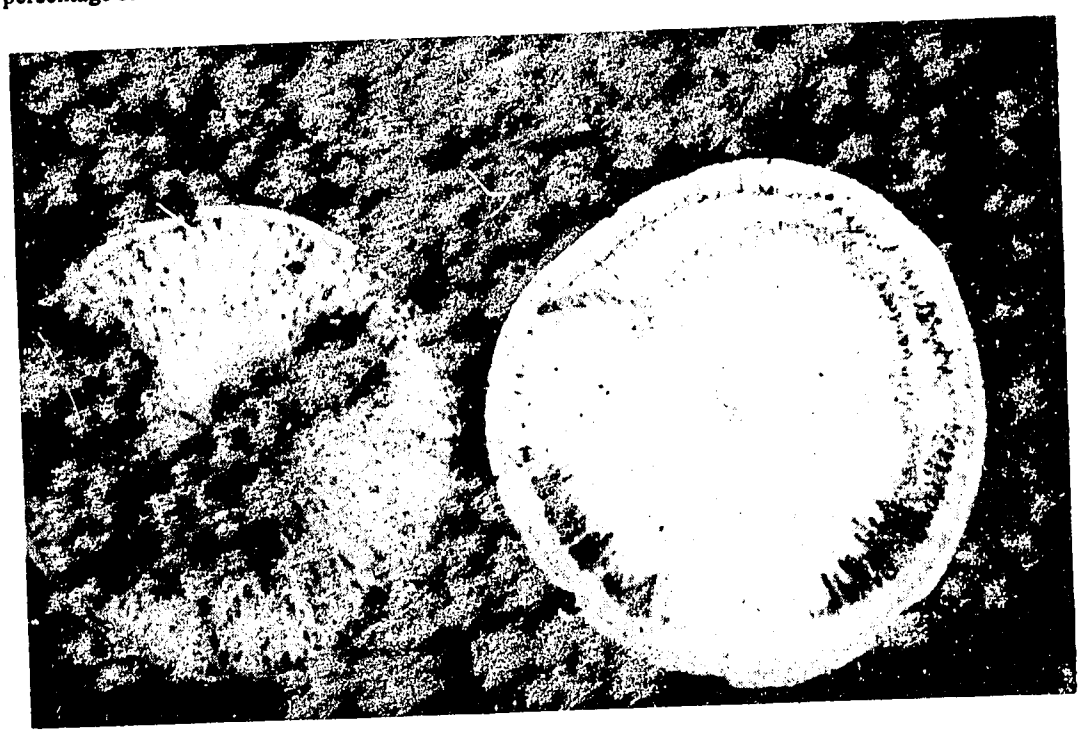

Figure 1. Cassava root deterioration: left, microbial and right, physiological.

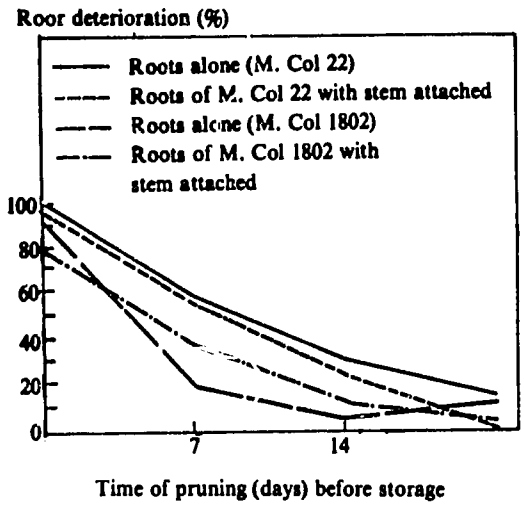

Figure 2. Effect of pruning on cassava root deterioration after 20 days of storage.

When roots were stored after pruning, physiological deterioration, which normally occurs during the first two days of storage, was prevented; however, after ten days microbial rotting occurred (Fig. 5), but this was prevented by using a dip of Manzate and sodium hypochlorite (4 x 10^3 and 2.5 x 10^4 ppm a.i., respectively).

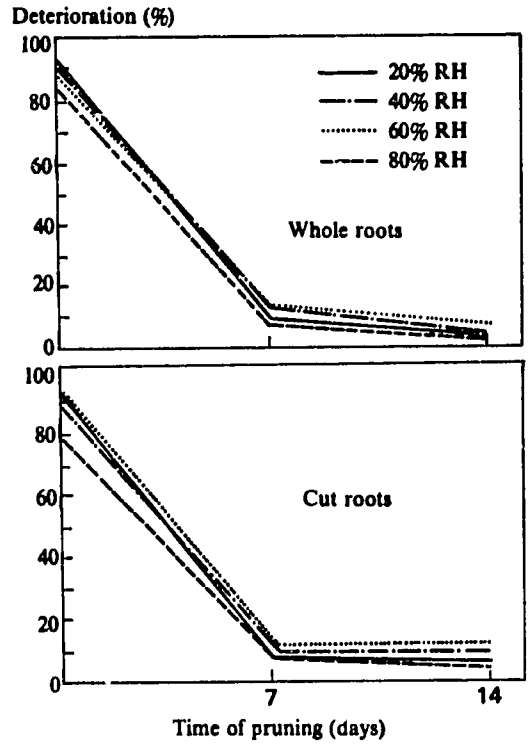

Figure 4. Deterioration of M. Colombia 22 roots in relation to plant pruning after 20 days storage at 35°C and 20, 40, 60 or 80% RH for 12 hours.

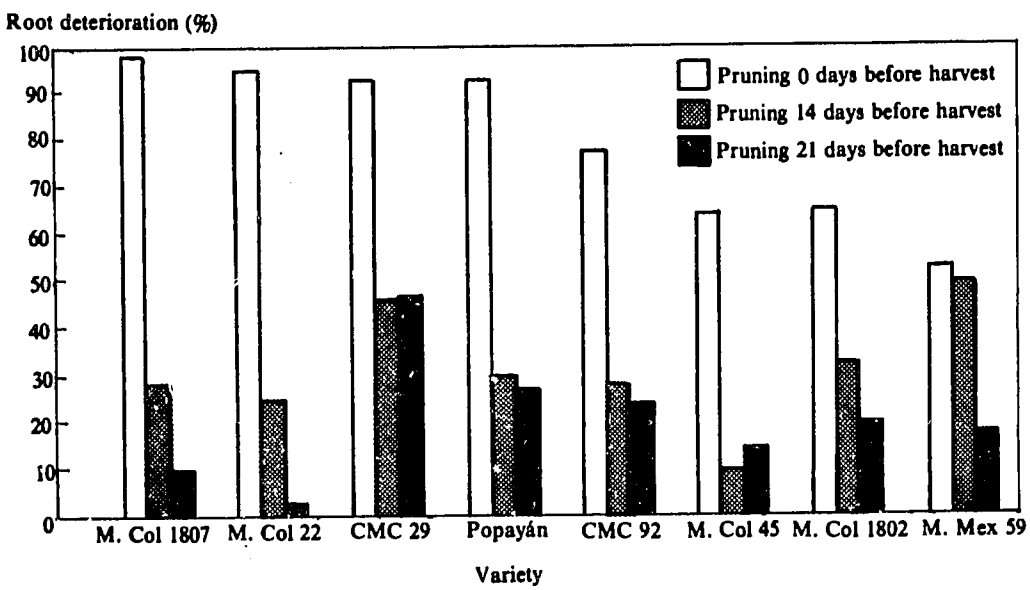

Figure 3. Root deterioration of 8 varieties pruned 0, 14 and 21 days before harvesting and stored for 20 days.

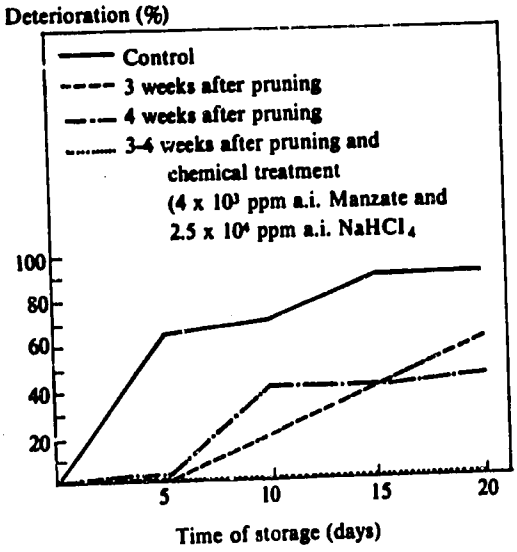

Figure 5. Effect of plant pruning and chemical treatment on root deterioration (M. Col 113).

Storage in bags

Storage in burlap and paper bags improved the number of undeteriorated roots when compared with controls (Fi_. 6), but treatments still gave a high percentage of both microbial and physiological deterioration even five days after storage. Paper bags lined with polyethylene, on the other hand, prevented physiological deterioration. There was, however, a tendency for microbial deterioration to occur after about ten days, in a manner very similar to that found in the pruning treatments. This tendency was partially prevented by treating the roots with sodium hypochlorite (2.5 x 10^4 ppm a.i.) and completely prevented by a treatment with 4 x 10^4 ppm a.i. of Manzate (Fig. 7). Further trials showed that this concentration of Manzate allowed some microbial rot and that at concentrations of 8 x 10^4 ppm a.i., excellent control was always obtained (Fig. 8). Preliminary studies on quality showed that HCN levels were apparently reduced during storage and that eating quality was improved by time of storage if physiological deterioration was prevented.

It appears that light does not influence the protectant effect of the chemical used. All roots kept in polyethylene bags with different colors deteriorated at the same rate.

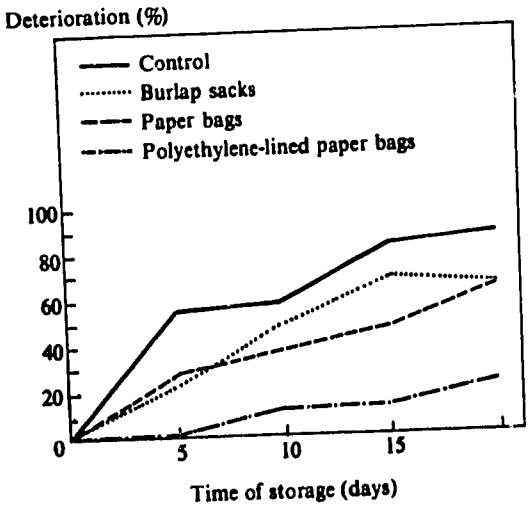

Figure 6. Effect of storage in bags on cassava (M. Col 113) root deterioration.

General discussion

Our results with regard to the definition of the two types of cassava root deterioration were in agreement with those reported by Booth (1), except that vascular streaking appears to be a common symptom. Physiological deterioration develops as

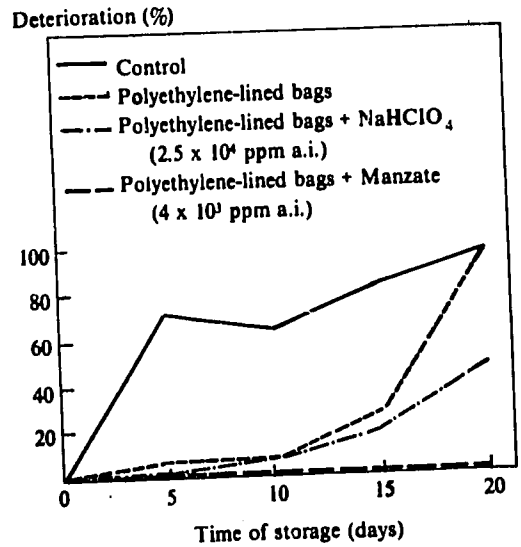

Figure 7. Effects of polyethylene-lined paper bags and chemical treatments on deterioration of stored roots (CMC 40).

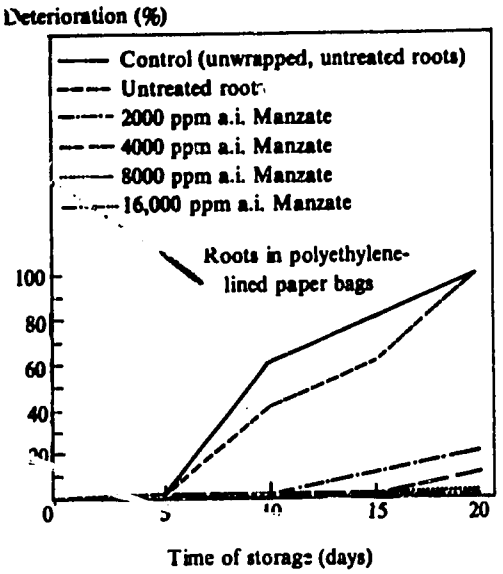

Figure 8. Prevention of cassava root microbial deterioration with Manzate (CMC 40).

a dry rot which ends in a light to dark brown discoloration, always found as a ring around the outermost part of the cortex. Vascular streaking, which is also associated with physiological deterioration, is commonly present at the initiation of microbial deterioration as the result of microbial invasion and degradation. This vascular streaking did not have any symptomatological pattern and always ended in tissue maceration, fermentation and discoloration. Microbial activity was always detected.

It appears that physiological deterioration can be prevented both by pruning the plants two to three weeks before harvest and by packing the roots in polethylene bags. If pruning is done and new shoots are allowed to develop before harvest, its effect on physiological deterioration decreases. This suggests that the leaves produce some principle that is translocated to the roots, inducing the initiation of physiological deterioration. Booth (1) reported that this deterioration is associated with mechanical damage to the roots; however, in the pruning system, wounded roots did not show signs of physiological deterioration. It appears that the principle is somehow eliminated or minimized in the roots after pruning; this view is supported by the decline of this type of deterioration when the time from pruning to harvest is extended.

When roots are stored under humid conditions, curing apparently takes place (1) and the consequent healing of wounds prevents physiological rotting. Recent work done by John Marriot while at CIAT suggests that there is another factor involved that is related to water loss. When water loss was reduced by artificial means, physiological deterioration was delayed (Marriot, personal communication). This interesting result may explain why high moisture content is loosely correlated with resistance to this type of deterioration. This physiological process may initiate only when a critical low moisture content is reached; varieties whose roots have a low moisture content may reach this level more rapidly. Furthermore, when roots are placed in polyethylene bags, the high humidity environment may not only favor root curing and healing but also reduce water loss sufficiently to prevent physiological deterioration.

Deterioration due to microbial activity is a separate entity, distinct from physiological deterioration. It is induced by a complex of microorganisms able to degrade root tissues. The use of surface sterilants alone is apparently ineffective, probably because sterilization is difficult and there is always an opportunity for reinfections. On the other hand, protectants such as Manzate can be used to prevent reinfections.

It thus seems that protectants can be used to prevent microbial rotting; and either pruning or high humidity conditions, to prevent physiological deterioration. The pruning treatment has some adverse effects on the quality of cassava for fresh consumption. The roots become slightly harder and dry matter content increases slightly, which means that cooking has to be prolonged. On the other hand, it improves the quality of cassava for industrial use. Cassava drying and starch extraction are facilitated by the high dry matter content: transportation costs are reduced and processing is easier.

Although Oudit (6) suggested that storage in polyethylene bags with no further treatment gave no deterioration after 20 days, we always had microbial rotting 7 to 10 days after harvest. However, when polyethylene-lined paper bags, were used in conjunction with protectants, cassava could be stored safely for up to three weeks after

harvest with no change in cooking quality. The problems of toxicity from the surface protectants are minimal because the roots are always peeled before cooking. The use of several chemicals and their translocation in the roots remains to be investigated.

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Entomology sessions

142

The cassava mite complex: taxonomy and identification*

Carlos H.W. Flechtmann**

Abstract

A taxonomic key is presented for classifying the mites that attack *Manihot* spp. Methodology (sampling and slide preparations) is explained, and morphologic characters important in their identification are given and illustrated. Data are given on geographic distribution, host plants and damage caused by *Eutetranychus banski, E. enodes, E. orientalis, Allonychus reisi, Mononychellus caribbeanae, M. tanajoa, M. mcgregori, M. bondari, Oligonychus coffeae, O. peruvianus, O gossypii, Tetranychus yusti, T. tumidus, T. mexicanus, T. sayedi, T. truncatus, T. neocaledonicus, T. amicus, T. lombardini, T. kanzawai, T. urticae* and *T. cinnabarinus*.

Introduction

Spider mites have become of increasing importance as pests of *Manihot* spp. (Euphorbiaceae). During recent years economic entomologists have been increasingly concerned with these mites; and since organic chemicals are often effective for the control of only certain species or vary in their degree of effectiveness among species, it is important to make accurate determinations of the spider mites with which they are concerned. This contribution is intended to aid in making determinations.

Twenty-two species of spider mites are known to occur on *Manihot* spp. throughout the world, and two or more species may be encountered on the same plant. In addition different species may predominate as the season advances. Their classification is made difficult by a certain number of factors; these mites show a certain degree of variation whose limits are often difficult to determine. Their distribution has been altered by man by transporting them to new areas and their populations have been affected by the use of pesticides.

Methodology

Sampling

Spider mites are identified accurately only with microscopic slide preparations, and samples must be taken periodically for examination in the laboratory. The coloration and/or markings of the adult bodies, their size, feeding and spinning habits may be indicative of the species involved; thus a number of separate samples are more desirable than a composite collection when gathering material.

* This paper is by no means a definite work or even a completed one. Species listed can be found in print elsewhere, and we hope that this work will lead to its own revision and, ultimately, its own obsolescence.

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Samples should not be restricted to the cassava leaves; weeds should not be overlooked. Both sexes should be collected. Spider mite males often appear similar to the nymphal stages, being small and slender; all sizes and shapes should be collected.

The most satisfactory method of collecting specimens is to take infested leaves to the laboratory in paper or plastic bags. These may be stored for a week or two under refrigeration. In the field the material should be kept from the sun. Leaves with heavy infestations may be placed in vials containing 70% ethyl alcohol.

Slide preparation

Spider mites are best mounted in Hoyer's medium, consisting of 40 ml distilled water, 30 g gum arabic, (crystals), 200 g chloral hydrate and 20 g glycerine.

The materials should be mixed at room temperature in the sequence listed; stirring is necessary over a period of a few days.

Live mite or alcoholic specimens may be placed directly into a drop of Hoyer's medium on the slide; females should be oriented dorsoventrally with the legs spread; profile mounts should also be made. Male spider mites must be mounted in profile to allow perfect view of the aedeagus. After the cover slips have been placed over the medium, the slides are heated gently until the solution begins to show bubbles; this heating expands and clears the specimens. Specimens can be rolled into position by moving the cover slips. The slides are kept flat at 55°C for 24 to 48 hours. Ringing the cover slip with an excess of Hoyer's or with Zut is desirable.

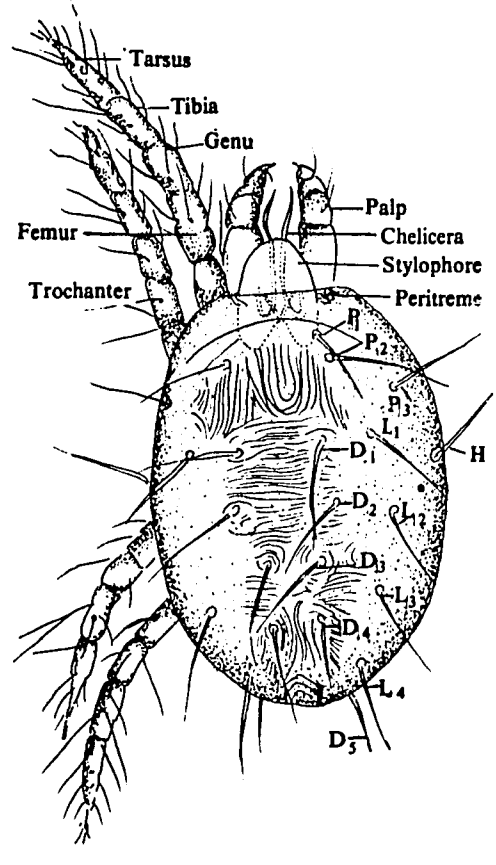
Diagnostic characters

The identification of cassava spider mites with the aid of a compound microscope is based on the differentiation of relatively few characters.

The Tetranychidae Donnadieu possess long, recurved whiplike movable chelae, set in the stylophore or fused basal segments of the chelicerae; the fourth palpal segment bears a strong "claw"; tarsi I and II usually bear specialized duplex setae; the claws possess tenent hairs and the empodium may or may not have tenent hairs; the female genitalia is characteristic of the family. Normally there are three pairs of propodosomal (P_1, P_2, P_3), four pairs of marginal (L_1 . . . L_4), five pairs of dorsal (D_1 . . . D_5) and one pair of humeral (H) setae (Fig. 1). Setae may shift, drop out or extra pairs may be added.

All spider mites presently known on *Manihot* spp. are within the subfamily Tetranychidae, characterized by the absence of empodial tenent hairs.

The peritremes (Fig. 1) consist of two divergent arms that arise medially near the anterior end of the body. Their extended position varies as the lobelike base of the mouthparts (stylophore) is everted or retracted. Characteristics of the termination of the



Source: Jeppson, Keifer and Baker (14)

Figure 1. *Tetranychus* sp. Female, dorsal view. P_1, P_2 and P_3 are dorsal propodosomal setae; H - humeral setae; D_1 . . . D_5 dorsocentral hysterosomal setae, and L_1 . . . L_4 ,dorsolateral hysterosomal setae.

peritremes are sometimes important for species recognition.

The fore tarsus (Fig. 2a) bears two pairs of intimately associated setae, called duplex setae (Fig. 2a-e). A single pair of duplex setae is found on tarsus II. The position of the duplex setae and the relative lengths of the members of each pair are important for identification. The end of the tarsus bears a pair of tenent (knobbed) hairs on each side, each pair representing the remains of a true claw (Fig. 2c); the empodium is located between these tenent hairs and structure is of taxonomic value.

The pattern of integumentary striations on the dorsum of females is of significance and the final identification is usually based on the shape of the male aedeagus (Figure 3); therefore, males must be mounted laterally.

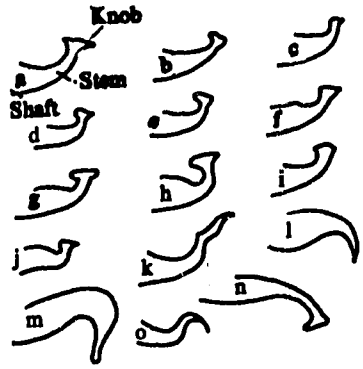
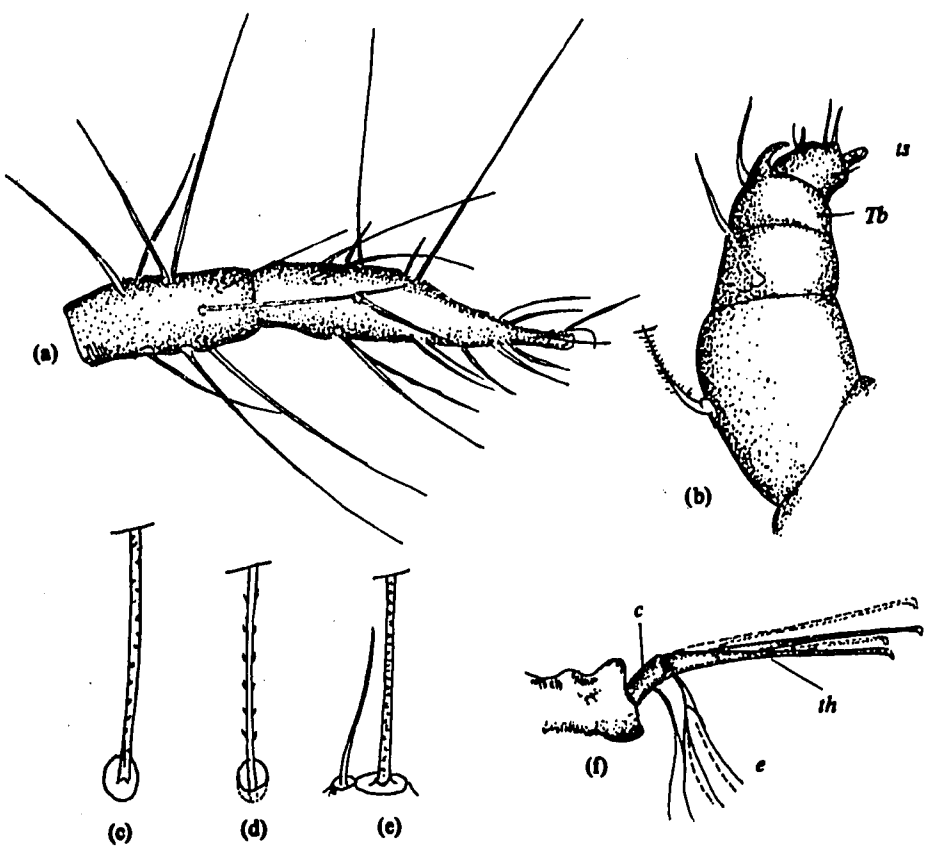


Figure 3. Aedeagi: (a) *Tetranychus mexicanus*, (b) *T. neocaledonicus*, (c) *T. truncatus*, (d) *T. tumidus*, (e) *T. urticae* and *T. cinnabarinus*, (f) *T. yusti*, (g) *T. kanzawai*, (h) *T. lombardini*, (i) *T. sayedi*, (j) *T. amicus*, (k) *Oligonychus gossypii*, (l) *O. peruvianus*, (m) *O. coffeae*, (n) *Mononychellus tanajoa* and (o) *Oligonychus biharensis*.



Source: Pritchard and Baker (23)

Figure 2. *Tetranychus* sp. (a) Tarsus and tibia I of female, (b) female palpus (*Tb*, tibia; *ts*, terminal sensillum), (c) sensory seta, (d) tactile seta, (e) duplex seta and (f) tarsal appendages (*c*, remains of true claws; *e* empodium; *th*, tenent hairs).

Key to the genera and species of spider mites known on *Manihot* spp.

1. Tarsus I without closely associated duplex setae, or duplex setae absent; empodium absent . . . . . *Eutetranychus* 5
- Tarsus I with 2 pairs of duplex setae; empodium present, clawlike or split distally 2

2. With 2 pairs of para-anal setae 3
- With one pair of para-anal setae 4

3. Empodium clawlike, with proximoventral hairs ..... *Allonychus reisei*
- Empodium ending in a tuft of hairs; hysterosomal striae longitudinal between 3rd pair of dorsocentral setae . . . . . *Mononychellus* 7

4. Empodium clawlike, with proximoventral hairs; duplex setae of tarsus I distal and approximate . . . . . *Oligonychus* 10
- Empodium split distally, usually into 3 pairs of hairs; duplex setae of tarsus I well separated . . . . . *Tetranychus* 12

5. Body with dorsal setae (P, H, D and L series) very short and borne on small tubercles ..... *Eutetranychus enodes*
- Marginal body setae longer than the dorsal median setae 6

6. Setae D_3 and D_4 of the histerosoma form a rectangle; striae are longitudinal between D_3 ..... *Eutetranychus orientalis*
- Hysterosomal setae D_3 are much closer together than D_4; striae on the hysterosoma transversal except for a V-shaped pattern between setae D_2 and D_3 ..... *Eutetranychus banksi*

7. Dorsal body striae anastomosing; female tibia I with 7 tactile and one sensory setae ..... *Mononychellus caribbeanae*
- Dorsal body striae not anastomosing; a slightly reticulate pattern may be present posteriorly; female tibia I with 8 or 9 tactile and one sensory setae 8

8. Body setae D_1, D_2 and D_3 are ca. one half as long as the distance between their bases. Tibia I with 9 tactile setae and one slender solenidion ..... *Mononychellus tanajoa*
- Dorsal hysterosomal setae all of about equal length; tibia I with 8 or 9 tactile setae and one slender solenidion 9

9. Dorsal body setae on tubercles, long, strong, serrate, slightly broadened distally, all of about equal length except for the shorter P_1, P_3 and H_1. Tibia I with 8 tactile and one slender solenidion ..... *Mononychellus mcgregori*
- Dorsal body setae pubescent, set on small tubercles. Tibia I with 9 tactile setae and one slender solenidion ..... *Mononychellus bondari*

10. Tibia I with 7 tactile setae, aedeagus bent ventrad, at a right angle to shaft ..... *Oligonychus coffeae*
- Tibia I with 9 tactile setae; aedeagus bent dorsad or ventrad 11

11. Body with dorsal setae obviously widened proximally and acutely tapering distally; aedeagus bent ventrad ..... *Oligonychus peruvianus*
- Body with dorsal setae slender; distal part of aedeagus with ventral side of bend undulate ..... *Oligonychus gossypii*

12. Female with proximal pair of duplex setae on tarsus I more or less in line with most of the proximal tactile setae ..... *Tetranychus yusti*
- Female with proximal pair of duplex setae distad of other proximal tactile setae 13

13. Empodium with an obvious empodial spur, at least one third as long as the proximoventral hairs 14
- Empodium (except for legs I and II of male) with the empodial spur very tiny or absent 16

14. Knob of aedeagus with anterior projection broadly rounded ..... *Tetranychus tumidus*
- Knob of aedeagus with anterior projection angulate 15

15. Aedeagus with knob 4 times as wide as its stem, the caudal angulation much longer than the anterior angulation ..... *Tetranychus mexicanus*
Aedeagus with knob about twice as wide as its stem, with small acute angulations anteriorly and posteriorly ..... *Tetranychus sayedi*

16. Stem of aedeagus apparently truncated, its posterior edge acutely angulated and rounded anteriorly ..... *Tetranychus truncatus*
Stem of aedeagus ending in a distinct knob 17

17. Knob of aedeagus globular, berry shaped ..... *Tetranychus neocaledonicus*
- Knob of aedeagus not globular 18

18. Axis of knob of aedeagus forming an angle with the axis of shaft, the posterior angulation acute and longer than the rounded anterior angulation ..... *Tetranychus amicus*
- Axis of knob of aedeagus parallell with axis of shaft 19

19. Knob of aedeagus with posterior angulation longer than anterior angulation, acutely angled posteriorly and rounded anteriorly 20
- Posterior angulation of knob of aedeagus no longer than anterior angulation 21

20. Male palpus with terminal sensillum slender, 4 times as long as broad ..... *Tetranychus lombardini*
- Male palpus with terminal sensillum about twice as long as broad ..... *Tetranychus kanzawai*

21. Adult summer females green or yellowish in color; dorsal integumentary striae with lobes mostly large, rounded, some being rather oblong and others narrower and relatively pointed ..... *Tetranychus urticae*
Adult summer females brownish red in color; dorsal striae of female with lobes mostly triangular; an occasional rounded lobe may occur between the typical triangular lobes ..... *Tetranychus cinnabarinus*

Allonychus reisi Paschoal, 1970

Allonychus reisei Paschoal, 1970, Ph.D. Thesis, Piracicaba: 84.

This species, described from São Paulo (Brazil) on azaleas and *Ficus elastica*, occurs according to Urueta (27) on cocoa, *Matisia* and *Manihot utilissima* in Colombia.

No relation to host plants is given.

Eutetranychus enodes Baker and Pritchard, 1960

Eutetranychus enodes Baker and Pritchard, 1960, Hilgardia 29(11):469.

This species was related from Zaire (ex-Congo) on *Manihot esculenta*.

Hosts of *E. enodes* also include figs, peaches, *Raffia* and *Vigna*.

Mites of the genus *Eutetranychus* are generally upper leaf surface feeders.

Eutetranychus orientalis (Klein, 1936)

Anychus orientalis Klein, 1936, Bull. Agric. Res. Sta. Rehovot 21:3.
Anychus latus (Canestrini and Fanzago) Sayed, 1942, Bol. Soc. Fouad 1er Entomol. 26:125.
Anychus ricini Rahman and Sapra, 1940, Proc. Ind. Acad. Sci. II (Ser. B):194.
Eutetranychus monodi André, 1954, Bol. Inst. Franc. Afr. Noire (sér. A) 16:859.
Eutetranychus orientalis Baker and Pritchard, 1960, Hilgardia 29(11):464.

This species is primarily a pest of citruses, having been found in Israel, Turkey, Jordan, Iran, Egypt, Cyprus, Sudan, Afghanistan, India, South Africa, Formosa, East Transvaal, Thailand, Pakistan, Philippines and Taiwan. Baker (1) lists *E. orientalis* on *Manihot* from Thailand and the Philippines. Hosts other than cassava include papaya, bananas, peaches, squash.

Lal and Pillai (15) report this species as a brownish green dorsum feeder on cassava from India, observing that even cassava varieties fairly resistant to *Tetranychus telarius (T. cinnabarinus)* were heavily infested.

Eutetranychus banksi (McGregor, 1914)

Tetranychus banksi McGregor, 1914, Ann. Entomol. Soc. Amer. 7(4):358
Eutetranychus banksi McGregor, 1919, Proc. U.S. Natl. Mus. 56(2303):644.
Eutetranychus rusti McGregor, 1950, Amer. Midl. Nat. 44:669.
Anychus verganii Blanchard, 1940, Rev. Fac. Agron. La Plata 3(2):24.

This species, commonly known as the Texas citrus mite, occurs in North, Central and South America. It deposits its eggs along the midrib of leaves; the eggs are flat and disklike. Adult females and nymphs vary in color from tan to brownish green; the legs are pale. Females are robust, broad and flattened.

McGregor (18) reported this mite species from Ecuador as causing a "browning of Yucca leaves," describing it as *Eutetranychus rusti*.*

Hosts of *E. banksi*, in addition to yucca, include almonds, castor beans, citruses, coffee, croton, *Eritrina Esenbeckia*, figs, *Firmiana*, *Hevea*, *Holocalyx*, *Morus nigra*, papaya.

Mononychellus caribbeanae (McGregor, 1950)

Tetranychus caribbeanae McGregor, 1950, Amer. Midl. Nat. 44(2):283.
Eotetranychus caribbeanae Pritchard and Baker, 1955:147.
Mononychus caribbeanae Wainstein, 1960:199.
Mononychellus caribbeanae Tuttle, Baker and Abbatiello, 1976. Intl. J. Acarol. 2(2):51.

This species, described on cassava from Puerto Rico, also occurs in Florida (USA), Mexico and Costa Rica on dogwood, *Dahlbergia*, *Platymiscium* and cassava (9). It has also been recorded on cassava from Peru, Barbados and Christchurch, West Indies.

McGregor (18) lists it on cotton and cassava in Haiti, Puerto Rico, St. Kitts Island, Leeward Group and Ecuador. It has also been found on cassava from Nicaragua, Panama and the Bahamas by Yaseen and Bennett (29) and from Andros Island by Bennett (4).

No relation to the host plant is given.

Mononychellus tanajoa (Bondar, 1938)

Tetranychus tanajoa Bondar, 1938, Rev. Entomol. 9(3,4):441.
Mononychus tanajoa Flechtmann and Baker, 1970, Ann. Entomol. Soc. Amer. 63(1):160.

* We do not know whether he referred to yucca meaning cassava or *Yucca* sp. (Liliaceae, Agavaceae).

Mononychellus tanajoa Fletchtmann and Baker, 1975, Rev. Brasil. Entomol. 19(3):117.

M. tanajoa was described as a serious cassava pest in Bahia (Brazil); it has also been collected on cassava in Colombia, Trinidad and Uganda (11, 17), and on *Manihot* spp. in the Bahamas, Panama and Guyana.

This mite attacks the lower surface of newer cassava leaves, which then develop many small yellow spots and show abnormal growth. The stems turn brownish and the epidermis ruptures; they dry progressively from the tip to their base. Heavy infestations, which occur mainly during long dry periods, may result in the death of the whole plant. Nestel (21) states that during dry period, it is difficult to differentiate between the symptoms of severe infestation by this mite and those of African cassava mosaic.

Varieties of cassava resistant to attack by this mite have been identified (26). Costa (7) wrote on chemical control of this mite, pointing out that there are 42 cassava varieties resistant to *M. tanajoa* in Bahia (Brazil).

Mononychellus mcgregori (Flechtmann and Baker, 1970)

Eotetranychus planki (McGregor) (in part) Pritchard and Baker, 1955:150.
Mononychus mcgregori Flechtmann and Baker, 1970, Ann. Entomol. Soc. Amer. 63(1):160.
Mononychellus mcgregori Flechtmann and Baker, 1975, Rev. Brasil. Entomol. 19(3):117.

This species, described from Brazil on *Phyllanthus*, also occurs in Argentina on *Cassia*.

Urueta (27) lists *M. mcgregori* from Colombia on *Desmodium sida* and *Manihot utilissima*, stating that it is of no economic importance.

Mononychellus bondari (Paschoal, 1970)

Mononychus bondari Paschoal, 1970, Ph.D. Thesis, Piracicaba, 60, 80.
Mononychellus bondari Flechtmann and Baker, 1975, Rev. Brasil. Entomol. 19(3):117.

Paschoal (22) described this species on *Manihot utilissima* from Minas Gerais (Brazil); Flechtmann and Baker (12) list it on the same host plant in other areas of Brazil and Urueta (27) on cassava from Colombia.

No relation to host is given.

Oligonychus coffeae (Nietner, 1861)

Acarus coffeae Nietner, 1861, Obs. Ennem. Coffee Tree Ceylon.
Oligonychus merwei Tucker, 1926, Ent. Mem. Dept. Agric. Pretoria 5:6.
Oligonychus coffeae Pritchard and Baker, 1955:315.

This species was described from Sri Lanka (Ceylon); it has also been reported on *Melaleuca* and camellia from Florida (USA) and on tea from Sri Lanka; on *Parthenocyssus*; in South Africa and on *Quisqualis* from Australia.

Meyer (19) presents a long list of hosts from Africa, and Rodrigues (25) lists it on *Manihot esculenta* from Moçambique.

No relation to host is given.

Oligonychus peruvianus (McGregor, 1917)

Tetranychus peruvianus McGregor, 1917, Proc. U.S. Natl. Mus. 51(2167):581, 589.
Paratetranychus peruvianus McGregor, 1954, Rev. Ecuat. Entomol. Par. 2(3,4):369.
Paratetranychus trinitatis Hirst, 1922, Proc. Zool. Soc. London, 1921:801.
Oligonychus peruvianus Pritchard and Baker, 1955:342.

Described from Peru on willows, this species has also been recorded from Trinidad and California on grapes and cotton. McGregor (1954/55) lists it from Ecuador on yucca.* Yaseen and Bennett (29) report it on cassava from Colombia.

No relation to host is given.

Oligonychus gossypii (Zacher, 1920)

Paratetranychus gossypii Zacher, 1920, Zts. angew. Entomol. 7:183.
Oligonychus gossypii Pritchard and Baker, 1955:359.

Originally described on cotton from Togo, West Africa, this species has been recorded on cassava and beans from Sierra Leone; on papaya from Portuguese West Africa (24) and from São Tomé (Angola); on cotton, Gamara (Nigeria); on *Bridelia*, *Berlinia*, cassava *Combretum*, shade trees, roses, citrus, peaches and *Acacia* from Zaire (19) and on cocoa from Ecuador (18). Carmona (15) reported *O. gossypii* on *Manihot utilissima* from Luanda (Angola).

No relation to host is given.

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* We do not know whether he referred to yucca meaning cassava or *Yucca* sp. (Liliaceae, Agavaceae).

Oligonychus biharensis (Hirst, 1925)*

Paratetranychus biharensis Hirst, 1925, Proc. Zool. Soc. London: 69.
Paratetranychus hawaiiensis McGregor, 1950, Amer. Midl. Nat. 44:340.
Oligonychus biharensis Pritchard & Baker, 1955:364.

The females of this species have 9 tactile setae on tarsus I; the male aedeagus is bent dorsad, keying out to *O. gossypii*. The females of *biharensis* are distinct in having the peritremes retrorse distally and the males by the characteristic shape of the aedeagus (Fig. 3o).

This species is injurious to mango in Mauritius; its hosts also include roses, loquat, litchi, cotoneaster and camphor. It is known from India, Hawaii, Thailand, Malaya, Philippines, Antigua, Brazil and Mexico (14).

Lal and Pillai (15) report this species from India as a pale dusky dorsum feeder, forming large populations on several varieties of cassava.

Tetranychus yusti McGregor, 1955

Tetranychus yusti McGregor, 1955, Rev. Equat. Ent. Par. 2(3,4):368, (1954/55).

This species, originally described on cotton from Ecuador, has been recorded from southern USA, Mexico and Central America on a wide variety of plants mainly of no economic importance, belonging to the Compositae, Fabaceae (Leguminosae) and Poaceae (Gramineae). It is injurious to soybeans in Delaware (USA), where it was reported under the name of *Tetranychus lobosus* Boudreaux. Economic host plants include cotton, roses, okra, sweet potatoes, sunflowers, white clover, marigold, peas, beans, cowpeas and peanuts (14). Baker (1) reports this mite on *Manihot esculenta* from Thailand.

The females of *T. yusti* are carmine in color and may be confused in the field with *T. neocaledonicus*, *T. tumidus*, *T. truncatus* and *T. cinnabarinus*. They can best be distinguished by the genitalia of the male.

Tetranychus tumidus Banks, 1900

Tetranychus tumidus Banks, 1900, U.S. Dept. Agric. Techn. Ser. 8:73.
Tetranychus antillarum Banks, 1917, Ent. News 28:194.

This mite occurs in southeastern USA, California, Brazil, Hawaii, Puerto Rico, Panama, Guam, Bermuda, Central America, Mexico and Trinidad, being a serious pest of cotton, celery, eggplant, beets, okra, peas, dahlia, palms, *Marantha*, mint, avocados and many ornamental and tropical plants (14). This species is reported on cassava from St. Augustine, Trinidad and Yaseen and Bennett (29) report it on cassava from Mexico.

Injury of this mite to many plants appears as reddening of the upper surface of the leaf; the reddened area may be either a small blotch or many such blotches that often encompass the entire leaf surface, eventually resulting in defoliation of affected plants (14).

No reference to damage on cassava was given.

Tetranychus mexicanus (McGregor, 1950)

Septanychus mexicanus McGregor, 1950, Amer. Midl. Nat. 44(2):323.
Tetranychus mexicanus Pritchard and Baker, 1955:411.

This species occurs on citrus, Johnson grass, *Magnolia*, cocoa and many fruit and ornamental plants. Its distribution includes Mexico, Texas, Brazil and Argentina. Urueta (27) lists *T. mexicanus* from Colombia on citrus, coconuts, *Anona*, *Passiflora*, *Elaeis* and *Manihot utilissima*.

No relation is given to cassava as a host plant

Tetranychus sayedi Baker and Pritchard, 1960

Tetranychus sayedi Baker and Pritchard, 1960, Hilgardia 29(11):543.

Described originally on *Manihot* from Stanleyville (ex-Belgian Congo), *T. sayedi* was also reported on *Manihot* from Kisangani, Zaire by Meyer (19).

No relation to host is given.

Tetranychus truncatus Ehara, 1956

Tetranychus truncatus Ehara, 1956, J. Fac. Sci. Hokkaido Univ., Ser. VI, Zool., 12:507.
Tetranychus kanzawai (nec Kishida) Yokoyama (in part), 1929, New Text b. Sericult. Ins. Pests:525.

This species, described from Japan on mulberry, was recorded by Baker (1) from Thailand, Taiwan and Philippines on many plants including *Manihot esculenta*.

The females are carmine in color. No relation to host plants was given.

* Not included in key because information arrived after classification was finished.

Tetranychus neocaledonicus André, 1933

Tetranychus neocaledonicus André, 1933, Bull. Mus. Natl. Hist. Nat. (Sér. 2) 5:302.

This species was originally described from New Caledonia on cotton. It has been recorded under the specific name of *cucurbitae* from India, Fiji, Hawaii, Venezuela, southern USA, Puerto Rico, the Bahamas and Mauritius. It is also known from Kenya, Zaire, Moçambique, Egypt, Zambia, Malawi, Rhodesia, Swaziland and Angola (19). Populations have been reported on more than 100 plants. We found this species in northeastern Brazil (Ceará) on cassava and other plants.

Chazeau and Gutierrez (6) list *T. neocaledonicus* on *Manihot utilissima* from Madagascar (Malagasy Republic) and present a study on a prey/predator complex formed by this mite and Phytoseiidae. They also state that *T. neocaledonicus* is susceptible to heavy showers during the rainy season and that cassava can easily bear the spider mite population level resulting from the combination of these factors.

The females are bright red in color. The mites derive their food from the plant leaves, producing white spots that gradually coalesce. Leaves lose their green color, gradually wilt, dry and drop. The decreased vitality and leaf drop adversely affect growth, flowering and fruiting. Damaged portions of the leaves of some plants turn red. The mites web profusely and may form a thick sheath of webbing that covers the entire plant (14).

Tetranychus amicus Meyer and Rodrigues, 1966

Tetranychus amicus Meyer and Rodrigues, 1966, Garcia de Orta 13(3):10.

This species was originally described from Mocambique on cotton, being also reported on bananas and *Veronia* in Transvaal. Rodrigues (25) reports *T. amicus* on peanuts and *Manihot esculenta* from Moçambique, and Meyer (19) from several plants in South Africa.

The females are dark red in color.

Tetranychus lombardini Baker and Pritchard, 1960

Tetranychus lombardini Baker and Pritchard, 1960, Hilgardia 29(11):551.

This species is known only from Africa; it was described from Moçambique on cotton and is known on a great number of plants from South Africa, Transvaal and Swaziland, including peanuts, papaya and tomatoes (19). It has been reported on *Manihot esculenta* from Moçambique.

The females are dark red with a dark spot on either side of the body.

Tetranychus kanzawai Kishida, 1927

Tetranychus kanzawai Kishida, 1927, Zool. Mag. 39:105; Ehara, 1956, J. Fac. Sci. Hokkaido Univ., Ser. VI, Zool., 12:504.
Tetranychus hydrangeae Pritchard and Baker, 1955:425; Meyer, 1974:227.

This species was originally described from Japan on mulberries. Ehara (8) lists it from Japan on tea, hops, grapes, peas, peaches apples and pseudacacia. Wainstein (28) (*apud*: Meyer, 19) treated *Tetranychus hydrangeae* as a synonym of *T. kanzawai*, which was confirmed by Meyer (19). It is worldwide in distribution on hydrangeas.

Baker (1) treated them as different species, listing them on *Manihot utilissima*, *Manihot maritima* and several other plants from Taiwan, Thailand and Philippines.

The females are carmine red in color.

Tetranychus urticae Koch, 1836

Tetranychus urticae Koch, 1836, Deutsch. Crust., Myriap. Arachn., Fasc. 1:10.

The common green two-spotted spider mite has a worldwide distribution and has been recorded on more than 150 hosts, including most of the important agricultural crops. It is also one of the most destructive to its host. Urueta (27) lists it on cassava from Colombia; it is now being reported on cassava from Brazil and Peru.

The mites are greenish in color and attack mainly the lower surface of the median leaves; but in cases of heavy attack, they inhabit all plant surfaces, spinning a considerable amount of webbing. In many situations populations have rapidly developed resistance to available acaricides.

Tetranychus cinnabarinus (Boisduval, 1867)

Tetranychus cinnabarinus Boisduval, 1867, Essai Entomol. Hortic., Paris.:88.
Tetranychus telarius (Linnaeus) Pritchard and Baker, 1955:432 (in part).

Comments on problems of nomenclature that

have arisen concerning the aforementioned names which include about 59 synonyms, as well as various solutions that have been suggested, can be found in Meyer (19). *T. cinnabarinus* will have to serve for the carmine mite in all its forms, races and strains.

This species is distributed worldwide and is a pest of many cultivated plants. It has been reported on cassava from Luanda (Angola) (19) and is now being reported on cassava from Mont Serrat (West Indies) and Bahia (Brazil). This species has also been found on cassava in India, reported as *T. telarius*, red mites, by Pillai in 1968 (*apud*: Lal and Pillai, 15).

Family Tenuipalpidae

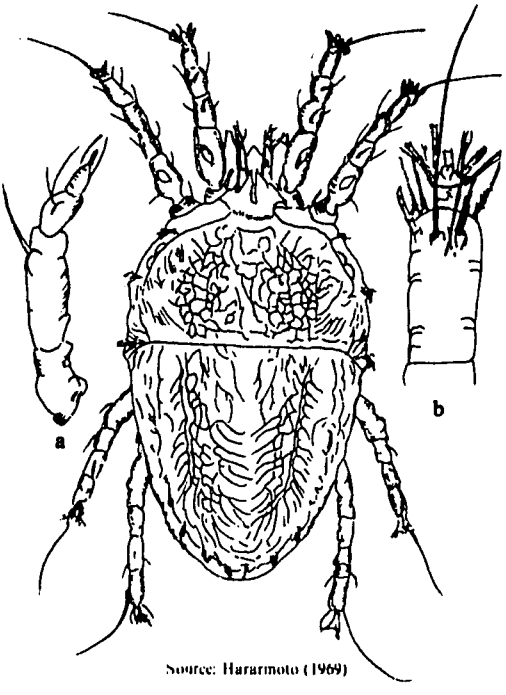
One species of false spider mite has been reported on cassava (Fig. 4).

Brevipalpus phoenicis (Geijskes, 1939)

Tenuipalpus phoenicis Geijskes, 1939, Meded. Landb. Hoogesch. Wageningen 42(4):230.

Brevipalpus phoenicis Pritchard & Baker, 1958, Univ. Calif. Publ. Entomol. 14(3):233.

This species is distributed throughout the world and feeds on a great variety of plants. It has been collected once from cassava in Brazil and Paraguay (11).



Source: Hararmoto (1969)

Figure 4. *Brevipalpus phoenicis* - **Dorsal aspect of female: (a) palpus, (b) tarsus II.**

Acknowledgments

We are grateful to Aart van Schoonhoven, Anthony Bellotti and Jaime Piedrahita, entomologists from the Centro Internacional de Agricultura Tropical, Colombia; to Fred D. Bennett, Commonwealth Institute for Biological Control, who did collecting of mites in their areas; and to Z.M. Nyiira and Jacob Ogwang, who provided material from Uganda.

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* We were unable to locate a copy of this paper.

Mononychellus tanajoa (Bondar): biology, ecology and economic importance*

Z.M. Nyiira**

Abstract

Results are given of studies on the biology and ecology of the green cassava mite *Mononychellus tanajoa*, carried out under laboratory conditions in Trinidad and Uganda. Population studies in Uganda showed that mite densities are mainly related to the pattern of rainfall, abundance of natural enemies (*Oligota* sp. and *Stethorus* sp.) and the availability of nutrients in the leaves. Although it is apparent that the population of *M. tanajoa* is self-limiting, little is known about the mechanism involved.

Introduction

The green cassava mite *Mononychellus tanajoa* (Bondar) was, until recently, limited to the Neotropics, where it is considered a pest of little economic importance on cassava (13). It has now been reported from Uganda, where it is a serious pest during the dry season. During severe infestations, there is heavy defoliation of the cassava plant (11), and yield losses as high as 46 percent have been reported (10). This mite has also been reported damaging cassava plantations in the adjacent territories of Rwanda, Zaire, Congo (Brazzaville), Kenya, Tanzania and Zanzibar (Table 1).

Preliminary studies have been carried out on the biology and ecology of *M. tanajoa* to provide the necessary data for planning its control.

Biology

Originally described by Bondar in 1938 (4) as *Tetranychus tanajoa*, it was renamed *Mononychellus tanajoa* by Flechtmann and Baker (6) from specimens obtained on *Manihot* sp. from northern Brazil. Recent studies show that while *M. tanajoa* restricts its feeding to *Manihot* spp., the range of species on which it feeds and breeds covers *M. esculenta*, *M. glaziovii*, *M. dichotoma*, *M. piauhyensis*, *M. heptaphylla* and *M. carthagenensis*. Trials conducted in Uganda to see whether the mite fed on other Euphorbiaceae were unsuccessful.

The life history of the green cassava mite consists of the egg and four active stages. Under laboratory

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Table 1. World distribution of *M. tanajoa*.

Distribution	Control measures recommended	Reference
Brazil	Zolone, Phodiatox and Diazinon (5); natural enemies observed but not evaluated	(4, 6, 8, 12)
Burundi	No information available	Dept. of Agriculture, Burundi
Colombia	Natural control (not evaluated)	(3)
Congo (Brazzaville)	No information available	Personal communication, Univ. of Brazzaville
Guyana	Natural enemies (not evaluated)	(3)
Kenya	Biological control	Personal observation, CIBC report
Paraguay	Not specified	(1)
Rwanda	Breeding for resistance	Institute of Agronomy, Burundi
Surinam	Not specified	(13)
Sudan	No information available	Personal observation
Tanzania	Breeding for resistance	Personal communication
Trinidad	Natural control (not evaluated)	(3)
Uganda	Natural control (partial evaluation); chemicals tried but abandoned; evaluation of plant resistance	(9)
Venezuela (?)	—	(13)
West Africa (?)	—	(2)
Zaire	—	Personal observation
Zanzibar	Breeding for resistance	Dept. of Agriculture, Zanzibar

conditions in Trinidad, Yaseen and Bennett (13) reported that at 26.8 ± 2.2°C and 82% RH morning and 55% RH afternoon, the previposition period lasted 1-2 days, and duration of the egg, larval, prothonymphal and deutonymphal stages were 3-4, 1-2, 1-2 and 2-3 days, respectively. Total egg to adult period was 11-13 days. Males matured faster than females. Females laid from 21-65 eggs during 8-14 days of their life (up to 18 days).

Similar results were found in Uganda. At a mean room temperature of 22.9 ± 3.6°C, the preoviposition period lasted 1-3 days. Larval, protonymphal and deutonymphal stages were 2-3, 3 and 3 days, respectively. The total egg to adult period was 8-13 days.

Oviposition took place both during the day and at night. Few eggs were laid outside the temperature range of 14-35°C; more eggs per female were laid at 32° than at lower temperatures. Temperature also affects incubation, fecundity rates and duration of the nymphal period. Between 22.5 and 28°C, incubation took 5 days compared to 4 days at 32°; at 35° the eggs failed to hatch.

Mites were capable of laying eggs in relative humidities ranging from 10-100%; maximum oviposition was, however, recorded between 50-70% RH. The egg-laying life span ranged from 12-23 days; from 35-117 eggs were laid by 25 individual mites. Egg laying decreased during the last days of the life span of females (as long as 60 days). Mean hatchability of eggs from mated females was 54.4% (range 25-100%).

Population dynamics

Population studies carried out in Uganda (10) and elsewhere (13) show that mite densities are mainly related to the pattern of rainfall, the abundance of natural enemies and the availability of suitable nutrients in the leaves.

Regular observations from 1972 to date indicate that there is an apparent decrease in the population of adult females as the leaves become more bronzed although the absolute number of females does not decrease until after the population peaks. There is usually a general increase in the ratio of adult males, possibly because females emigrate from dense population sites to less dense ones.

Adult *M. tanajoa* females readily migrate from unfavorable foliage by producing threads from which to lower themselves and drift with air currents. This migration increases as bronzing on leaves become severer.

Observation trials carried out to compare the rates of reproduction of *M. tanajoa* on damaged and undamaged leaves where 5 adult females of *M. tanajoa* were placed on each leaf and removed after 5 days showed that the rate of oviposition reached after 15 days was lower on bronzed leaves. Development and feeding appeared to be affected on severely infested leaves from which nutrients had been depleted.

This phenomenon of intraspecific competition is common among leaf-feeding tetranychids as demonstrated by McMurtry (7). He observed that populations of *Oligonychus punicae* (Hirst) were self-limiting and that as its populations on leaves of *Persea indica* became higher, active emigration commenced.

At high densities the surface of the cassava leaves becomes bronzed from excessive feeding, apparently rendering it unfavorable for continued mite reproduction. Furthermore, these bronzed leaves cannot recover because they cannot photosynthesize sugars so natural senescence usually follows. Thus periodic resurgence of the mite population occurs on younger leaves, which are suitable for feeding and reproduction.

Although it is apparent that the *M. tanajoa* population is self-limiting at high densities, little is known about the mechanism involved. It is not known whether age distribution and sex ratio of the population change as the density becomes high; whether the decrease in suitability of heavily infested leaves is due entirely to physiological conditions and/or the physical effect from accumulated waste products and cast skins; and whether there is a direct effect of crowding in addition to leaf deterioration which contributes to the decline of mite populations.

Seasonal population trends

Data have been collected since 1972 to determine annual and long-term mite population fluctuations. Annual fluctuations are greatly

influenced by the presence or absence of suitable leaves for food, as well as climatic factors such as rainy or dry weather, relative humidity and wind. This last factor is mainly responsible for mite dispersal.

The long-term population trend, however, appears to be greatly influenced by natural control factors. Highest peaks of *M. tanajoa* populations in most parts of Uganda, especially the Lake Victoria regions, were recorded during 1973 and mid- and late 1977. These peaks coincide with low numbers of active predators of the mite.

This observation confirms the theory advanced for the effective performance curve of biological control systems. It is reasonable to suggest that the green cassava mite population was high in 1973 before its predators were firmly established in the natural control cycle. The population was arrested mainly by *Oligota* sp. and *Stethorus* sp. predators. However, the predator populations were affected by the consequent reduction in the *M. tanajoa* population, which caused them to migrate to plants infested with other spider mite species or hosts. This allowed a natural increase to another peak in the number of host mite populations in 1977.

Discussion

The biological study of *M. tanajoa* has revealed that the mite has a short life history of about 13 days, with a preoviposition period of 1-3 days. Maximum observed oviposition occurs 9-14 days after the final molt. Mean generation time is 17 days, during which time the mite population has a potential of multiplying istelf about 70 times, at a finite rate of 1.28 mites per female per day. Rapid larval development was observed to occur between 25 and 32°C and at relative humidities between 50-70 percent.

In the laboratory the green cassava mite breeds continuously. In the field breeding is reduced to a minimum during the humid rainy season, either through mechanical destruction of various stages of the mite or through the effect of moisture on the egg tissues and on the physiology of the eggs and active stages of the mite.

There is an apparent four-year mite population cycle in Uganda, which appears to be influenced by natural control systems, particularly the predators. In addition to biological control measures (13), it is recommended that an integrated approach using early-maturing, tolerant cassava varieties be used (9). Work should also be done on developing resistant varieties. The efficiency of chemical control was studied in Brazil and Uganda (5,9); but under small farm conditions, it is not practical.

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Field evaluations of cassava cultivars for resistance to tetranychid mites

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Abstract

The results are given of two field trials evaluating resistance of cassava cultivars to tetranychid mites. The cultivars were selected at CIAT (Colombia) and planted at the experimental farm of CENIAP (Venezuela). Using an injury scale of 0 to 5 for terminal buds and leaves, av damage and standard deviations were determined. A list is given of 19 cultivars with different degrees of resistance.

Introduction

At present cassava is widely grown and there is great interest in developing commercial operations on a large scale. From the standpoint of plant protection, damage caused by tetranychid mites is probably one of the most important limiting factors. The crop completes its cycle in about twelve months, during which time it needs to withstand a long dry period in the majority of the areas where it is cultivated. These environmental conditions favor the development of high populations of different Tetranychidae, which can cause total defoliation of plants, affecting root yields (2-3).

One of the more efficient and economic approaches to solve this problem is the use of resistant varieties. The Centro International de Agricultura Tropical (CIAT) began research along these lines in Colombia (1). Since selections were made under laboratory or greenhouse conditions, it was decided to conduct evaluations in the experimental fields at CENIAP in Maracay, state of Aragua, Venezuela. This paper reports the results obtained during the 1975-76 and 1976-77 trials.

Methods

Planting material was selected by A. Bellotti from the CIAT collections and mailed to Venezuela, where C. Arias from CENIAP was in charge of planting and cultural practices. E. Doreste from the School of Agronomy at the Universidad Central de Venezuela was responsible for the sampling and all observations on mite populations.

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Experiment 1

A total of 102 cultivars were planted in two plots, using a random block design at a distance of 1.20 m between rows and 1 m between plants. Each plot was formed by 4 plants of the same cultivar. Planting was done on June 18, 1975 and harvesting was done 12 months later.

Experiment 2

Planting was done on August 16, 1976 and harvesting was done on June 9, 1977. The same experimental design was used but only 51 cultivars were evaluated.

Sampling method

The sampling method was based on observations of two plants selected at random from the four in each plot; level of damage to terminal buds and mature leaves was determined separately, using the scale below:

For the analysis and statistical interpretation of data, different degrees of susceptibility were established, using the average of all damage levels determined on terminal buds and leaves, which gives the damage level by cultivar and the standard deviation. Those cultivars with values below the mean ($\bar{x}$) minus two standard deviations were considered as highly resistant and those below the mean minus one SD, as slightly resistant. Those over the mean plus two SD were considered as highly susceptible; all those with values equal to the mean with one SD more or less were considered as normal.

Comments

In the first trial, a few mites were observed at the end of October, when the plants had reached about 1 m in height. By December 10, a level of damage 1 was observed on the terminal buds of Col 485, 544, 873 and 1867 and on the leaves of Ecu 44. Level 2 damage was registered on Mex 22 and Col 452-B. The mite infestation became general in January. On January 29 and February 12 plants were well irrigated. On the 4th of February infestation was high, but by the end of the month the plants had recovered and there was new foliage as a result of the irrigation. On March 18 it rained heavily, and by the end of the month infestation was general. Final observations were made on June 3 when a great recovery of the plants was noted, many having new terminal buds and healthy leaves. Mite populations were not abundant, and many dead and some apparently diseased mites were found. The mites may have been attacked by a fungus; abundant colonies of a Phtyoseiidae were observed on the terminal buds.

Level of damage	Terminal buds	Leaves
0	No damage, no spots	No mites or damage
1	Mites present, a few spots	A few mites on some leaves, some whitish spots
2	Many mites, terminal leaves with spots	Whitish spots, few mites on many leaves
3	Buds affected, nearby leaves with many spots	Fairly extensive damage, many mites on some leaves
4	Deformed buds, nearby leaves with many mites	Extensive damage, many mites on several leaves
5	Dead buds, defoliation, many mites	Severe damage, defoliation, many mites on all leaves

During the second experiment it was necessary to irrigate lightly four times during the dry season (Jan.-Mar.). On January 21 there were no plants available for evaluation in two blocks containing cultivars Col 804, 525*, 292*, 320, 612, 230 and 15 as a result of poor germination and growth. The other plots had plants with healthy foliage; only cultivars Col 425, 526, 560, 586, 1058 and 131 had damage levels of 1 and 2. By February 16 infestation was generalized, and some terminal buds had been attacked heavily, showing deformation. Nevertheless, damage was not too heavy on the whole, which means the mite populations was young and in a developing stage. One month later damage was general and quite heavy, and some old stems and other debris were infested with termites. There was abundant rainfall at this time and from the middle of May onward, it rained regularly. No more counts were made after May 21 because of plant recovery; nevertheless, some cultivars (Col 526, 395, 81, 323, 551, 247, 198, 320 and 266, Ven 15) showed no signs of recovering.

Results

Experiment 1

Based on the results of seven field counts, the cultivars were grouped into three categories: a large group with normal to high susceptibility and two small groups, one showing resistance and the other great susceptibility. Calculated statistical values were as follows:

$\bar{x} = 1.95$ $\bar{S} = 0.04$
$S = 0.41$ $C.V. = 21.03$

From these values we consider the standard error low and the coefficient of variation acceptable for this type of biological population, which means uniformity of population distribution under field conditions. The cultivars were grouped in the following categories on the basis of mean damage levels and SD:

High resistance (X-2S), values under 1.13: Ecu 133 and Mex 20.

Low resistance (X-S), values between 1.13 and 1.54: Mex 28, 29, 31 and 1005; Col 890, 1325, 282, 10, 480, 65, 85 and 1010-B.

Susceptible, values between 1.55 and 2.35: Col 710, 808, 1138, 654, 348, 1142, 395, 1657, 673-A, 949, 867, 1805, 961, 982, 485, 900, 1807, 420, 76, 22, 971, 1157, 929, 601, 873, 1073, 660, 647, 659, 1710, 658, 1025, 1605, 1802, 1651, 966, 494 and 73; CMC 39; Mex 27, 5, 59, 41, 56, 22, 53, 66 and 52; Pan 31 and 48; Extranjera; Ecu 160 and 155.

Highly susceptible (X + S) values between 2.36 and 2.76: Llanera; Col 248, 544, 1813, 399, 706, 463, 544, 452-B, 642, 667 and 110; Mex 44.

Extremely susceptible (X + 2S), values over 2.77: Col 5.

Cultivars not analyzed: Mex 24 and 23; Col 607, 1062, 717, 1766, 1540, 272, 820, 9 and 144; Ecu 137, 144, 83, 142, 125 and 177; CMC 84.

Experiment 2

A total of four field counts were made during the first four months of 1977; final observations were made in May for those cultivars that had not shown any recovery symptoms to that date (Ven 15; Col 256, 395, 81, 323, 1551, 247, 198, 320 and 266). Evaluations were made according to the scale described in Experiment 1. The general mean for the cultivars and the standard deviation were determined, giving the following values:

$\bar{X} = 2.28$ $\bar{S} = 0.05$
$S = 0.38$ $C.V. = 16.67$

Standard error and the coefficient of variation also showed conditions of uniformity in the field. Based on these analyses, the cultivars in this experiment were grouped as follows:

High resistance (X-2S), values under 1.53: none.

Low resistance (X-S), values between 1.52 and 1.90: Col 323, 520 and 414; Ven 157 and 45-C.

Susceptible, values between 1.91 and 2.66: Col 247, 551, 156, 379, 81, 191, 593, 725, 1333, 568, 336, 282, 1828-A, 1050, 256, 283, 395, 1833, 1055 and 1856; Ven 15, 133, 11, 35 and 10.

* Both plots

Highly susceptible (X + S), values between 2.66 and 3.04: Col 425, 131, 647, 1058, 198 and 34.

Extremely susceptible (X + 2S): None.

Cultivars not analyzed: Col 914, 1097, 15, 576-A, 560, 693, 804, 525, 266, 292, 751, 320, 612, 320 and 586.

Conclusions

Based on the results obtained in these two field trials, the following conclusions were reached:

1. Resistance to tetranychid mites in cassava apparently exists.
2. Highly promising sources of resistance are cultivars Ecu 133 and Mex 20. Promising ones are Mex 28, 29, 31 and 1005; Col 890, 1325, 282, 10, 480, 65, 85, 1010-B, 323, 520 and 414; Ven 157 and 45-C.
3. Additional field experiments should be conducted with these cultivars and other promising ones obtained from greenhouse screening, as well as some of the commercial varieties.

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Biological control of the green mite *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae) in Africa

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Abstract

The green mite *Mononychellus tanajoa* was first detected in 1973 on cassava cultivars in East Africa, where it causes damage of economic importance. The International Development Research Centre (IDRC) financed a biological control project for East Africa. Based on studies of predators carried out in Trinidad, as well as on surveys of naturally occurring predators in Africa (*Oligota* sp., *Typhlodromus* sp., *Stethorus* sp. and *Orius* sp.), *O. minuta* was considered the most adequate. *O. minuta* was mass released in Kenya during the dry season from Jan.-Mar. 1977. A recovery survey in western Kenya is planned for early 1978 to assess establishment and spread of *O. minuta*. Future plans include the establishment of nurseries for *O. minuta*, *Typhlodromalus* and other predators in West Africa; breeding rooms are being built at the Agriculture and Forestry Research Station at Muguga, Kenya.

Background to the project

Severe infestations of a green mite, identified as *Mononychellus tanajoa* Bondar, a neotropical species, were reported on cassava in Uganda in 1972 (7). It was first noticed near Kampala in November of that year and quickly spread until by the end of 1973, the whole of Uganda was infected. It was found in northern Tanzania, around Mwanza, in early 1974 and in western Kenya, around Kisumu, in June of the same year. Since then the mite has continued to spread, both by wind and by movement of infested planting material, and is known to be in Burundi and eastern Zaire (Bukavu), the whole of Western and Nyanza Provinces of Kenya and northern Tanzania as far south as Nzega (Fig. 1). It is probably in southern Sudan, central Zaire and possibly even in the Republic of Congo. It has been found recently in Zanzibar, where it must have been taken by man (K. Leuschner, personal communication).

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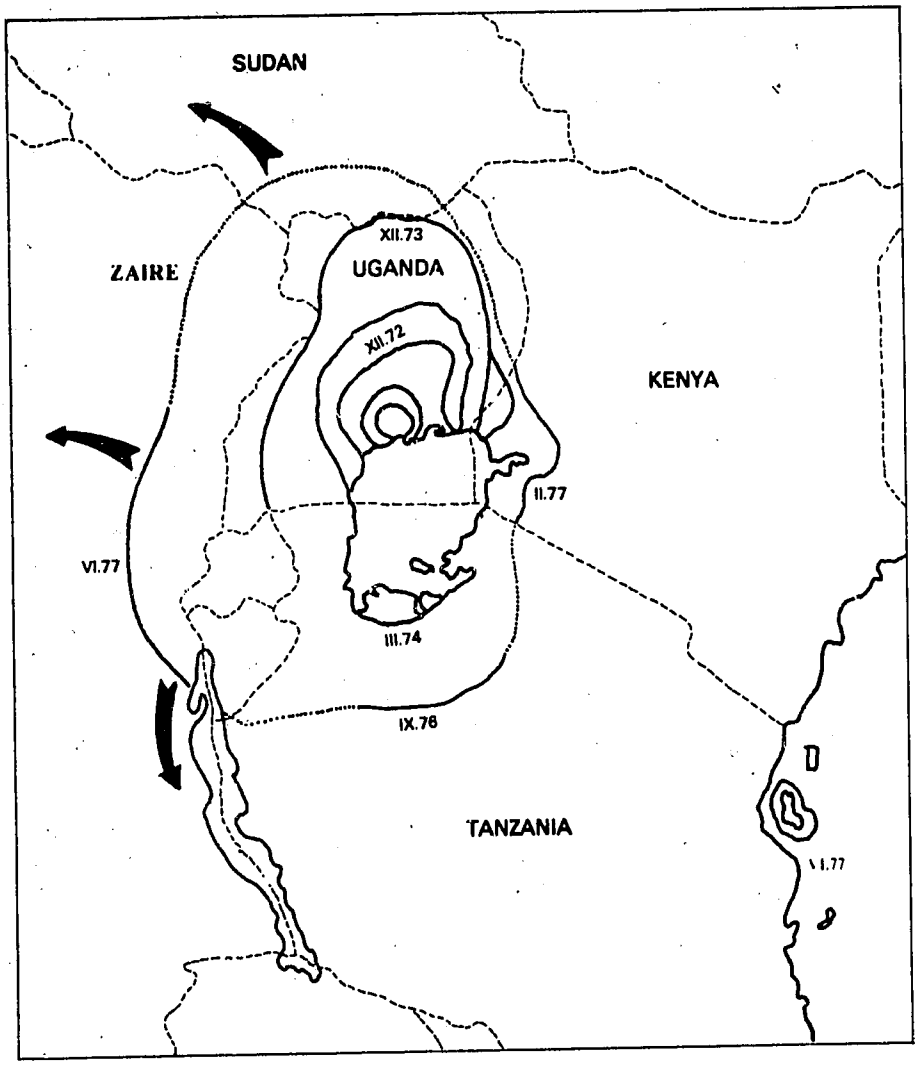

Figure 1. The spread of the green cassava mite since its introduction into Uganda in 1971.

In Uganda, northern Tanzania and Zanzibar the initial attack was devastating, with defoliation, stunting and root rot (9). Shukla (12) reported 50 to 80 percent loss of yield in Tanzania. A decline in infestation usually follows the initial devastation; but in western Kenya, for reasons as yet unknown, there was no heavy first attack.

Cassava is an important subsistence crop in many parts of Africa, but as yet its potential as a cash crop for animal food and starch is largely unexploited so that chemical control of the pests is not economically feasible. However, because it is a staple food in some areas and in others a famine crop that ensures survival when the local staple fails, governments are concerned about the losses, especially when the pest first appears in such destructive numbers, and they want it controlled. The International Development Research Centre (IDRC) has financed a project for East Africa to investigate the possibilities of biological control, as this method offers the only solution until more work on the development of resistant varieties has been carried out.

Biological control of mites

Phytophagous mites are almost universally subject to predation but are not known to be attacked by insect parasites. They were usually not considered pests before the widespread use of pesticides after the Second World War. Predators are more adversely affected by broad-spectrum pesticides than mites, and there is even evidence that the application of pesticides can stimulate the fecundity of mites (14). Development of resistance to acaricides among mites has only served to complicate matters.

Few attempts at classical biological control of mites have been made. The introduction of phytoseiid predators from California into Jamaica against the pine mite *Oligonychus milleri* (McG.) has been unsuccessful so far (1). Efforts have been made to improve existing natural control in fruit crops by reducing or eliminating the use of pesticides in order to encourage native predators [see Huffaker & Messenger (6) for examples], and in some instances mass releases of one of the predators at crucial times have been used where natural control has been inadequate; e.g., *Typhlodromus* spp. against *Tarsonemus pallidus* Banks on strawberries (5) and *Stethorus picipes* Csy. against *Oligonychus punicae* (Hirst.) on avocados (8).

The predatory mite *Phytoseiulus persimilis* Athias-Henriot has been widely used in glasshouses in Europe to control *Tetranychus urticae* Koch, and some success has been claimed using it outside during the summer (2, 13). Oatman and McMurtry (11) have also reported good control of *T. urticae* on field strawberries in southern California. Much work has been done in glasshouses to produce an integrated control program for all pests, as *P. persimilis* cannot work if broad spectrum sprays have to be used. Although the procedures developed have received only limited commercial acceptance, they can be very effective when properly supervised (4).

Thus the present project for the biological control of the green cassava mite in Africa is entering a relatively new area in attempting to use introduced predators against a mite attacking a field crop.

Investigations on *M. tanajoa*

In the Neotropics

Studies began at the West Indian Station of the CIBC in April 1974 on cassava mites and their natural enemies. Several species of *Mononychellus, Oligonychus* and *Tetranychus* are known to attack cassava in the Neotropics but are generally considered to be of little economic importance (16). *M. tanajoa* was described from Brazil in 1938 but has not been investigated in detail before. Its biology, dispersal, food preferences and natural enemies were studied recently in Trinidad by Yaseen (15), who found that its life cycle was 9 to 10 days in the dry season and 12 to 13 days in the wet season and that rainfall was an important factor in the reduction of the mite population. *Manihot* spp. are the only host plants, and young plants (2 to 8 months old) were the most heavily infested. There appear to be differences in the level of attack in different varieties of cultivated cassava (*Manihot esculenta* Crantz). The mites are dispersed by winds below 5 mph.

Yaseen and Bennett (16) reported phytoseiids, cecidomyiids, staphylinids, coccinellids and thrips preying on cassava mites in the Neotropics. Detailed investigations have been made in Trinidad on *Oligota minuta* Cam. (Staphylinidae), *Typhlodromalus limonicus* (Garman & McG.)* and *T. rapax* De Leon (Phytoseiidae),* a thrips, a cecidomyiid and *Stethorus* sp. Of these *O. minuta* and the phytoseiids are important predators, with their numbers directly related to those of the pest. Detailed studies on the biology of *O. minuta* showed that its activity was well synchronized with that of the mite, that the developmental period was short (15-18 days), enabling it to react quickly to a build-up in host numbers, that it is a voracious feeder, both larvae and adults consuming all stages of the mite; and that it can feed on other tetranychids when *M. tanajoa* is scarce (17).

In East Africa

Following the initial reports of the mite in Uganda, Nyiira (9) carried out studies which

* The classification of the Phytoseiidae is under revision. To avoid confusion the names used in recent reports are given. The genera involved are closely related and can be expected to fill very similar niches.

largely agree with the findings in Trinidad. Although there appeared to be no primary resistance to the mite in local varieties of cassava, some varieties recovered from mite attack, indicating that tolerance existed. In Tanzania, Shukla (12) found that differences in levels of attack on different varieties were related to hairiness of the leaves, so he has begun some selection work on this aspect.

In Uganda local predators soon became established on the heavy mite infestations but have so far not been reported elsewhere. They were *Oligota* sp., *Typhlodromus* sp.,* *Stethorus* sp., (Coccinellidae) and *Orius* sp. (Anthocoridae), but only *Oligota* sp. was common.

Releases in East Africa

The generic similarity between the predator complex found in Trinidad and that which moved onto the pest in Uganda caused some disappointment. Nevertheless, since Yaseen and Bennett (17) reported numbers of *O. minuta* approximately twenty times higher than Nyiira (10) had found for the Ugandan *Oligota* sp. and because of its density-dependant relationship and long association with *M. tanajoa*, it was felt that *O. minuta* should be superior to any facultative African predators. The same reasoning applied to the Neotropical phytoseiids. Thus, it was decided that *O. minuta* should be released in East Africa and a visit was timed to coincide with the dry season from January to March 1977, when mite populations were expected to be at their highest (3). Prerelease surveys and releases were planned for Kenya, Uganda and Tanzania so that the effect of the predator on the mite populations could be assessed. The program had to be modified because at the time of the visit it was only possible to travel within Kenya, and plans to send predators to Uganda did not work out.

The prerelease surveys in Kenya showed that the cassava-growing area of Nyanza and Western Provinces was almost completely infected (Fig. 2) but that other major cassava-growing areas east of Mt. Kenya and in Coast Province were clear. The populations in western Kenya were very low (less than 50 mites per leaf), but several sites were found with sufficient numbers to ensure that the predators would find enough food for initial survival. Four shipments of *O. minuta* containing ca. 3670 adults were received from Trinidad; and from three of these, ca. 1660 were released at nine sites. In addition ca. 6000 adults from the fourth shipment, which had been delayed in transit, were put on cassava plants infested with red spider mite in a glasshouse. A fifth shipment failed to arrive. In three shipments that arrived on time (within two days), heavy mortality occurred among adults not released on the day of arrival, so when this was realized every effort was made to get from Nairobi airport to the release site 200 miles away the same day.

Future plans

The green cassava mite will almost certainly continue to spread until it is present in all cassava-growing areas of Africa. How long this takes will depend on the wind and on movement by man; but judging from its recent sudden appearance in Zanzibar, it will be quite soon. The spread cannot be stopped, but its effects could be reduced if it were monitored and predators released at the front, as well as in already infested areas. The ability of the predators themselves to move into new areas is not known; therefore, releases need to be as widespread as possible. This is why the release program that has already been carried out is disappointing because it was restricted to one small area with low mite populations.

Future plans include setting up cultures of *O. minuta*, *Typhlodromalus* spp. and possibly other predators in East Africa, from where material can be taken to release sites. Breeding rooms for this purpose are nearing completion at the Agriculture and Forestry Research Station at Muguga, near Nairobi. A recovery survey in western Kenya is planned for early 1978 to see whether *O. minuta* has become established in the release sites and has spread and to see whether it has had any effect on mite populations although this may not be apparent yet.

* The classification of the Phytoseiidae is under revision. To avoid confusion, the names used in recent reports are given. The genera involved are closely related and can be expected to fill very similar niches.

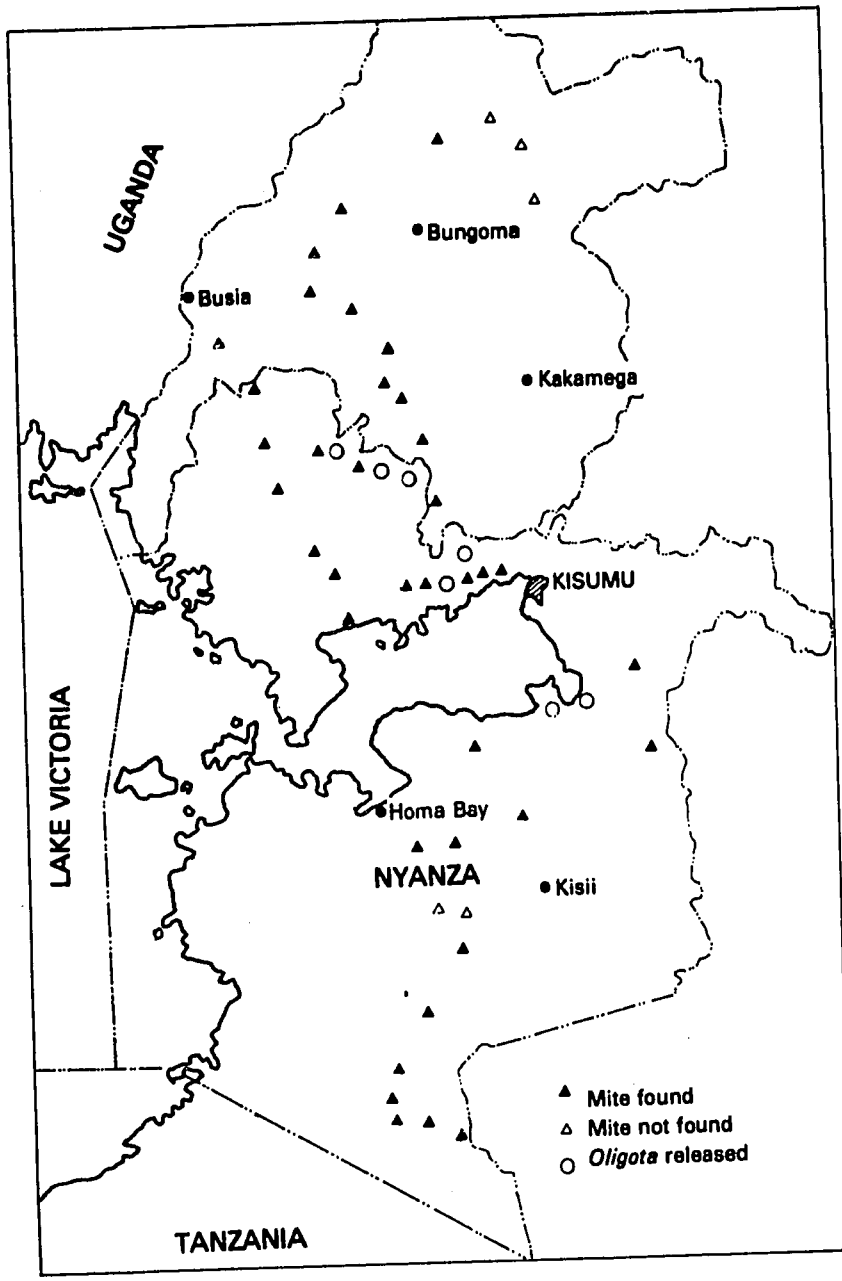

Figure 2. Sampling sites and release points of *Oligota minuta* in western Kenya.

The green cassava mite was initially an East African problem, but it is rapidly becoming Pan-African. It is hoped that government and international research organizations throughout Africa will cooperate in this project so that the spread of the pest can be monitored and predators released quickly.

Acknowledgments

Investigations on cassava mites by the Commonwealth Institute of Biological Control both in the Neotropics and Africa are financed by the International Development Research Centre, Ottawa, Canada.

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The biology and ecology of the tetranychid mite complex in cassava in perspective

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Abstract

A brief review is presented on the nomenclature of the cassava mite complex. The biology and ecology of the most important ones are discussed: *Tetranychus urticae, T. cinnabarinus, T. tumidus, Oligonychus peruvianus, O. gossyppi, Mononychellus tanajoa* and *M. megrogori*. Aspects of biological and behavioral differences, type of injury caused and host plant resistance are also dealt with.

There is a paucity of information on the mites attacking cassava. Moreover, the literature reviews on cassava reveal that there may be some confusion with *Tetranychus urticae* Koch, *T. telarius* and *T. bimaculatus* (4-5, 13). A tetranychid complex affecting cassava does exist, as has been shown by Flechtmann (12) and Bellotti and Schoonhoven (2), and hopefully clarification will result. The pupose of this paper is to take a brief look at the nomenclature of the cassava mite complex and discuss the biology and ecology of the most important ones.

We agree with Boudreaux (3) that in identifying living specimens, "color is a dependable scientific character when considered with other morphological features." Color in living specimens is of utmost importance in recognizing the greenish form *T. urticae*, formerly known as *T. bimaculatus* or *T. telarius*, and the reddish form, *T. cinnabarinus* (Boisduval), also formerly referred to at times as *T. telarius* in older literature. On a world distribution comparative basis, *T. cinnabarinus* is found in the warmer regions while *T. urticae* is more cosmopolitan and will overlap with *T. cinnabarinus* in the warmer climates but extends into the colder regions as well.

The following table summarizes the current tetranychid mite complex of cassava:

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Table 1. The cassava mite complex*

Species		Color of adult females	Reported from
Mononychellus	*tanajoa***	greenish	South and Central America, East Africa
"	*caribbeanae*	greenish	Caribbean
"	*bondari*	greenish	Brazil
"	*chaemostetosus*	—	Brazil
"	*mcgregori****	greenish	Colombia
Oligonychus	*peruvianus***	greenish	Colombia
"	*gossypii*	greenish	Brazil
Tetranychus	*urticae***	greenish	Cosmopolitan
"	*cinnabarinus****	red	Brazil, Africa, India
"	*tumidus****	red	Brazil, Mexico, Caribbean
"	*neocalidonicus* Andre	red	Malagasy Republic, Brazil
"	*yusti* McGregor	red	Thailand

* After Bellotti and Schoonhoven (2)
** Major species
*** Less important, but potentially capable of becoming major species

Based on host lists available, other mite species that could conceivably be candidates for infesting cassava are:

Tetranychus turkestanti (Ugarov & Nikoloski), adult females greenish
" *marianae* McGregor, red
" *desertorum* Banks, red

Yield losses are generally a function of severity of damage and plant maturity. The younger the plant under mite attack and the longer the duration of attack, the more severe the defoliation and yield loss. In a study to determine the effects of mite damage on cassava yields, CIAT entomologists infested cassava artifically once or twice, starting when the plants were 2 to 10 months of age. When cassava plants were infested artificially at 2 and 8 months (attack of 6 months' duration), a yield loss of 53 percent resulted (7).

Biological and behavioral differences

Tetranychus urticae is capable of diapause, which enables the mite to overwinter in northern climes. When plants become severely damaged and a shortage of food exists, it is capable of going into a "semidiapause" or nonfeeding phase, which causes the mite to become hyperactive and spin large quantities of silk; concomitantly it aggregates at the terminal points of the plant. This type of behavior is the result of the species attempt to survive periods of food stress by dispersing to better feeding sites. Life history studies of this species are readily available. A life history/life table study (17) determined under a diurnal temperature of 15 to 28.3°C gave a life cycle developmental time of 16.1 and 16.9 days for males and females, respectively. After a preovipositional period of 2.1 days, females oviposited an average of 2.4 eggs/day for 15.7 days when cultured on strawberry leaflets. The intrinsic rate of increase (r_m) was 0.143. The life cycle of *T. urticae* was determined on excised cassava leaves at a diurnal temperature of 25 and 28° and 60 to 70% RH (7). Under these conditions average developmental time of eggs to adult was 8.83 and 9.27 days for males and females, respectively. The average number of total eggs produced per female was 40, which compared closely to 37.9 in a previous study (17).

T. cinnabarinus, the carmine mite, and *T. tumidus* Banks are major pests of cotton and thrive in climatic areas most suitable for cotton production. Even in the northern limits of its distribution, these species do not enter winter diapause. A critical life history/life table study of *T. cinnabarinus* (13) showed that at 24°C and 38% RH, developmental time (egg to adult) was 10.3 and 10.9 days for males and females, respectively. Highest oviposition was obtained at 24°C and 38% RH (i.e., an average of 115 progeny per female), and the intrinsic rate of increase (r_m) was 0.237, but was increased to 0.340 at 30°C and 38% RH. Thus, judging from comparative controlled condition tests, it is apparent that *T. cinnabarinus* could be more of a threat to cassava than *T. urticae*, especially in the drier climes (25).

Oligonychus peruvianus McGregor infests cotton and other crop plants, as does *O. gossypii* (Zacher). There are no known life history/life table data available (15).

The *Mononychellus tanajoa* (Bondar) life cycle was determined on excised cassava leaves (7). Under diurnal temperature conditions of 27 and 30°C (12 h dark/light) and 60-75% RH, the developmental time of eggs to adult was 7.66 days for males and 8.14 days for females. Optimal temperature for egg development was 28-32°C with a RH of 60%. From a world species point of view, *M. tanajoa* is very important, apparently second only to *T. urticae* in damage to cassava.

There is a dearth of information on other members of the remaining *Mononychellus* spp. The members of this complex may apparently be found on *Manihot* spp. as well.

Feeding preferences and type of damage caused

The tetranychids possess hard, needle-like stylets, which when straightened out from their curved resting position, pierce the leaf cells and suck the cell contents. Turgor pressure of the cell facilitates feeding. Feeding normally from the lower surface, they damage the spongy mesophyll cells although the lowest palisade layer can often be injured as well (1). When feeding from the top surface, the mites may reach through the palisade layers into the mesophyll cells. The chloroplasts disappear and a deficiency of photosynthesis occurs. Transpiration increases, probably due to injured leaf tissue. There is evidence that salivary toxins are introduced in the feeding process, which may hasten leaf chlorosis (22,28). There may be peculiarities in the type of injury caused by a given mite species to a particular host plant. Some plants are more susceptible to bronzing and defoliation by a particular mite species than others, and perhaps plant reaction to toxin is the underlying cause for these differences.

In cassava it has been noted that *Tetranychus urticae* initially attacks the mature leaves on the lower part of the plant; and as the season and infestation progresses, the population moves upward. Infested leaves have yellow dots along the veins, which change to a rusty reddish color; and as the infestation develops, badly infested leaves are shed. Defoliation becomes a function of soil moisture, duration of attack (especially as related to plant age) and mite population build-up.

Oligonychus peruvianus also attacks the lower and intermediate portion of the cassava plant. The females of this species spin a spot of silk on the underside of the leaf alongside the midrib and lateral veins. The female deposits her eggs in a colony under this silk spot where they hatch, feed and mature. Injury manifests itself as yellowish spots that turn brown. Heavy infestations of *O. peruvianus*, like *T. urticae*, will also cause premature defoliation of lower leaves (18).

Mononychellus tanajoa and *M. mcgregori* are green mites that attack the apical bud of the growing plant and the developing leaves, causing distorted growth, blotching and bronzing of the leaves and finally defoliation. Severe damage stunts plant growth and induces lateral growth (18-19).

Ecology

Much has been written about tetranychid ecology (28). The extremes of very dry/very wet conditions are deleterious. Prolonged dessicating conditions are harmful to the eggs and larvae as are very wet conditions. Feeding is impaired especially by prolonged wet conditions. Temperature, of course, is on the other side of the equation. The species known to affect cassava are apparently all

moderate in their response to humidity and temperature. Water balance has to be maintained. Drought conditions affect osmotic pressure of the cells and the plant's chemistry in general, in such a way that it benefits mite egg production, even though longevity may be decreased. The population attempts to maintain water balance through increased feeding (puncturing of cells), which causes increased transpiration. Hence in a drought situation, the death of the plant is hastened considerably by the chain of events triggered by lack of moisture.

It is well known that tetranychid mites are sensitive to their host plant's nutrition. For example, studies by Rodriguez (23), Suski and Badowska (27) and other workers (28) show that comparatively high foliar nitrogen is generally reflected by increased mite fecundity. Much the same is true of phosphorus. The results of the numerous studies made indicate that the nutritional status of the plant is quite an important factor and can determine whether a particular mites species will barely maintain its population or whether the population will explode. Studies on the chemistry of the cassava plant should be valuable in understanding population dynamics of mites and in dealing with this problem. Since chemical entities are also dynamic, hinging on many factors such as varietal differences, plant age, etc., the "nutritional ecology" is truly complex.

Host plant resistance

Host plant resistance to mites has been reviewed up to 1969 (28), and examples in cotton, oranges, geraniums, beans, apples, peaches, tea and tomatoes are cited. Considerable work has been published since, and studies of resistance of cassava to tetranychids have been initiated at CIAT in Colombia (6-7), in Venezuela (11) and in Brazil (8). At CIAT (6) preliminary screening of 1884 varieties against *O. peruvianus*, 427 against *T. urticae* and 45 against *M. mcgregori* showed there was intermediate resistance to *M. mcgregori* but only low-level resistance to *T. urticae*. In a later study (7), 1973 varieties screened for resistance to *T. urticae* again produced only low levels of resistance; however, 12 were selected as promising and 270 were selected as having low-level resistance. Of 1349 varieties screened against *M. tanajoa* however, 40 showed intermediate resistance and 210 were selected as promising. The conclusion was that there was more resistance to *M. tanajoa* than to *T. urticae* and that there was little cross resistance between these two species. In Venezuela Doreste *et al.* (11) field tested varieties selected previously at CIAT. These workers concluded that "the possibility of resistance to tetranychid mites in cassava varieties apparently exists," and two highly promising varieties were identified along with some 17 promising ones.

The nature of resistance

The mechanism or nature of resistance in cassava should be investigated. For example, in studies to determine the nature of resistance of strawberries to *T. urticae*, we found a number of essential oils as the allelochemics involved in the resistance scheme (9, 25). These allelochemics apparently change their pattern as the plant ages, for the plant is generally quite susceptible before fruiting but later becomes relatively resistant after harvest (10). We also showed that the glandular hairs of plants such as tomatoes, *Nicotiana* and cucurbits produced allelochemics that reacted as toxicants/repellents on *T. urticae* (16, 20-21,25). Since pubescence has been demosnstrated as a characteristic of thrips-resistant cassava varieties (2), it would be advisable to search for permanent pubescence in cassava foliage as one feature for resistance to tetranychids. Researching the biochemical nature of resistance to mites should also be a critical part of any integrated pest management system.

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Thrips on cassava: economic importance, sources and mechanisms of resistance

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Abstract

A report is given of experiments conducted at CIAT (Colombia) to evluate the economic importance of thrips, a dry-season pest of cassava in tropical America. It was found that yield losses due to thrips attack in this area ranged from 8-15% in susceptible varieties, depending on environmental conditions, and 11% in varieties with intermediate resistance. Calculated production losses for Colombia amount to 58,150 t/yr (7.67% of the total yearly production). Of 1254 clones in CIAT's cassava germplasm collection screened for resistance to *Frankliniella williamsi* and *Corynothrips stenopterus*, 20% showed no damage and 28%, slight damage. As regards the possible nature of resistance, a strong relationship between number of hairs on the leaf lobe and degree of resistance was found; there was no correlation with leaf HCN content. Although it is more economical to breed for increased yield potential, breeders should reject all cultivars showing susceptibility (grades 4-5) to thrips during dry seasons.

Thrips are considered an important pest of cassava in Central and South America during the dry season. They attack plants during all growth stages. Severely affected susceptible varieties show stunting, leaf deformation and reduction in leaf area; growing points may die, causing side buds to sprout. The following thrips species are reported attacking cassava: *Scirtothrips (Euthrips) manihoti* in Brazil (2) and Colombia (1), *Frankliniella williamsi* and *Frankliniella* sp. in Mexico (4) and Colombia (1); and *Corynothrips stenopterus* in Trinidad (7) and Colombia (1).

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Economic importance

Yield losses induced by thrips have been calculated roughly at 15 percent by Normanha and Espino (4) in heavy attacks on susceptible varieties. It was necessary to have data on quantitative losses in order to evaluate the usefulness of insecticides for controlling thrips and of breeding for thrips resistance.

In three experiments conducted at CIAT (Colombia), yield reductions induced by thrips were evaluated in two susceptible (M Mex 34 and M Ecu 117) and two resistant (M Mex 29 and 31) cultivars (6). Comparisons were made between

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plants treated biweekly with dimethoate (0.75 liters a.i./ha) and untreated plants. Thrips damage was evaluated on a 0-5 scale: -0= no symptoms; 1= irregular yellow leaf spots only; 2= leaf spots, slight leaf deformation, parts of leaf lobes missing, brown wound tissue in spots on stems and petioles; 3= severe leaf deformation and distortion, poorly expanded leaves, internodes stunted and covered with brown wound tissue; 4= as above. but with growing point dead and sprouting of lateral buds; and 5= lateral buds also killed, plants greatly stunted, giving a witcher'-broom appearance.

Results of the first experiment are given in Table 1. As can be seen, there was a 4.7 and 12.7 percent yield loss during a moderate thrips attack in resistant and susceptible cultivars, respectively. Assuming there is an equal attack in resistant and susceptible cultivars by insects other than thrips, yield reduction due to thrips alone is 12.7-4.7 or 8% in susceptible cultivars. During the second experiment, there was a heavy thrips attack during the dry season. M Col 1438 yielded significantly more than the others and more than twice as much as the lowest yielding M Mex 34 (Table 2). Yield increases following insecticidal application were statistically significant. Percentage of yield increase of the susceptible cultivars was significantly more than for the resistant ones, while there was an overlap for those with intermediate resistance; mean yield reduction due to thrips alone was 22.0-6.6 or 15.4% for susceptible cultivars and 11% for ones with intermediate resistance.

Table 1. **Yield of thrips-susceptible and resistant cassava cultivars, 10 months after planting, with and without insecticidal application.**

Cultivar	Yield (t/ha) Without insecticides	With insecticides**	% yield reduction
M Mex 29 (R)*	33.2	36.2	
M Mex 31 (R)	36.0	36.3	
Av	34.6	36.3	4.7
M Mex 34 (S)	27.9	34.1	
M Ecu 117 (S)	38.0	41.5	
Av	33.0	37.8	12.7

* Resistant (R) or susceptible (S) to thrips
**dimethoate applied every 15 days at 0.75 liters a.i./ha

In the last experiment, thrips damage reached grade 3 to 4; however, yield reduction ranged from 5.6% for M Col 1696 to 28.4% for M Col 1767 (Table 3). Varietal effects were statistically significant ($P < 0.10$), but insecticide treatment and variety by treatment effect were not. The mean yield reduction of all varieties was 4.1 t/ha or 17.2%. It was concluded that yield losses due to thrips attack in the Valle del Cauca range from 8 to 15% in susceptible varieties, depending on environmental conditions, while in varieties with intermediate resistance, they were 11%.

Calculated effect of attack on commercial production in Colombia

A survey was made by the cassava economy section on cassava production and production problems in each of the five production zones in Colombia (3). Data collected included acreage under cassava, the different varieties used and average yield. These cultivars were rated for thrips resistance in the CIAT germplasm bank, and production loss from thrips was calculated, assuming 11% loss for intermediate-resistant and 15.4% for susceptible varieties, as follows: the acreage per variety per production zone was multiplied by its average yield. The total production per variety thus obtained was considered 89% of the potential production of an intermediate-resistant variety and 84.6% of a susceptible one. The aforementiones 11 and 15.4% were considered the yield losses due to thrips per zone per variety and were added for each variety and zone (Table 4). Production losses from thrips were around 20,000 tons per year each in Zone II (Valle, Caldas) and Zone III (Tolima, Santander). The total estimated thrips loss amounted to 58,150 t/yr, which corresponds to 7.6% of the yearly production in Colombia.

Resistance

CIAT maintains a germplasm bank of some 2200 cassava clones from several Latin American countries. Part of this collection was evaluated for resistance to thrips (*Frankliniella williamsi* and *Corynothrips stenopterus*) at the end of each of two

Table 2 .Yield of thrips-susceptible, intermediate resistant and resistant cassava cultivars 10 months after planting, with and without insecticidal protection.

Cultivar	Yield (t/ha) Without insecticides	With insecticides **	Av ***	% yield reduction**
M Col 890 (R)*	17.3	18.0	17.6e	3.9a
M Col 113 (R)	23.9	25.8	24.8cd	7.4ab
M Col 65 (R)	25.5	27.9	26.9bc	8.6ab
Av	22.2	23.9		6.6
M Col 22 (IR)	28.1	33.1	30.6b	15.1bc
M Col 1438 (IR)	34.0	42.5	38.2a	20.0 cd
Av	31.0	37.8		17.6
M Col 1703 (S)	21.5	25.7	23.6cd	163bcd
M Mex 34 (S)	14.3	18.9	16.6e	24.3d
M Col 248 (S)	18.0	24.1	21.0de	25.3d
Av	17.9	22.9	21.0de	22.0

* Resistant (R) intermediate resistance (IR), or susceptible (S) to thrips
** Dimethoate applied every 15 days at 0.75 liters a.i./ha
*** Means not followed by the same letter are significantly different (P=0.05).

successive dry seasons (5). The previously described damage scale was used. Of 1254 clones evaluated, 20% showed no damage and 28% slight damage. Only 3.5% were so heavily attacked that the growing points died. The highest yielding clones found so far in the germplasm collection (M Col 22 and 113) are resistant to thrips; no high yielding clones were found in classes 4 and 5.

Table 3. Yield of thrips-susceptible cassava cultivars, 10 months after planting, with and without insecticidal application.

Cultivar	Yield (t/ha) Without insecticides	With insecticides*	% yield reduction
M Col 1696	20.2	21.4	5.6
M Col 1745	21.9	24.0	8.8
M Col 1670	20.2	22.4	9.8
M Col 1765	20.8	24.3	14.4
M Col 1703	21.5	27.1	20.7
M Col 1777	19.5	25.3	22.9
M Col 1701	16.8	22.5	25.3
M Col 1767	16.9	23.6	28.4
Av	19.7	23.8	17.2

* Dimethoate applied every month at 0.75 liters a.i./ha

Possible nature of resistance

A correlation was found between degree of resistance and the number of thrips present on the

Table 4. Yearly estimated yield losses from thrips attack per cassava production zone (based on data collected from CIAT plantings)

	Zone	Production loss (tons)
I	Cauca, Nariño	1,696
II	Valle, Caldas	19,938
III	Tolima, Santander	20,476
IV	Meta, Llanos	13,999
V	Atlántico, Magdalena	2,046 or 7.6%
	Total	58,150

buds (r=0.52*). However, similar numbers of insects were found on resistant and susceptible clones and thrips were also found on plants with no damage symptoms. There was a strong relationship between number of hairs per leaf lobe and degree of resistance (r=0.85**) (Table 5). Leaves of susceptible clones had few or no hairs whereas leaves of resistant clones had many. Number of hairs was similar in resistance categories 3, 4 and 5. Number of hairs is related to flowering; the number was constant until flowering, after which the number of hairs per leaf lobe decreased as did resistance to thrips. No relationship was found between thrips resistance and leaf HCN content (r -0.32). Other factors such as plant vigor and apical dominance may also be involved.

Table 5. Damage score, number of thrips, leaf cyanide level and leaf pubescence of different clones per resistance rating.

No. clones	Damage score	No. thrips/ terminal bud (av 3 rep.)	Leaf cyanide (ppm)	Av no. hairs/ leaf lobe
9	0	0.7	752	21,540
6	1	3.4	567	12,735
8	2	1.2	942	5,273
7	3	1.6	928	58
7	4	3.8	894	65
4	5	4.4	925	618

Conclusions

Yield losses from thrips even in long dry seasons are not large, especially when compared with production potential differences among varieties. Breeding for thrips resistance is, therefore, less profitable than breeding for increased yield potential. However, as thrips resistance does occur in high frequency and is easily evaluated for, we conclude that in breeding for improved cassava varieties, the breeder should reject all those showing susceptibility to thrips during dry seasons.

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Biological control of the mealybug *Phenacoccus manihoti* Matile-Ferrero: prospects and necessity

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Abstract

Results are given of preliminary research on the biological control of the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero in the Neotropics and West Africa. Propagation of *Phenacoccus* spp. was successful on a potato medium. A survey was made of natural enemies in West Africa; only two predators (*Spalgis lemolea* and *Acalypha* sp.) were found. Because of the scarcity of predators and possible absence of parasites, it will be necessary to introduce them from the Neotropics. To determine optimal techniques for shipping these natural enemies from the Neotropics, an evaluation was made of longevity of adult *Aenistus phenacocci*, *Hyperaspis emerata* and *Nephus* sp. on different diets. [illegible] found that adults fed a honey diet could survive a 10-day shipping period provided temperatures did not greatly exceed 30°C. An appendix table summarizes known biological control attempts against mealybugs.

Until the recent calamitous outbreak in West Africa, mealybugs had seldom been reported causing serious damage to cassava. Infestation had been reported by a number of polyphagous species, all better known as pests of other crops; viz., *Ferrisia virgata* (Ckll.), *Pseudococcus longispinus* (Targ.), *Planococcus citri* (Risso) and *Phenacoccus madierensis* Green (13). These mealybugs probably reach damaging levels only when senescent or debilitated plants undergo stress during long dry periods. However, in the early 1970s there were reports of devastating outbreaks in the Congo Republic and Zaire. Matile-Ferrero (9) discovered that they were due to a hitherto unknown species which she named *Phenacoccus manihoti*. The importance of this pest is attested by the special IITA-sponsored workshop, convened to consider control measures in June 1977 (8).

Because of its importance, CIBC submitted proposals to the International Development Research Centre (IDRC), Canada, in late 1976, requesting financial assistance for investigations on *P. manihoti* and related species in the Neotropics, with the aim of supplying promising natural enemies for biological control in West Africa. The project was authorized in April 1977.

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Biological control of mealybugs was reviewed at the Zaire workshop by Beardsley (2) and Greathead (6). Greathead's annotated list of known attempts (Appendix 1) shows that biological control was tried against at least 22 species on some 26 occasions, of which 17 are known to have achieved a degree of control and only 5 were definite failures. The successes were attained by parasites, predators of both on a wide range of crops growing in tropical and temperate regions. The prospects are therefore good for introducing biological control of *P. manihoti* in Africa, where few predators and no parasites have been detected.

Outside Africa *P. manihoti* is only known definitely from Belém, Brazil, where it was collected in 1971 (9). It is presumably the cause of a mealybug (*Phenacoccus* sp.) outbreak on cassava at Belém in 1975 reported by Albuquerque (1) Certainly the symptoms described are the same as those encountered in Africa as a result of a *P. manihoti* attack. In Colombia Bellotti and Schoonhoven (3) reported *P. gossypii* Townsend and Cockerell as a pest of cassava. Because of its sudden devastating appearance in Africa and its relative unimportance in South America, it has been concluded that *P. manihoti* is a Neotropical species accidentally transferred to West Africa.

This paper discusses preliminary investigations on natural enemies of *Phenacoccus* spp. in the Neotropics and in West Africa.

Investigations in the Neotropics

Recent surveys on cassava in Trinidad have failed to reveal attack by *Phenacoccus* spp. and no records were collected during investigations on tetranychid mites on cassava over the past three years (14). However, [illegible] seen (personal communication, 1977) collected *Ferrisia virgata* and a few individuals of a *Phenacoccus* sp. on cassava in Tobago, which were submitted to the Commonwealth Institute of Entomology for identification. D.J. Williams (personal communication, August 1977) has commented: "It seems to be the same as one I have often identified from the Caribbean and may be the same as one you have sent from *Sida* sp. I think I may have identified it as *P.* nr. *surinamensis*. How it differs from *P. manihoti* from West Africa I cannot say as yet but it is certainly very close. I think parasites of the Caribbean species may well suit the African species." Fennah (5) also collected a *Phenacoccus* sp. from cassava in Grenada.

On the South American mainland the situation is confusing. As already noted, mealybugs are present on cassava in Colombia and can be quite abundant (A. Bellotti, personal communication, 1977). In contrast Francis Geraud (Fundación Servicio para el Agricultor, Cagua, Venezuela) reports that although he had contacted people working on cassava and other entomologists "so far it seems that no one knows about such an insect or related mealybug in Venezuela." However Ernesto Doreste (personal communication, Nov. 1977) has encountered low infestations of an unidentified mealybug on cassava in some regions of Venezuela. On the other hand, *P. manihoti* has been positively identified from Brazil and is the probable cause of the outbreak at Belém reported by Albuquerque (1), who considers the mealybug to be a recent introduction from French Guiana or Surinam.

Based on present evidence, it would seem most likely that there has been a recent extension of *P. manihoti* into Brazil, and possibly Colombia, from a natural distribution area in the extreme north of South America, where it is so scarce that it has not yet been recognized as a pest. If this is correct, there is a striking parallel with *Planococcus kenyae* on coffee in East Africa. This mealybug appeared suddenly in outbreak proportions in eastern Kenya. Its origin was eventually traced to Uganda, where it was of negligible importance. Parasites from Uganda, subsequently introduced, achieved rapid and complete control in Kenya [see Greathead (6) for review and references]. Alternatively, a change in host plant may be involved as evidently occurred when the aleyrodid *Aleurodicus coccois* (Curtis), long known from coconuts in the Neotropics, suddenly appeared as a serious pest of cashew in southeast Brazil during the 1960s (4). A further possibility is that some change in farming practice (disruption of the ecosystem through large-scale planting of cassava, loss of resistance, change to susceptible varieties) has created conditions where *P. manihoti* can assume a greater importance than formerly. Unfortunately, it has not yet been possible to conduct surveys to settle these uncertainties and assess the impact of natural enemies at different host densities.

Natural enemies of *Phenacoccus* spp. in the Caribbean

In the absence of infestations of *Phenacoccus* spp. on cassava in Trinidad, surveys were undertaken on other plants. Over the years *Phenacoccus* spp. have been recorded in Trinidad from a number of plant genera including *Wedelia, Acalypha, Sida, Lantana* and *Hibiscus*; but the identity of these species has not been resolved satisfactorily (see foregoing remarks by D.J. Williams). However, CIBC card files (accumulated over 25 years) list *Phenacoccus gossyppi* (T and C), *P. grenadensis* Green and Laing (a synonym of *P. madierensis*), *P.* sp. near *parvus* Morrison and *P.* sp. near *surinamensis* Green. The natural enemies recorded on these, including records collected during the present survey, are listed in Table 1.

Hyperparasites

Some data indicate a high degree of hyperparasitism. In Trinidad *Aenasius phenacocci* is

Table 1. Records of natural enemies of *Phenacoccus* spp. in the West Indies from CIBC card files and present investigations.

Natural enemies	Area reported
Parasites	
HYMENOPTERA : ENCYRTIDAE	
**Aenasius phenacocci* Bennett	Trinidad
**Bothriocrsera bicolor* Comp. and Zinna	Trinidad
Acroaspidia myrmicoides Comp. and Zinna	Trinidad
Acerophagus sp.	Trinidad
Apoanagyrus sp.	St. Vincent
**Anagyrus* sp.	Bahamas
**Pseudaphycus* sp.	Bahamas
Predators	
COLEOPTERA : COCCINELLIDAE	
Diomus ochroderus (Muls.)	Trinidad
Nephus bilucernarius (Muls.)	Trinidad
**Nephus* sp. near *flavifrons* Melsh.	Trinidad
Hyperaspis donzeli (Muls.)	Trinidad
**H. jucunda* (Muls.)	Trinidad
**H. onerata* (Muls.)	Trinidad
**Hyperaspis* sp.	Bahamas
DIPTERA : SYRPHIDAE	
**Baccha* spp.	Trinidad, St. Vincent, Nevis
**Baccha* sp.	Bahamas
CECIDOMYIIDAE	
Vincentodiplosis coccidorum (Felt)	Trinidad, St. Vincent
sp. or spp. indet.	Trinidad, Bahamas
CHAMAEMYIIDAE	
Leucopis bella Loew	St. Kitts, Nevis
**?Leucopis bella*	Bahamas
NEUROPTERA : CHRYSOPIDAE	
**Chrysopa* sp. (p)	Trinidad, Bahamas

* Recorded during the present survey

attacked by at least three hyperparasites (F.D. Bennett's records); in the present study, rates of hyperparasitism over 50 percent were recorded from collections of *P. madierensis* from *Lantana montevidensis* (Table 2). Subsequently, predation by coccinellids was so high that the population of mealybugs collapsed and adequate samples could not be obtained.

In Peru Salazar (11) reported *Anagyrus pseudococcus* (Girault), *Anagyrus* spp., *Acerophagus* sp., *Paranusia* sp., *Grandoriella lanasi* Domen, *Leptomastidea* sp., *Aenasius masii* Domen and *Coelaspidia* sp. as parasites of *P. gossypii* on cotton and an additional parasite *Pezaphycus* sp. from this mealybug on *Gossypina glauca*.

Samples of natural enemies of *Phenacoccus* sp. from *Acalypha* sp. collected at Andros, Bahamas, showed even higher rates. Thus 21 adults of the primary parasite *Anagyrus* were reared against 150 of the hyperparasite *Prochiloneurus* sp. (i.e., 87.9% hyperparasitized), and of 73 puparia of *Leucopis ? bella*, 54 were attacked by *Pachyneuron* sp. (i.e., 69.2%).

Laboratory studies in Trinidad

Propagation of *Phenacoccus* spp.

It is standard practice to culture mealybugs on sprouted potato tubers using methods developed by Smith and Armitage (12). For mass production of the larger coccinellid predators e.g., *Cryptolaemus montrouzieri* (Muls.), potatoes are usually planted in flats (wood slat trays) and held in the dark until 20- to 25-cm sprouts are produced before inoculating them with mealybug eggs or crawlers. In the present investigations, where small coccinellids and parasites were to be studied, potatoes with short sprouts (up to 2.5 cm) were used successfully.

Table 2. **Hyperparasitism of *Aenasius phenacocci* from *Lantana montevidensis* in Trinidad. All hyperparasites were *Prochiloneurus dactylopii* (How.)**

Date		No. of mummies collected	Hyperparasitized
April	8	21	52.4
	15	17	59.3
	22	9	66.7

Each potato was infested by placing two or more egg masses of *P. madierensis* (from *Lantana montevidensis*) on it. The infested tubers were held on wire mesh stands in glass jars (12.5 cm diameter, 20 cm high) or plastic tubes (10 cm diameter, 10 cm high) fitted with lids with a 7.5 cm circular hole covered by organdy (or thicker cloth) glued into place. This technique was also found satisfactory for breeding *P. manihoti* in tests conducted in the United Kingdom.

Studies with natural enemies

Thus far, studies have concentrated on developing suitable breeding techniques and methods for shipping adults to West Africa, bearing in mind that in the absence of quarantine facilities, only adults or "clean" material can be sent and that as transit times of up to 10 days are expected, adults must still be capable of reproduction on arrival.

Initially, longevity of predator and parasite adults was determined when held on honey or a coccinellid diet (developed for aphidophagous species) comprising agar, honey and sugar. The tests were made in one-dram glass vials either with fine honey droplets on wax paper or drops of diet on strips of index card in a laboratory room at 29 ± 3°C. Honey droplets were renewed after 10 days. The results for three species, compared to longevity on mealybugs in rearing containers (Table 3),

Table 3. **Longevity of adult *Aenasius phenacocci*, *Hyperaspis onerata* and *Nephus* sp. near *flavifrons* on different diets.**

Species and diet used	No. tested	Days survived	
		Range	Mean
A. phenacocci			
Honey	11	12-31	22.5
Diet*	11	2-11	4.0
Mealybugs	17	2-20	9.8
H. onerata			
Honey	13	16-29	21.1
Diet*	6	2-6	4.7
Mealybugs	8	8-40+	Indet.**
Nephus sp.			
Honey	10	8-36	16.7
Diet*	11	4-10	7.8
Mealybugs	Not recorded but often 30 days or more		

* Coccinellid diet comprising agar, honey and sugar

** Six were alive when observations stopped at 40 days.

indicate that adults provided with honey should survive a 10-day shipping period, provided temperatures do not greatly exceed 30°C. Comparable tests have not been made with *Hyperaspis jucunda*, but this species regularly survives 20 days or more on honey or mealybugs.

Quantitative data are not yet available but *Aenasius phenacocci* has produced progeny after being help in vials on honey for 15 days and both *Hyperaspis* spp. have reproduced after 20 days on honey alone.

Because of problems in obtaining suitable potatoes (erratic supply, failure of crawlers to settle on one batch, rotting of over 60% of another), it has not been possible thus far to determine the reproductive potential of the natural enemies being studied.

Investigations in West Africa

Matile-Ferrero (9) lists natural enemies reared from *P. manihoti* in the Congo (Table 4) but has indicated in discussion that these were reared from bulk samples that may have contained several other coccids, including other mealybug species. The only natural enemy found in Zaire during the 1976 outbreak season was the predatory lycaenid butterfly, *Spalgis lemolea* (10). Samples taken

Table 4. Natural enemies reared from mealybug samples, chiefly composed of *Phenacoccus manihoti* in the Congo.

Natural enemies	Comments
HEMIPTERA: ANTHOCORIDAE	
Cardistethus exiguus Poppius	
LEPIDOPTERA: LYCAENIDAE	
Spalgis lemolea Druce	Common predator of pest mealybugs in West Africa
DIPTERA: CECIDOMYIIDAE	
Dichrodiplosis n.sp.	
Leptodiplosis sp. near *aonidiellae*	Female only
COLEOPTERA: COCCINELLIDAE	
Exochomus concavus Fursch	
E. flaviventris Mader.	Common mealybug predator in Africa
Scymnus rufifrons Fursch	
S. sp. near *ghesquieri* Mader.	
Stethorus sp.	Usually mite predators
HYMENOPTERA: APHELINIDAE	
gen. et sp. indet.	Male only
ENCYRTIDAE	
Blepyrus insularis (Cam.)	Parasite of *Ferrisia virgata*
SIGNIPHORIDAE	
Chartocerus sp.	? Hyperparasite
CERAPHRONIDAE	
gen. et sp. indet.	Hyperparasite

Source: Matile - Ferrero (9)

from the few pockets of infestation present in June 1977 yielded a few predators, but a persistent infestation of *P. madierensis* on *Acalypha* sp. in the same area supported a much higher predator population. Neither species was parasitized (Table 5).

These, admittedly very limited, observations suggest that few natural enemies have transferred to *P. manihoti* and because of the catastrophic mealybug populations that develop during the dry season (normally May to September) are of negligible importance in limiting outbreaks.

Conclusions

The apparent scarcity of predators and possible absence of parasites of *P. manihoti* in Africa, together with the near certainty that it is a recent introduction from South America where it is evidently of negligible importance in most places, suggests strongly that the introduction and establishment of natural enemies from the Neotropics will lead to a degree of biological control, hopefully complete. Optimism is supported by the high success rate of biological control attempts against mealybugs and other Coccidae.

Preliminary studies in the West Indies indicate the presence of promising natural enemies of related species which warrant trial against *P. manihoti*, but studies on *P. manihoti* itself are urgently needed and will be undertaken as soon as possible. It is likely that specific primary parasites will be found and other predators, most likely Coccinellidae, which will be effective if established in Africa. Experience has shown that parasites are usually most effective in maintaining mealybug populations at a low level but that predators are useful in reducing initial high populations to a level where parasites can contain them and also in dealing with incipient outbreaks where control has temporarily broken down.

Table 5. Natural enemies from samples of *Phenacoccus* sp. from Bas-Zaire (June 28-29, 1977).

Locality	Approx. no. of adult mealybugs	Natural enemies
Phenacoccus manihoti on cassava		
M'Vuazi (experimental plots)	300	
(farmer's plot)	300	1 scymnine*
Kimpesi (experimental plots)	400	
12 km SW Mbanza Ngungu (farmer's plot)	550	16 scymnine larvae* 1 cecidomyiid larva
Phenacoccus madierensis on *Acalypha* sp.		
M'Vuazi (garden at research station)	150	Many *Coccodiplosis citri* (Barnes) Cecidomyiidae** 16 scymnini* *Spalgis lemolea* (pupae on leaves)

* The scymnini comprise at least two species, which are being studied by R.D. Pope (British Museum of Natural History).

** Previously known only from type series from *Phenococcus citri* (Risso) collected in South Africa

Biological control offers the only short-term solution to the cassava mealybug problem in Africa as pesticides cannot be used because young cassava foliage is picked daily and forms the chief source of protein in the diet of many tribes in the Congo and Zaire. Chemical control is also too expensive and dangerous for application by subsistence farmers and is besides seldom very successful against mealybugs.

With these points in mind, it was concluded at the Zaire workshop that control should be sought by attempting biological control with all urgency; that breeding programs should look for resistant varieties for backing up biological control and for long-term protection; and that chemical methods should be developed only for treating planting material to moderate the inevitable spread of the mealybug throughout the cassava-growing areas of Africa. CIBC hopes through its current IDRC-sponsored program to provide the agents necessary for the achievement of the first of these objectives.

Acknowledgments

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APPENDIX

Summary of known biological control attempts against mealybugs

Mealybug/host	Country	Natural enemy	Origin/date	Result*	Comments	Reference**
Antonina graminis (Mask.)/ pasture grasses	USA (Texas, Florida)	*Neodusmetia sangwani* (Rao) (Encyrtidae)	India 1959	S	Reported increase in yield of up to 44%. Result reported in Bermuda (S-C) and also in USA (Ariz, Calif.) Mexico, Brazil, Israel. Introductions of *Anagyrus antoninae* (Timb.) are also being made into USA (Florida), Mexico, Israel, but results not yet clear.	(7)
Dysmicoccus boninsis (Kuw.)/ sugar cane	Guam	*Cryptolaemus montrouzieri* Muls. (Coccinellidae)	Hawaii 1926	F	It became established but seldom feeds on this species.	(12)
Dysmicoccus brevipes (Ckll)	South Africa	*Cyptolaemus montrouzieri*	USA (Calif.) 1900, 1924	F	The predator was unable to reach *D. brevipes*, but was successfully established against *Planococcus citri*. In Mauritius (1938-39) it also failed although it became established on the island.	(5)
	Puerto Rico	*Hambeltonia pseudococcina* Comp.	Brazil 1936-1937	? P	Some success is claimed but the same parasites failed to establish in Hawaii. Similarly, no success was achieved in USA (Florida) although it became established.	(2,7)
Ferrisia virgata (Ckll)/ coffee, fruit trees, ornamentals	Java	*Cryptolaemus montrouzieri*	Hawaii 1918	?	It became established on coffee which is no longer an important crop.	(12)

Appendix table cont.

Mealybug/host	Country	Natural enemy	Origin date	Result*	Comments	Reference**
	USA (California)	*Acrophagus texanus* (How.) (Encyrtidae)	Mexico 1965-1967	?	Released along with other species. Established, although one of the least promising species initially.	(3)
Nipaecoccus nipae (Mask.)/ subtropical fruits	Hawaii	*Pseudaphycus utilis* Timb. (Encyrtidae)	Mexico 1922	S	———	(11)
Nipaecoccus vastator (Mask.)/ shade trees, citrus	Egypt	*Anagyrus aegyptiacus* Moursi *Leptomastix phenacocci* Comp.	Java 1934-39	P	Other natural enemies introduced at the same time did not become established.	(8)
	Saudi Arabia	*Cryptolaemus montrouzieri*	Pakistan 1972-1973	?	*C. montrouzieri* became established but the final result is not known.	(14)
Phenacoccus aceris (Sign.)/ apples	Canada (BC)	*Allotropa utilis* Mues. (Platygasteridae)	Canada (Nova Scotia) 1938	C	The pest originated in Europe; *A. utilis* (origin unknown) was effective in Nova Scotia and so used.	(9)
Maconellicoccus hirsutus (Green)	Egypt	*Leptomastix phenacocci* *Anagyrus aegyptiacus* *Achrysopophagus* sp.	Java 1934-39	S	Other natural enemies introduced at the same time did not become established. *Hyperaspis maindroni* Sic. (Coccinellidae) was sent to New Guinea from India in 1971. Result not known.	(8, CIBC reports)
Planococcoides njalensis (Laing) and others/cocoa	Ghana	Many natural enemies of other species	Several countries 1948-1955	F	None are known to be established. Only *Pseudaphycus angelicus* (How.), a parasite of *Planococcus citri*, has been recovered.	(5)

Appendix table cont.

Mealybug/host	Country	Natural enemy	Origin/date	Result*	Comments	Reference**
Planococcus citri (Risso)/ citrus, grapes	USA (California)	*Cryptolaemus montrouzieri* *Leptomastidea abnormis* (Gir.) (Encyrtidae)	Australia 1891-1892 Sicily 1914	P	*C. montrouzieri* has been released in many countries. With complete success in South Africa (1924) but this depended on the prior establishment of *Dactylopius* spp. against prickly pear cactus. *C. montrouzieri* interfered with control of the weed. Establishment and partial success was achieved in Chile (1931), Hawaii (1915), Corfu (1933), Italy (Liguria only) (1919-20), Portugal (1929), Egypt (1923). In some countries, success can be attained by annual releases; viz., Egypt. Sicily, Spain, France. It failed in Cyprus and Israel, where the summer climate was too harsh, and its use was abandoned in Egypt as the colonization program was too costly. In all areas, an essential for success is the continued presence of hosts throughout the year. *L. abnormis* also contributes to control in Chile, and *Leptomastix dactylopii* How. in Spain (1948). Both these parasites were introduced into the USSR in 1960 and are established.	(3,5,7,8, 13)
Planococcus kenyae (Le Pelley)/coffee	Kenya	*Anagyrus* sp. near *kivvensis* (Comp.) (Encyrtidae)	Uganda 1938	C	Initial failure using parasites of other mealybugs. Successful species (and 4 others established) from same host in area of origin.	(5)
Planococcus lilacinus (Ckll)	Sri Lanka	Parasites (unspecified)	Philippines 195?	F		(12)

Appendix table cont.

Mealybug/host	Country	Natural enemy	Origin/date	Result*	Comments	Reference**
Pseudococcus calceolariae (Mask.)/citrus and other fruits (*gahani* Green, *fragilis* Brian of authors)	USA (California)	*Coccophagus gurneyi* Comp. *Hungariella pretiosa* (Timb.) (Encyrtidae)	Australia 1928	C	Success achieved after mass release of *Cryptolaemus montrouzieri* and establishment of another ladybird, *Scymnus binaevatus* (Muls.) from Australia had failed to give adequate control. *C. gurneyi* has also been used in Chile (1936) and the USSR (1960) with success and is established in South Africa (1934), but its effect has not been assessed.	(2,5,7)
Pseudococcus citriculus Green/citrus	Israel	*Clausenia purpurea* Ishii (Encyrtidae)	Japan	C	After solving problem of identity of pest, parasites of the *P. comstocki* group were tested.	(13)
Pseudococcus comstocki (Kuw.)/apples	USA (eastern)	*Allotropa burelli* Mues. (Platygasteridae) *Pseudophycus malinus* Gahan (Encyrtidae)	Japan 1939-1941	C	Partial success was obtained with *P. malinus* in Uzbekistan in 1945 following its introduction from the USA.	(2-3)
Pseudococcus longispinus (Targ.) (*adonidum* (L.) of authors)/citrus, avocados	USA (California)	*Anarhopus sydneyensis* Timb. *Hungariella peregrina* (Comp.) (Encyrtidae)	Australia 1933 Argentina 1934	P	Partial control with *H. peregrina* and *Anagyrus fusciventris* (Gir.), imported from California, was also achieved in Bermuda (1951). *Pseudophycus angelicus* (How.), introduced in South Africa (1934), failed, but recent introductions of *A. sydneyensis* and *P. peregrina* to Israel show promise of success.	(1-2,5,7)

Appendix table cont.

Mealybug/host	Country	Natural enemy	Origin/date	Result*	Comments	Reference**
Pseudococcus maritimus (Ehrh.)/pears and grapes	USA (California)	*Acerophagus notativentris* (Gir.) (Encyrtidae)	? 1943	S	———	(7)
Pseudococcus obscurus Essig/ grapes, pears	South Africa	3 encyrtids and 2 *Scymnus* spp.	USA (California) 1933-1934	?	None are known to be established, but ant control has led to "natural" control of the pest.	(5)
Pseudococcus spp.	Australia (Western)	*Cryptolaemus montrouzieri*	Australia NSW 1902	S	Substantial success has also been achieved in St. Helena (1973). *Coccophagus gurneyi* Comp. failed in the Cook Islands (1934). The result of recent introduction of *C. montrouzieri* is not known.	(12,14-15)
Rastrococcus iceryoides (Green)/coffee	Celebes	*Cryptolaemus montrouzieri*	Java 1928	S	———	(12)
Sacchariococcus sacchari (Ckll)/sugar cane	Hawaii	*Anagyrus saccharicola* Timb. (Encyrtidae)	Philippines 1930	S	Success also achieved in Barbados (1970) and it is established in St. Kitts (1971), both from Uganda stock. Attempts to use *C. montrouzieri* in Somalia (1933), Philippines (1928), Egypt (1923) were abandoned as the predator is unable to penetrate beneath the leaf sheaths. *Hyperaspis trilineata* Muls. from Barbados has failed in India (1970) and both coccinellids have been released and recovered in the Bahamas (1969).	(5,8,11-12, CIBC reports)

* F = Failure
P = Partial control
S = Substantial control
C = Complete control
? = Result unknown

APPENDIX

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Preliminary observations of the mealybug (Hemiptera: Pseudococcidae) in Zaire

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Abstract

Whiteflies and mites were the only important pests of cassava in Zaire until 1970 when the mealybug *Phenacoccus manihoti* was observed. The type of damage caused, economic importance and possible alternate hosts are discussed briefly. The life history of the mealybug and the influence of climatic conditions on insect development are described: The 2 principal means of dissemination are the use of infested propagating material and wind. Only a few parasites and predators that control it have been found; the most effective predator is *Spalgis limolea*. Four different approaches for handling this pest are recommended: breeding for resistance, biological control, cultural practices and chemical control.

Until 1970, when the mealybug was observed around Kimpese, whiteflies and spider mites were the only important cassava pests in Zaire. Since this first sighting, it has also been reported in Bas-Zaire and Bandundu. Outside Zaire there are definite reports from Congo (Brazzaville), and it has almost certainly reached north of Angola.

After the visit of Prof. G.A. Schaefers in 1974, samples of the insect were sent for identification to the Commonwealth Institute of Entomology, who reported that the pest was an undescribed species of the family Pseudococcidae. Concurrently the same species was detected on cassava in Brazil. From samples sent to the Institute, it was possible to identify the species as *Phenacoccus manihoti* (2). This strongly suggests that we are dealing with a newly introduced species, a view supported by its rapid progress, such as occurs when an insect is not part of an established ecosystem.

Type of damage caused

Initially, the mealybug attacks the terminal points of the cassava shoots. At a later stage, due to lack of food and space, the insect also settles on the petioles and expanded leaves. The damage to the plant is done in two ways: by sap sucking and possibly by introducing an unidentified chemical with the saliva, which stunts the shoots. Further symptoms are short internodes, little new leaf growth and leaf curling. With increasing

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population density all green parts of the damaged shoot eventually die, and dieback may or may not occur. Alternative infestation of lower l[illegible], together with natural leaf fall during the dry season, causes the so-called "candlestick" appearance of the cassava plant.

Economic damage

The economic damage to cassava caused by the mealybug is partitioned into loss of fresh leaves, which are eaten as "pondu," and root yield loss. With our present stage of knowledge, we can say there is a definite loss of fresh leaves since the shoots that are normally used for food are infested. To what extent root yield loss occurs as a result of insect attack is still unknown because accurate experimental data are not yet available. There is strong evidence that the age of the plant at the time of heavy attack and the soil type are very important in relation to root yield loss.

Biology

To provide a background to the mealybug research program, a summary of the life history of the insect and its dispersal in relation to climatic conditions is presented.

Life history

The mealybug seems to be parthenogenetic only. No males have been observed, either in the field or in laboratory populations. The eggs are enclosed in an ovisac of felted waxen threads known as the "wooly mass." The eggs are first yellowish white and later turn yellow to light brown. Eggs with visible eyespots usually emerge a few days later. On the average the adult female l[illegible] a total of 440 eggs during its life span; the average incubation period is 8 days. The duration of nymphal stages is about 25 days at 25°C. The life span of adults is about 29 days.

These data show the great development potential of the insect. The number of generations per year may vary in different regions according to climatic conditions. Studies of the climatic data available in M'Vuazi for the last 15 years gave evidence that temperature, humidity and rainfall are the principal factors controlling development. In Figure 1 the monthly means of temperature,

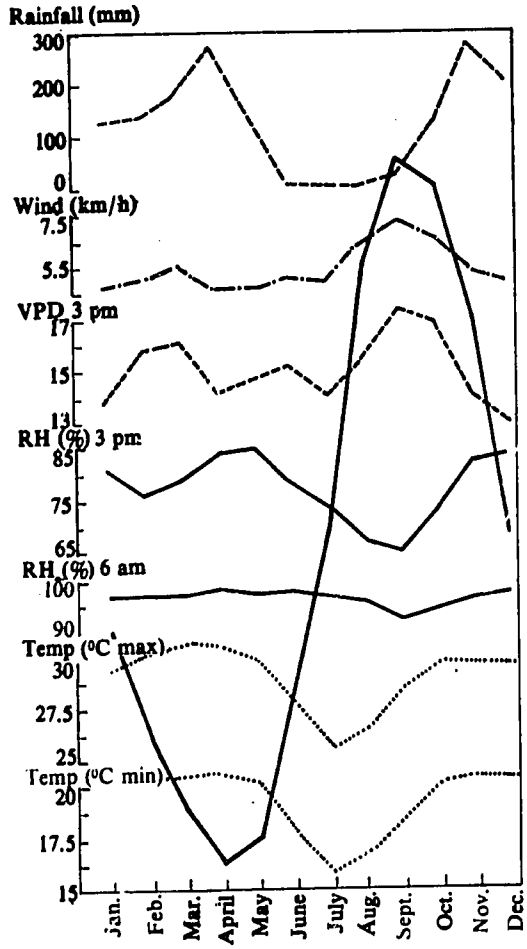

Figure 1. Projected mealybug population development in relation to environmental factors.

relative humidity, vapor pressure deficit (VPD), wind speed and rainfall are graphed together with an assumed population development of the mealybug. The latter, which illustrates the hypothetical situation over one year, is based only on observations by H.C. Ezumah over the last two years and during my last two visits.

The most obvious conclusion is that the dry season seems to be necessary for building up the mealybug population. Up to July the development is relatively slow, probably because of low temperature, low VPD and residual moisture in the soil, which are necessary for plant growth. Increasing drought stress and temperature seem to favor the population build-up. Particular attention will be paid to possible developmental stages of the

insect adapted to overcome unfavorable conditions, such as the rainy season when it is seldom found. These could be dormant eggs, larvae or adults. Thus far, it has been found that second larval stages hibernate frequently in the dormant buds.

Parasites

We mentioned previously that the success of the mealybug in Zaire is due to the fact that it is not part of an established ecosystem. This view is supported by the observation that only a few parasites and predators of importance have been found so far. The most effective predator observed is *Spalgis limolea* (Lycaenidae, Lepidoptera). Although parasitism is only one of the constraints that keeps insect pests within certain population density levels, this factor can be an important aspect of control.

Alternate host plants

Several unidentified weed species and *Capsicum* sp. were found with mealybugs in cassava fields, however, it seems that most of them, except *Capsicum* sp., served merely as temporary host plants because only individuals but no colonies were found.

Dispersal

There are two principal ways by which the mealybugs spread: by passive transport on infested planting material and as unsettled first instar nymphs (crawlers).

Dispersal by infested planting material

Infested planting material is probably the way in which the mealybug entered the country and is possibly the major reason for spread over both far and short distances. Close observations of mature stems that could be used as planting material indicated that first and second instars are frequently found on buds. In an experiment with treated (insecticide) and untreated cuttings, no mealybug colonies could be observed on the sprouting treated cuttings whereas there were several colonies on the untreated ones.

Wind dispersal

The second way mealybugs are dispersed is by wind. It was observed that only first instars (crawlers) became airborne. Close observations on crawler behavior showed that they hatch mostly in the morning. After hatching, a perhaps positive phototactic behavior makes them move to the upper leaves and tips of the plant, thus exposing them to the wind. These restless movements continue until about 12 o'clock. A subsequent study of the wind speed in the morning shows a steadily increasing speed from 6 to 12 noon. At 10 o'clock the wind reaches a speed higher than 2 km/h, which seems to be enough to make many crawlers airborne. The question of how far crawlers can travel by wind was also subjected to a preliminary study. Four sticky traps, 1.70 and 1.20 m from the ground, were placed at 2, 15, 25 and 35 m from the source of infection. After 3 days the first trap caught 100; the second, 7; the third, 2; and the fourth, none. No equipment was available to measure wind speed.

Based on this experiment and data from Beardsley (1), it can be assumed that airborne crawlers are mainly responsible for effective short-distance spread. Nevertheless, there are also indications that strong winds can carry them over much longer distances. This was supported by the following experiments: Sticky traps (petri dishes) were placed at 1, 2, 3 and 4 m height and 20 m from the nearest source of infection. Over a period of three days, 6, 8, 5 and 9 crawlers, respectively, were caught at the different heights. Presumably crawlers will fly longer distances at a height of 4 m than at 2 m.

Since the wind direction from Bas-Zaire to Bandundu is mainly westwards during the dry season, the mealybug infection front might slowly proceed in this direction even without dissemination by infected planting material.

Projections for future work

With these preliminary observations, it is possible to make proposals for future work. Four different approaches to handle the problem can be projected: (a) breeding for resistance, (b) biological control, (c) cultural practices and (d) chemical control.

Breeding for resistance

Breeding for resistance will probably be the best solution, but this takes time. Investigation of the material available in Zaire (both from INERA and IITA) gives the impression that our germplasm base is not sufficiently large although not all of the material has been exposed to mealybug attack. Therefore, future steps taken by the entomologist should be systematic exposure of the available material to find appropriate screening methods. If necessary, introduction of more germplasm through IITA should be planned.

Biological control

Grants have already been given to the Commonwealth Institute of Biological Control in order to survey the range of parasites and predators in this country and if necessary introduce species from the source of origin of the pest. As this involves predominantly entomological studies, a postdoctoral fellow might be appropriate for this type of work in Zaire.

Cultural practices

This type of approach seems to be the most promising short-term method to reduce the problem in the near future. Investigations should be based on (a) planting time, (b) soil moisture conservation and other agricultural practices to improve plant growth and (c) mixed cropping.

Experiments carried out by Ezumah indicate that planting around November results in less root yield loss. This observation is supported by comparison of climatological data and population development of the mealybug (Fig. 1). By the time the mealybug population has built up, the cassava is already between 9 and 11 months old. It was also observed that plants on soils with a higher water table are more tolerant to infestation. Improvement of physical and mineral fertility could reduce the impact of the mealybug by strengthening the plant. Observations of dispersal by wind suggest the utility of mixed cropping as an additional means of restricting spread. The second crop should serve as a windbreak.

Chemical control

Chemical control of mealybugs should not be emphasized at present although some chemicals should be screened for their effectiveness against the insect to have some information if needed. Insecticides should be used only for dipping cuttings in order to reduce the spread of the pest in the country. An additional use of insecticides on an experimental basis would permit the critical establishment of yield loss.

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The white scale (*Aonidomytilus albus* Ckll.) on cassava

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Abstract

Scale insects have appeared as pests of cassava in South America, Asia and Africa as a result of the increase in area planted to cassava and because of the use of insecticides on other crops. The most important species are *Aonidomytilus albus* and *Saissetia* sp., which are generally found on the stems and occasionally on the petioles. Damage is greatest when the plant is attacked during the early stages of growth before it is well established. The habits and instars of the insect are described, and the means of dissemination are given. Infestation of propagating material by scale insects can reduce the percentage of germination significantly, as well as delay initial growth. The most serious damage (death of lateral buds) results in the loss of planting material. Control measures are discussed.

Cassava has long been an important crop for small farmers in many parts of the tropics. With the recent increase in cultivated area and the continual use of pesticides on other crops, new entomological problems have developed in cassava, one of which is the scale insect. Scales have been reported attacking cassava stems in many cassava-growing regions of the Americas (2-5,8, 11), Asia (6, 9) and Africa (13) (Table 1). The most important scales appear to be *Aonidomytilus albus* (7) and *Saissetia* sp. (9). Yield losses resulting from scale attack are not known, but reduction in yield and root quality have been reported (13). Yield losses recorded at CIAT on a per plant basis reached 19 percent on heavily infested plants.

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Type of damage

The insects are generally found on the stems of cassava plants and occasionally on the petioles. The damage, which results from the sucking habit of the insect, depends largely on whether heavy infestation occurs during the early stages of growth or later on when the plant has become well established. In the former case the leaves lose their chlorophyll and gradually dry up; this is followed by complete desiccation of the stem and ultimate death of the plant in a heavy infestation. Those plants that manage to survive an early infestation of this type are generally found to have poorly developed and unpalatable roots. When heavy infestation occurs later in the development of the plant, symptoms of attack noted above are only shown to a slight degree, but the roots must be

Table 1. Scale insects reported attacking cassava family.

Family and species	Reported from
DIASPIDIDAE	
Aonidomytilus albus	Americas, Africa
=*Coccomytilus dispar*	Asia (Taiwan, India)
=*Lepidosaphes dispar*	Americas
Lepidosaphes alba	Cuba
Pinnaspis minor	Peru
=*Hemichionaspis minor*	Peru
COCCIDA	
Saissetia hemisphaerica	Madagascar
=*Lecanium hemisphaerica*	Mauritius
S. nigra	Madagascar, Malaya Indonesia
S. coffeae	Madagascar
S. miranda	Colombia
Coccus viridis	Madagascar
Mytilaspis dispar	Madagascar
Eurphizococcus sp.	Brazil
Monophebus sp.	Brazil

Source: Bellotti and Schoonhoven (2)

harvested within a few months or they become inedible (12-13).

Studies at CIAT (4) with scale-infested cuttings showed that these insects can reduce germination of cuttings greatly (Fig. 1). Insecticidal treatment of cuttings completely covered with scales did not increase germination (Fig. 2). Apparently, damage had occurred before planting. Moreover, initial plant growth is retarded in scale-infested cuttings (Table 2)

Table 2. **Plant height and number of leaves per plant, 40 days after planting cuttings infested to various degrees with the scale *A. Albus* (grade 0= no scales; grade 3 = completely covered).**

Grade of infestation	Plant height	No. of leaves/ plant
0	33.4a	32.6a
1	32.9a	28.2ab
2	23.1b	19.2b
3	5.5c	4.8c

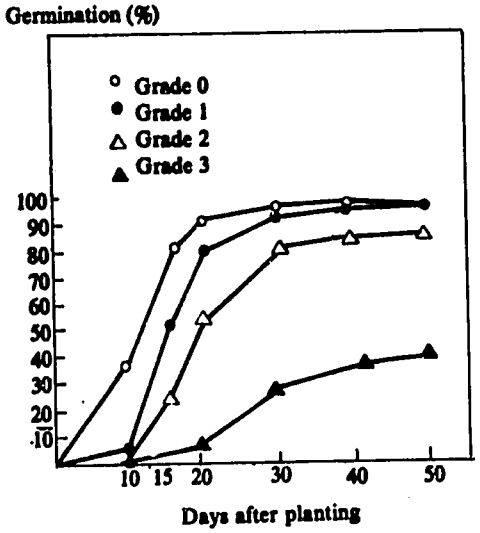

Figure 1. Germination of cuttings with various degrees of scale infestation (grado 0 = no scales, grade 3 = covered with scales).

Greatest damage from scale attack appears to be the loss of planting material as a result of the death of lateral buds on stems. Studies at CIAT (unpublished data) with cuttings infested at several levels (0-4) showed different percentages of loss in germination (Table 3)

Life history, description and habits

The biology of the scale has been studied by Swain (13) in Tanganyika. The biology of *A. albus*

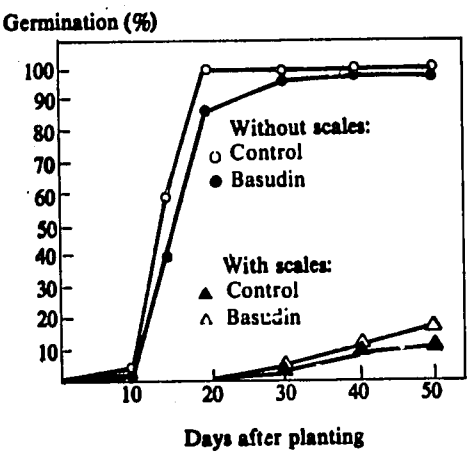

Figure 2. Effect of scales and insecticidal treatment on germination of cuttings.

Table 3. Reduction in germination by *Aonidomytilus albus* at different grades of infestation.

Grade*	% germination	% loss
0	95	5
1	91	9
2	85	15
3	23	77
4	9	91

* Grade: 0: Clean cutting
1: Very few scales around the buds
2: Few scales around the bud and internodes
3: Scales completely covering buds and 50% of the internodes; loss of basal leaves
4: 90% of the stem cutting covered by scales, fall of leaves and desiccation of stem

Table 4. Biology of the white scale (*A. albus*).

Stage	Minimum (days)	Maximum (days)	Average
Female			
Nymph I	7.0	11	9.0
Nymph II	3.5	6	4.7
Nymph III	7.0	12	9.5
Total	17.5	29	23.2
Male			
Nymph I	7	11	9.0
Nymph II	4	9	6.5
Prepupa / Pupa	4	5	4.5
Total	15	25	20

was studied in detail by Bernardo Belosa at CIAT in 1977 (Table 4), who found results similar to Swaine's.

The female of *A. albus* is mussel shaped and covered with a waxy white excretion. It has neither wings nor legs and is approximately 2 to 3 mm in length. The cast skins of the first and second nymphal stages are incorporated in the scales. Unlike the females, males have well-developed legs and wings. The female produces an average of 47 eggs, depositing them between the upper scale covering and the lower cottony secretion. As the eggs are laid, the female gradually shrinks in length and finally shrivels up Eggs hatch in 4 days; the first nymphal instar (crawlers) are oval shaped with a depressed pale pink body. They are locomotive and can disperse. The crawlers become fixed in 1 to 4 days, usually settling down in the angle of a stem node, where they proceed to cover themselves with two or three conspicuous white threads. They molt in 11 days; four days later the second molt occurs, resulting in the production of the adult female which commences oviposition in 1 to 2 days. The female generation lasts from 22 to 25 days.

Dissemination in the field

The possible means by which infestation can spread from plant to plant and field to field are (a) wind dispersal of crawlers, (b) active migration of crawlers on the ground and (c) passage of crawlers from infested to clean material when cuttings are being handled prior to planting. The most important means of dissemination is by storing infested cuttings with clean ones (12).

Control methods

Cultural control

Scale attacks appear to increase when cassava is grown continually on the same land, which involves an increased use of insecticides. This could be avoided by crop rotation; e.g., cassava, maize, beans.

Chemical control

Chemical control may be required during the dry season. Measured in percentage of adults killed, Metasystox (0.1%) and parathion were the most effective (1, 12). As for chemical treatment of cuttings, dipping those that are infested with crawlers in a DDT emulsion for 5 minutes reduces infestation; however, heavily infested cuttings still germinate poorly (4, 13). Preventive control of stored cuttings has been successful.

Biological control

Heavy predation of *A. albus* by a coccinellid *(Chilocorus distigma)* is reported (10).

Hymenopterous parasites (*Aspidiophagus citrinus* and *Signaphora* sp.) have been reported from Cuba (3). At CIAT the following predators have been found: *Coccidophilus* sp., *Scymus* spp. and *Pyroderces* sp.; a brown, spongelike fungus (*Septogosidium* sp.) was also found growing on *A. albus*.

Clean planting material

The most important factor in successful cassava cultivation is the use of uninfested planting material. As shown in Table 3, losses in germination of cuttings attacked by *A. albus* are often as high as 90 percent.

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Studies on the cassava fruit fly *Anastrepha* spp.

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Abstract

Two species of fruit flies have been identified as attacking cassava in Colombia: *Anastrepha pickeli* in the Valle del Cauca (altitude 1000 m) and *M. manihoti* in the coffee-growing regions (1200 m). When this insect attacks the fruit of cassava, it does not cause economic losses; but when it attacks the stem, it bores tunnels where a bacterial pathogen *Erwinia carotovora* var. *carotovora* can be found causing severe stem rot. When environmental conditions are favorable, the cassava plants can recover rapidly from this damage even when growing terminals have rotted or died. Severest fruit fly damage is observed in planting material; the use of infested cuttings results in losses in germination as well as yield. Environmental conditions favorable to fruit fly development and aspects of its biology are discussed. *Opius* sp. is a parasite of larvae in the cassava fruit but has not been observed in the stems. The use of systemic insecticides is discussed, and results are given of field experiments designed to determine which baits or attractants would trap fruit flies or increase the effectiveness of insecticides.

The fruit fly has been reported as a pest of cassava only in the Americas. When it attacks the fruit, it causes no economic losses (3-4). In recent years we have also observed fruit flies causing damage to cassava stems in several countries of Central and South America. Two species of fruit flies have been identified as attacking cassava in Colombia: *Anastrepha pickeli* (Tephritidae), collected at the CIAT farm in the Valle del Cauca (altitude 1000 m), and *M. manihoti*, found in the coffee-growing regions (1200 m) where in recent years it has become a serious pest of cassava.

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Type of damage caused

When oviposition occurs in the fruit, the larvae bore throughout the fruit, destroying the developing seed. The infested fruit shrivels and becomes soft, turning yellow green in color (1).

Larval tunneling in the stem results in brown galeries in the pith area. A bacterial pathogen (*Erwinia carotovora* var. *carotovora*), often found in association with fruit fly larvae, can cause severe rotting of stem tissue (2). The presence of the larvae within the stem can often be noted by the white liquid exudate that flows from the larval tunnel and exit holes. In severe attacks, growing points may

collapse and die, retarding plant growth and encouraging growth of lateral buds. Buds located along infected stem portions are first invaded and necrosed. Younger plants (2-5 months) suffer more from damage than older ones.

Field observations have shown that damage in cassava plantations can be extensive. On one field 84 percent of the plants were observed with fruit fly/bacteria damage while in another field about 75 percent of the plants had collapsed, 20 to 30 cm below the growing points.

The effect of this damage on cassava production is not known. In one study 100 plants damaged by fruit flies were harvested, root yield recorded and compared to the yield of 100 undamaged plants. There was a 5 percent reduction in root yield of the damaged plants. Affected plants were stunted and may have been shaded by their healthy neighbors; hence yield losses may have been overestimated. It is also suspected that this secondary rotting may cause a reduction in germination when infested stems are used as planting material and that yields from damaged planting material may be reduced.

This paper will discuss the biology and ecology of the fruit fly, the economic damage it causes, and possible control methods.

Biology and ecology

The yellow- to tan-colored female inserts the egg in the succulent part of the stem, about 10 to 20 cm from the tip, so that about one third of the egg with a slender white rod protrudes. After hatching, the white to yellow larvae bore up- or downwards in the stem pith region. Since numerous eggs may be deposited in one stem, several larvae may be found per stem. This provides an entrance for the bacterial pathogen that causes stem rotting.

The fruit fly/bacterium association is not fully understood. It appears that the bacterium is present on the stem, where it can live epiphytically. Rain is probably the principal means of dissemination. Investigations have not definitely concluded that the fruit fly is a vector of the pathogen; however, observations indicate that the fruitfly/pathogen association exists naturally and that the insect can disseminate the causal organism.

The boring action of the larvae under high humidity conditions provides the wound needed for bacterial entrance into the stem. Under favorable environmental conditions of adequate rainfall and high humidity, rotting develops. The rotten stem is not a favorable environment for the larvae; inspection of rotting stems showed 40 percent larval mortality. This also indicates that the fruit fly may result from infestations of the cassava fruit or alternate hosts rather than from stem infestations. The fruit of several other plants commonly found in areas of high fruit fly populations have been examined, but no additional hosts to these species have been identified yet.

Mature larvae leave the stem or fruit and pupate on the ground. The larval exit hole is clearly visible in the stem. Adults emerge in about 17 days. In some areas high fruit fly populations occur year-round, but extensive damage is usually associated with the rainy season. Damaged stems have been observed in cassava-growing areas ranging from coastal areas where there is minimal and sporadic rainfall to mountainous areas where rainfall is well dispersed throughout the year; however, observations indicate that high fruit fly populations correspond to areas of high humidity and dispersed rainfall.

Fruit fly larvae in cassava fruit are attacked by the parasite *Opius* sp. (Hymenoptera: Braconidae). A study on the CIAT farm showed a 4.9 percent level of parasitism; whereas in the coffee regions of Colombia, where fruit fly populations and damage are high, there was 16 percent parasitism. There have been no observations of larval parasitism in cassava stems.

Economic damage

It appears that cassava plants can recover rapidly from fruit fly damage, given adequate, well-distributed rainfall. Plants that had been severely rotted (dead or rotted growing terminals) when three months old were compared to healthy plants over a six-month period. Plant height measurements showed that within five months, the damaged plants recovered, attaining the same height as nondamaged plants (Fig. 1).

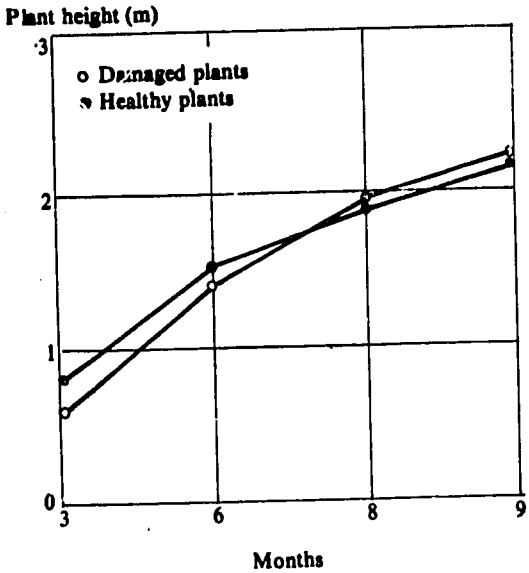

Figure 1. Recovery of cassava plants severely damaged by the cassava fruit fly (*Anastrepha* sp.) and bacterial stem rot (*Erwinia* sp.).

Experiments conducted to measure root yield loss due to plant damage resulted in no significant yield differences between treated and nontreated plots. However, because of the difficulty in controlling the very mobile adult, there were no great differences in plant damage between the treated and nontreated plots.

Damage to planting material

Extensive investigation is being carried out to determine germination and yield losses resulting from the use of *Anastrepha*-damaged planting material. Experiments were conducted on three farms, as well as at CIAT.

Cuttings were separated into five damage grades: 0 = no damage, 1 = a brown discoloration in the pith areas, 2 = discoloration and some rotting of pith at both ends of cuttings, 3 = severe rotting of pith, 4 = severe rotting of pith and tunneling throughout pith area.

Results in farmers' fields showed a decrease in cutting germination ranging from 5% for grade 1 to 16% for grade 4. Damaged cuttings showed an average of 9% reduction in germination compared to nondamaged cuttings (Table 1).

The effect of damaged cuttings on root yield was also measured. Damaged cuttings resulted in a 17.4% yield reduction when compared to undamaged cuttings. Yield losses ranged from 4.2% for grade 1 to 33.1% for grade 3. It is interesting to note that in every trial, damage grade 4 yielded higher than grade 3. Given the yields obtained in these experiments, a 17.4% yield decrease results in a loss of nearly 7 tons of cassava per hectare.

Control

Chemical control

Control methods using insecticide applications for the larval and adult stage of the fruit fly were studied. For larval control, carbofuran was applied at three different rates in the soil around each plant; and fenthion in solution was applied to the foliage at three different rates. Larval mortality for each systemic insecticide was recorded at 3, 8 and 16 days after application.

Results showed that fenthion gave 100 percent larval control at all three rates, 8 days after

Table 1. **The effect of damage caused by the fruit fly *Anastrepha manihoti* and the bacterial pathogen *Erwinia carotovora* on germination of cassava cuttings and plant yield.**

Damage grade	% germination	Yield (kg/ha) Farm no. 1	2	3	$\bar{X}$	% yield reduction	Yield CIAT (kg/ha)	% yield reduction
0	90.3	38,944	41,000	40,722	40,222	—	23,964	—
1	85.7	32,922	38.083	44,528	38,511	4.2	21,868	5.0
2	83.7	26,333	39,194	38,333	34,638	13.9	22,108	12,9
3	82.7	19,966	26,528	34,194	26,896	33.1	26.237	26.1
4	74.0	29,288	31,639	37,694	32,873	18.3	——	——

Table 2. The effect of carbofuran and fenthion on the control of cassava fruit fly larvae (*Anastrepha* sp.) in stems of cassava (var. M Mex 23).

Treatment	Rate	Application	% mortality of larvae at 3 days	8 days	16 days
Carbofuran	10 g/plant	Soil	9.7	45.0	69.0
Carbofuran	20 g/plant	Soil	23.0	64.0	50.0
Carbofuran	30 g/plant	Soil	24.0	53.0	20.0
Fenthion	1.5 cc/liter H_2O	Foliage	76.0	100.0	95.0
Fenthion	2.0 cc/liter H_2O	Foliage	97,0	100.0	91.0
Fenthion	2.5 cc/liter H_2O	Foliage	77.0	100.0	100.0
Control			22.0	24.0	40.0

application, and was still 90 to 100 percent effective after 16 days (Table 2). Control by carbofuran reached only 69 percent at 16 days. On the other hand, larval mortality in the untreated plants reached 40 percent, supporting the observation that the rotting stem is not a favorable medium for larval development. It should be noted that although larvae were controlled in the stem, the insecticidal sprays did not prevent infestation or rotting of stem tissue.

Attractants

Adult fruit flies are highly mobile and difficult to control. However, trapping of adult fruit flies with the appropriate bait or attractant could result in an effective means of control. This method could also be used to measure adult fruit fly populations in order to determine when control measures should be employed. Field experiments were designed to determine which baits or attractants would trap fruit flies or increase the effectiveness of insecticide application. The insecticide EPN was used because of its quick knockdown effect, which was necessary to get an accurate mortality count. Three bait combinations were studied: yeast, molasses and yeast plus molasses. Yeast alone was the most effective bait, causing more than double the adult mortality of the insecticide used alone (Table 3). The addition of molasses had no effect on

Table 3. Evaluation of yeast and molasses as baits mixed with the insecticide EPN for control of cassava fruit fly (*Anastrepha* sp.) adults in field trials.

Treatment (rate)	Adult mortality/ replication 1	2	3	4	Av adult mortality
EPN (12 cc/12 liters H_2O)	25	42	43	3	28.3a*
EPN (12 cc/12 liters H_2O) + yeast (0.5 kg)	71	103	41	17	580b
EPN (12 cc/12 liters H_2O) + molasses (0.5 liters)	49	49	18	14	32.5a
EPN (12 cc/12 liters H_2O) + yeast (0.5 kg) + molasses (0.5 liters)	34	79	24	3	35.0a

*Averages followed by different letters are significantly different at 0.05.

Table 4. **Comparison of five attractants in capture efficiency of the adult cassava fruit fly *(Anastrepha manihoti)* using McPhail traps.**

Attractant	Rate	Av no. of *Anastrepha* captured/wk
Brewers yeast	40 g brewers yeast, 6 g sugar, 1 g borax 400 cc H O	23.1
Hydrolyzed protein	55 cc/1000 c H_2O	17.1
Hydrolyzed maize	20 cc/1000 cc H_2O	60.7
Hydrolyzed yeast	20 g/1000 cc H_2O	21.9
Hydrolyzed soybean	20 g/1000 H_2O	18.4

mortality; and when combined with yeast, mortality was greatly reduced.

Five attractants—brewers yeast and hydrolyzed protein, maize and soybeans—were compared for effectiveness in fruit fly capture using the McPhail trap. Hydrolyzed maize gave nearly three times greater capture than any of the other attractants. (Table 4). Hydrolyzed maize was then compared with 100 synthetic fruit fly attractants obtained from the USDA. Results showed that hydrolyzed maize was nearly twice as effective as the most successful synthetic attractants. (Table 5).

Conclusions

Plant damage caused by the cassava fruit fly/bacterium association is most severe in areas of high humidity and well-dispersed rainfall. Nevertheless, these same conditions enable the cassava plant to recover from insect damage. If a leafy cassava variety is being grown in the area, there will probably be no economic loss caused by fruit fly damage.

Table 5. **Comparison of efficiency of 100 synthetic attractants, water and hydrolyzed maize in capturing adult cassava fruit flies *(Anastrepha manihoti)* using McPhail traps.**

Attractant	Av no. captured
Hydrolyzed maize	47.9
Water	1.42
p-Methyldithiocarbonilic acid Ammonium salt	32.00
Ethyl chrysanthemumate	28.00
Ammonium sulfate	24.66
Phenethyl anthranilate	15.5
Melonal (stench)	14.33

Chemical control to prevent plant damage is costly and impractical. The adults are highly mobile; and although baits increase insecticidal effectiveness, they are difficult to control. Larval control is also effective, but this does not necessarily prevent the bacterial pathogen from entering the stem and causing it to rot. The data presented on insect control in this paper are presented as scientific information, but their mention does not imply endorsement of these practices.

The greatest economic losses in cassava due to *Anastrepha* damage are in planting material. Both germination and yield losses can be considerable when infected planting material is used. The selection of healthy planting material is therefore highly recommended and should be included in any farm management program. We have observed in some areas of heavy fruit fly infestation that it is difficult to obtain sufficient completely healthy planting material. In this case it is recommended that slightly damaged (grades 1 and 2) cuttings be selected, and heavily damaged ones (grades 3 and 4) be discarded. All cuttings should then be treated with a fungicide before planting.

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Biology and economic importance of a cassava shoot fly, *Neosilba perezi* Romero and Ruppel

Van H. Waddill*

Abstract

The biological cycle of the shoot fly *Neosilba perezi*, a pest of cassava in Florida, was studied under laboratory conditions. The length of time in each immature stadium increased with decreasing temp. At 25.6°C total development time from egg to adult was 41 days; at 15.6° eggs took twice as long to hatch (6 days) and larvae failed to pupate. Seasonal population studies revealed a substantial rise in percentage of larval infestation from mid-July to early Aug., followed by a decrease. The percentage of larva-infested terminals peaked from late Oct. to early Nov. Simulated shoot fly damage had significant effects on plant height and no. of terminals/plant, but not on no. of leaves, roots, marketable yield or total yield. Insecticides should, therefore, be applied only when all the terminals on a plant are damaged more than once a month.

Introduction

Since the Cuban influx into southern Florida during the early 1960s, many crops not previously grown in the United States have been introduced, one of which is cassava *(Manihot esculenta* Crantz). The acreage planted to cassava is still small—about 200 ha in 1976.

Cassava is planted in the spring months (March-May) and is ready for harvest in 8 to 10 months. It is planted in rows approximately 1.2 m apart, and 0.75m is left betweeen plants. All cassava is currently grown on a limestone soil (Rockdale) and fertilized at a rate of 150 kg/ha of 8-16-16 or 12-6-12, applied at first cultivation. The four most commonly grown varieties are Señorita, Señorita Injertada, Señora Ponga la Mesa and Seda, yielding about 14 t/ha. Roots are marketed in 23-kg boxes for prices averaging from $5-7/box; thus the gross value of the crop could be as much as $4200/ha. The major markets are Miami, Jacksonville, Tampa, New York, Chicago and Los Angeles.

The most serious disease of cassava in this area is bacterial blight caused by *Xanthomonas manihotis*. Brown leaf spot, caused by *Cercospora henningsii*, is also present but is not considered of economic importance. Insect pests include the southern armyworm *Spodoptera eridania*, the

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banded cucumber beetle *Diabrotica balteata*, the hornworm *Erinnyis ello* and a shoot fly *Neosilba perezi*.

Of these pests, *N. perezi* is of concern to cassava growers who sometimes apply insecticides to control this shoot fly, which was first reported in this area in 1973. It was described initially as *Silba perezi* Romero and Ruppel (6) but is now considered in the genus *Neosilba*, based on the work of McAlpine (4).

Damage caused to cassava by other Lonchaeidae larvae has been described by Cardin (2) and Bellotti and Schoonhoven (1). The newly hatched larvae puncture and tunnel through the growing terminal, eventually killing it. According to Bellotti and Schoonhoven (1), economic loss due to *Silba pendula* Bezzi has not yet been shown although stunting of the plants has been observed.

Laboratory and field experiments were conducted at the Agricultural Research and Education Center at Homestead, Florida to study the biology of *N. perezi*, seasonal fluctuations in population and effect on cassava yield. This work was done primarily by John Boza as his MSc thesis project.

Biology

Material and methods

Rearing

The duration of each immature stage of *N. perezi* and adult longevity at 3 constant temperatures was determined in environmental chambers. The chambers were kept at 15.6 ± 1, 21.1 ± 1, 25.6 ± 1°C, and a light/darkness (LD) regime of 12:12. Moisture was provided by water pans placed at the bottom of each chamber.

Duration of the egg stage. *N. perezi* eggs were collected from infested terminals in cassava fields. To ensure that all eggs were less than 24 hours old, they were collected from terminals that had been found to be free of eggs the previous day. This was done simply by marking egg-free terminals with colored plastic ribbons. Cassava terminals with eggs were cut from the plant and returned to the laboratory where the eggs were removed with a small camel hair brush.

Duration of the egg stage of *N. perezi* was determined by placing the eggs in a 60 x 15 mm plastic petri dish containing a moist cotton ball and kept in an environmental chamber at the appropriate temperature. Eggs were inspected daily until eclosion.

Duration of the larval stage. Duration of the larval stage of *N. perezi* was determined by placing a single newly emerged larva on the terminal of a potted cassava plant. A variation of the Forno, Asher and Edwards (3) method of mist propagation of cassava tip cuttings was used to produce uniform batches of rooted tip cuttings suitable for larval maturation. Cassava tip cuttings ranging from 7 to 14 cm long were collected and placed in pots containing potting soil. These pots were placed in a mist bed in the laboratory until the cassava tip cuttings had rooted. The larvae were obtained from field-collected eggs that were held in an environmental chamber at 25.6 ± 1°C until eclosion.

Artificially infested plants were placed in an environmental chamber at the appropriate temperature and inspected daily for larval emergence holes. When inspection revealed an emergence hole, the plant was pulled from the pot and the pupae floated out of the soil by putting the soil in water. This was to ensure that the larvae had pupated.

Duration of the pupal stage. *N. perezi* pupae were obtained from larva-infested terminals collected in the field. Infested terminals were placed upright in a tray containing moist sand kept in an environmental chamber at 25.6 ± 1°C with a LD regime of 12:12. The sand was sifted daily to recover newly formed pupae.

Duration of the pupal stage was determined by placing pupae less than 24 hours old in a 60 x 15 mm plastic petri dish containing a moist cotton ball. The petri dish was kept in an environmental chamber at the appropriate temperature and the pupae inspected daily for adult emergence.

Adult longevity. Adult longevity of *N. perezi* was studied by placing newly emerged (less than 24 hours old) adults in 60 x 15 mm plastic petri dishes kept in an environmental chamber at the appropriate temperature. Moisture and nourish-

ment were provided by a cotton ball moistened with a 10% solution of sugar water. Adults were inspected daily until death occurred.

Mating tests

Pairs and groups of newly emerged adults were randomly selected and placed in 60 x 15 mm petri dishes or cages containing potted cassava plants. The cylindrical cages (15 cm high and 8.5 cm in diameter) were placed over potted plants. The petri dishes and cages were then placed in the appropriate environmental chamber and the plant terminals inspected daily for eggs.

Seasonal population

The seasonal populations of *N. perezi* eggs and larvae were studied on two different cassava farms from April 22 to November 17, 1976. Each of these plantations was divided into five sections, which were further subdivided into quadrants. Weekly examinations were conducted by noting the presence or absence of larvae and/or eggs in 20 terminals randomly selected from one of the quadrants in each section. One hundred terminals per planting were inspected each week. Quadrants were alternated so that each quadrant was counted only once every 4 weeks.

Mean number of eggs and larvae per terminal

Ramdom samples of terminals found to have eggs and/or larvae were removed from the plant and returned to the laboratory so that the number of eggs and/or larvae could be determined by use of a stereoscopic microscope.

Results and discussion

Rearing

The duration of the immature stages at 3 constant temperatures is presented in Table 1. The length of time required to go from one stage to the next increased with decreasing temperature. At 25.6°C, total development time from egg to adult was 41 days. At the coolest temperature (15.6°C), eggs took twice as long to hatch (6 days) and larvae failed to pupate. Development of the immature stages of *N. perezi* appears similar to *Silba pendula* (5), another cassava-infesting Lonchaeidae. According to Peña (5), it takes *S. Pendula* 49.7 days to develop from egg to adult, at an average temperature of 27°C compared to 41 days at 25.6°C for *N. perezi* to complete the same development. However, there is a difference in the time of day of adult emergence: *N. perezi* adults emerge in the morning between 7 and 9 whereas *S pendula* emerge between 4 and 5 in the afternoon.

As regards longevity, adult males and females did not respond the same as the immatures to different temperatures. Both sexes lived longer at the extreme temperatures than the intermediate one (Table 2). Females lived somewhat longer than the males. *N. perezi* adults live from 3 to 5 times longer than the average 4 to 5 days *S. pendula* adults live (5).

Mating tests

No adults were observed mating, nor were any eggs found in either the petri dishes or the cages. Neither Cardin (2) nor Peña (5) reported successful laboratory rearing of similar cassava-infesting lonchaeids. Much work remains to be done on this aspect.

Seasonal populations

The first sighting of a larva-infested terminal in one of the study fields was on May 12. The data from the study fields showed considerable agreement. Each field showed a substantial rise in percent of larval infestation from mid-July to early

Table 1 **Duration (days ± SD) of the immature stages of *N. perezi* held at constant temperatures.**

	Eggs		Larvae		Pupae	
Temp (°C)	No.	Duration	No.	Duration	No.	Duration
15.6	16	5.9 ± 0.9	-	-	34	33.4 ± 7.5
21.1	49	3.6 ± 0.9	4	26.3 ± 1.0	67	19.2 ± 1.5
25.6	48	3.0 ± 0.5	9	24.8 ± 3.3	195	13.0 ± 0.9

Table 2. Longevity (days ± SD) of adult *N. perezi* held at constant temperatures.

Temp (°C)	Male No.	Male Longevity	Female No.	Female Longevity
15.6	14	17.1 ± 15.0	38	25.0 ± 10.7
21.1	29	10.1 ± 5.8	32	13.5 ± 8.9
25.6	26	16.4 ± 7.0	26	17.4 ± 6.3

August, followed by a decrease (Fig. 1). The percentage of larva-infested terminals in both fields peaked from late October to early November. Cardin (2) reported a similar peak in the population of *Lonchaea chalybea* during late October and early November.

Effect on cassava yield

Materials and methods

The effects of *N. perezi* damage to cassava were simulated by damaging plants in field plots at several times during the growing season (at 1, 2, 3, 4, 5, 6 or 7 months after plant emergence). There was also a treatment that was damaged each of the 7 months and one undamaged one (control).

Originally cassava stem cuttings were planted approximately 18 cm deep in rows with 2 centers, with a total of 10 plants in each plot, but a few were lost because of wind or disease. The experimental design was a randomized complete block utilizing 4 blocks with 9 treatments. Weekly applications of dimethoate (272 g/ha) and the synthetic pyrethroid

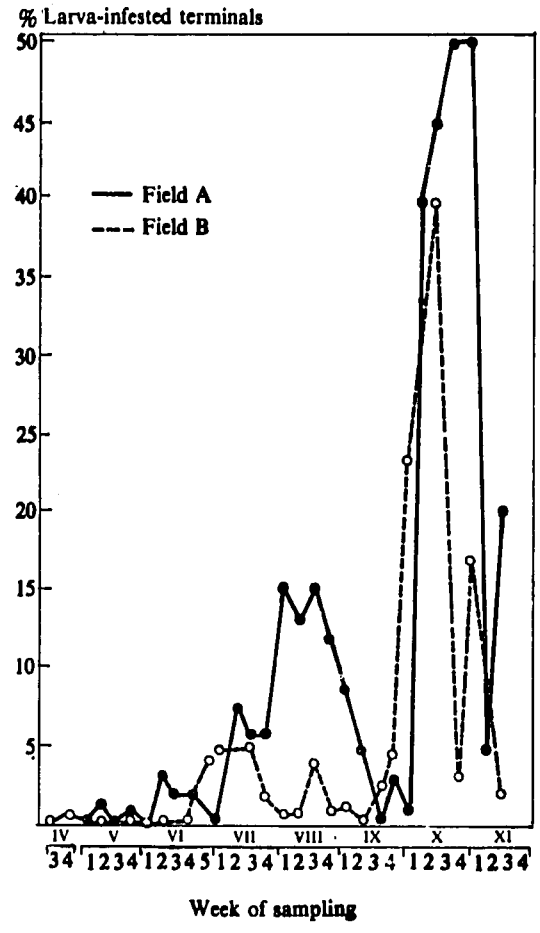

Figure 1. Percentage of *N. perezi* larva-infested terminals in two cassava fields surveyed from April 22 to November 17, 1976.

Table 3 Effects of simulated *N. perezi* damage on cassava growth and yield measured 8 months after planting.

Terminals clipped (mo after planting)	Yield/plant (kg) Total	Yield/plant (kg) Marketable	No. of roots	No. of terminals	No. of leaves	Height (cm)
1	2.22a*	1.89a	5.33a	12.00a	90.05a	214.9bc
2	1.96a	1.62a	4.43a	6.15c	83.58a	209.8c
3	1.97a	1.61a	4.54a	6.72bc	62.58a	227.8abc
4	2.21a	1.78a	4.95a	4.92cd	84.33a	219.5abc
5	2.04a	1.69a	4.60a	6.22c	74.83a	211.4c
6	2.11a	1.83a	5.19a	3.57c	58.42a	227.0abc
7	2.23a	1.89a	5.60a	6.62bc	67.24a	239.9ab
All 7 months	1.91a	1.52a	4.09a	8.44b	83.17a	158d
Control (0)	2.31a	1.90a	5.47a	5.94c	51.08a	240.5ab

* Means not followed by a common letter are significantly different (Duncan's Multiple Range test; $P < 0.05$).

Table 4. **The relationships between total yield (kg/plant), marketable yield (kg/plant), or number of marketable roots per plant and numbers of leaves (L), terminals (T) and plant height (H in cm), as described by multiple regression (first order model).**

Response	Equation*	R^2
Total yield	$-0.4881 + 0.004220L_y + 0.00938H_5 + 0.002289L_6$	0.693
Marketable yield	$-0.7901 + 0.005222L_3 + 0.014291H_y + 0.002152L_6 + 0.004842H_7$	0.685
Marketable roots	$3.505 + 1.0510T_2 + 0.02841L_2 + 0.1936T_7 + 0.03330H_7$	0.708

* Subscript on the T, L and H indicates the month after planting when the measurement was taken.

SD-41706 (54 g/ha) kept the plots relatively insect free. Copper manganate and terramycin were used weekly to control bacterial blight *(Xanthomonas manihotis)*.

N. perezi larval damage was simulated by clipping off approximately 3 to 4 cm from all the growing terminals on a plant. The number of terminals and plant height were determined monthly on all the plants in each plot; the number of leaves was counted on only 3 plants per plot. At the termination of the experiment, total yield, marketable yield and the number of roots were measured Differences in treatment responses were determined by use of Duncan's multiple range test.

The stepwise procedure was used to calculate multiple regression equations for a first order model. Total yield, marketable yield or marketable roots was used as the dependent variable and the number of terminals, leaves and plant height (cm) for each month were used as the independent variables. To determine whether an independent variable should be included in the equation, a significance level of 10% was used.

Results and discussion

Simulated fly damage had significant effects on plant height and the number of terminals per plant, but not on the number of leaves, roots, marketable yield or total yield (Table 3). Undamaged plants averaged 240.5 cm in height, compared to an average of 158.8 cm for those damaged once a month.

In general, damaged plants had more terminals than the undamaged controls since once the terminal is damaged, several new shoots grow from below the damaged area.

Interestingly, there were no significant yield differences. This was probably because damaged plants had approximately the same number of leaves as undamaged controls even though they were significantly shorter.

Although there were no significant differences in total yield, marketable yield or the number of marketable roots, regression may still be used to estimate these parameters. The linear regression equations produced by the stepwise procedure are presented in Table 4. The fit of these equations as measured by R^2 was fairly good. Each equation explains approximately 70 percent of the observed variation. Whether the equations make biological sense can be validated only by applying the equation to further field data.

The lack of significant yield losses due to simulated *N. perezi* damage indicates that insecticides certainly should not be applied unless all the terminals on a plant are damaged more than once a month.

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Cassava production and vegetative growth related to control duration of shoot flies and fruit flies

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Abstract

Silba sp. and *Anastrepha manihotis* were controlled on cassava for differing time periods up to 24 wk, beginning one mo after planting. Control increased branching height but did not significantly affect total height. Production was inversely correlated to control. Spraying the entire plant or the apical bud and upper stem provided equally effective control. Moderate *Silba* sp. attack stimulated branching and apparently increased total leaf area for photosynthesis and consequently increased production.

Cassava *(Manihot esculenta)* is commonly produced by subsistence farmers in Central America and is a major energy food source throughout the region. Although cassava is attacked by a variety of insect and mite pests, they are not usually considered limiting factors to crop production, especially by small farmers. As in other areas of the world, cassava has been grown as a low risk or survival insurance crop more than as a commercial crop; consequently, information on loss evaluation and economic importance is limited.

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Two pests groups that attack cassava in Central America are the shoot flies (Lonchaeidae) and fruit flies (Tephritidae). Several species of Lonchaeidae attack and kill cassava buds, causing abnormal ramification. Taxonomically, the adults are not well known, and more effort must be expended before the species (arbitrarily referred to as *Silba* sp.) considered in this paper can be definitely named. In fact, there may be a complex of species involved as we have received different identifications of adults reared in the laboratory from larvae extracted from cassava buds grown at Turrialba, Costa Rica. Information on *Silba pendula*, a lonchaeid similar to the one discussed herein, has been summarized recently by Bellotti and Schoonhoven (1). Eggs are oviposited primarily in terminal buds. Larvae bore into the shoot tissue, emerge after about 20 days and pupate in the

soil. Adults emerge about 26 days later. *Anastrepha manihoti* Costa Lima bores in fruits and stems and may be implicated in bacterial stem rot sometimes associated with shoot fly attack.

This paper presents information on the effect of controlling these two insects for different periods of time during plant development.

Material and methods

Cassava var. Valencia was planted during the last week of January 1976 in a randomized block design with 4 replications of 40 plants (4 rows x 10 plants), spaced fairly widely (1 x 1.5 m) since beans were intercropped from February through April. No fertilizer was applied and minimum maintenance was used to approximate small farmer practices. At weekly intervals, the cassava plants were sprayed with Diazinon EC (0.6 g a.i./liter) as a full coverage spray to wet for 8, 12, 16 and 24 consecutive weeks, beginning March 1, one month after planting. The same product was also applied at the same rate as a localized apical bud and upper shoot (10 to 20 cm) spray for 12, 16 and 24 weeks. No sprays were applied during the last six months of the crop cycle.

Total number of attacks by each pest on all plants per plot were recorded 7, 12 and 17 weeks after treatment initiation. Attack data was not recorded at later dates due to foliage density. Plant height was recorded 12, 17 and 27 weeks after treatment initiation and at harvest. The two center rows in each plot (20 plants) were harvested 12 months after planting and the following data recorded: (total production minus roots too small for fresh market), primary branching height and total height.

Results and discussion

Both pests were effectively controlled throughout the duration of each treatment. Figures 1, 2, 3 and 4 give the cumulative number of attacks per lot (40 plants) for the designated number of weeks after treatment initiation. Infestation was moderate but uniform, most plants having only one shoot fly attack (usually on the apical shoot) at

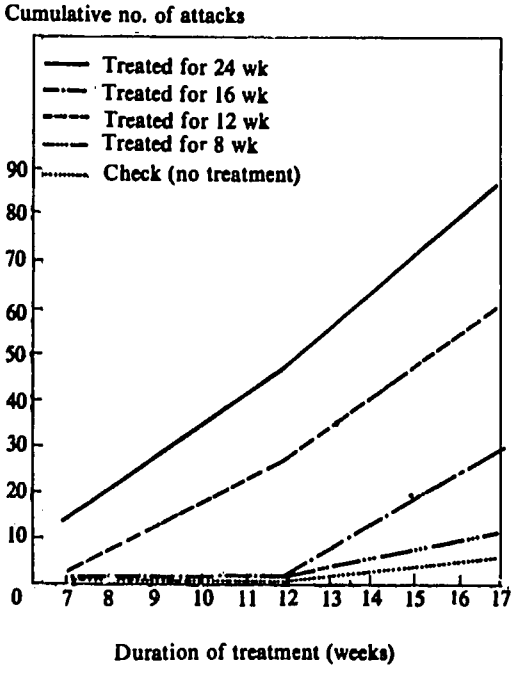

Figure 1. Number of *Silba* sp. attacks on cassava receiving complete foliar spray with Diazinon. Mean number of attacks per plot, 4 replications of 40 plants/plot. Weeks indicate points in time after treatment initiation when data were taken.

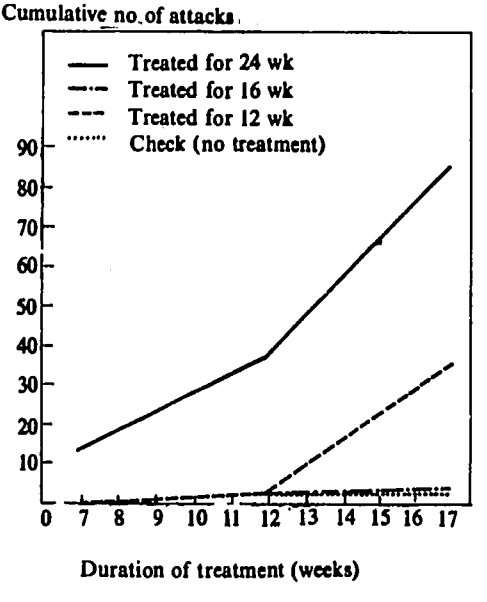

Figure 2. Number of *Silba* sp. attacks on cassava receiving localized bud and upper shoot spray with Diazinon. Mean number of attacks per plot, 4 replications of 40 plants/plot. Weeks indicate points in time after treatment initiation when data were taken.

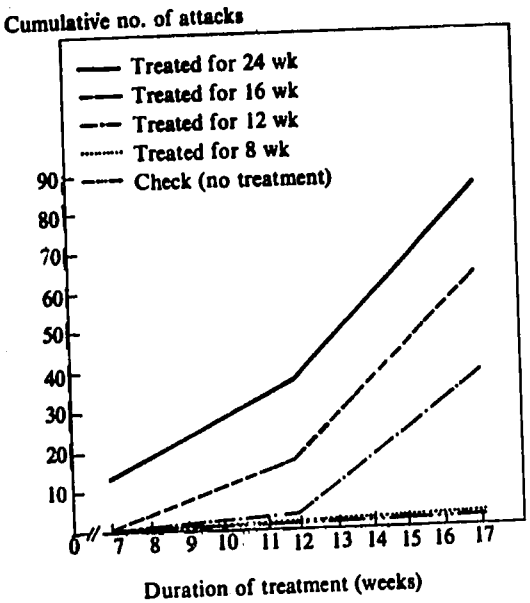

Figure 3. Number of *A. manihoti* attacks on cassava receiving complete foliar spray with Diazinon. Mean number of attacks per plot, 4 replications of 40 plants/plot. Weeks indicate points in time after treatment initiation when data were taken.

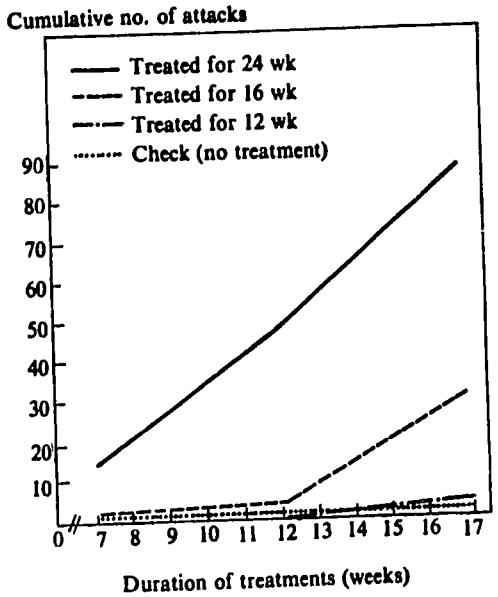

Figure 4. Number of *A. manihoti* attacks on cassava receiving localized bud and upper shoot spray with Diazinon. Mean number of attacks per plot, 4 replications of 40 plants/plot. Weeks indicate points in time after treatment when data were taken.

any period in time. Shoot fly attack was relatively consistent throughout the duration of the study and following cessation of toxicant application, increased proportionately to the check as apparent in treatments 3, 4 and 7. This would not be apparent in treatments 2 and 6 until sometime after the 16th week or until 24 weeks for treatments 1 and 5.

The analysis of variance gave highly significant differences between treatments 17 weeks after initiation of toxicant application. Treatments 1, 2, 5 and 6 as a group were not significantly different. Treatment 4 and the check were not significantly different but did differ from the other groups. Attack in treatment 3 was intermediate and different from the other groups.

It could be predicted that treatment 1 would be different from 2, and 5 different from 6 at a later time because 2 and 6 were sprayed for 16 weeks and 1 and 5 sprayed for 24 weeks and data recording was terminated prior to the time that this difference would be expressed.

A. manihoti attack followed a similar pattern, but the number of simultaneous attacks per plant tended to increase with time. Spraying only the apical bud and upper stem controlled both pests as effectively as spraying the entire plant. Under conditions of severe attack where control may be necessary, it may be more appropriate to spray only apical buds, thereby using less toxicant and reducing detrimental effects on benefical organisms.

Primary branching height was significantly correlated ($r = 0.78^*$) to the duration of control (Fig. 5) although total height at any time was not significantly affected. Total height in the check tended to be lower, probably because of earlier and more continuous attack throughout the growing period.

The correlation coefficient between total production and duration of insect control was highly significant ($r = -0.90^{**}$) and inversely related (Fig. 6). Commercial production showed the same relationship ($r = -0.92^{**}$).

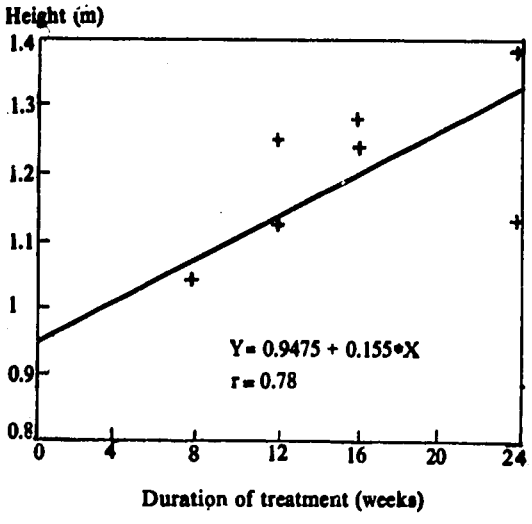

Figure 5. Primary branching height of cassava related to duration of treatment with Diazinon. Based on 4 replications of 40 plants/plot.

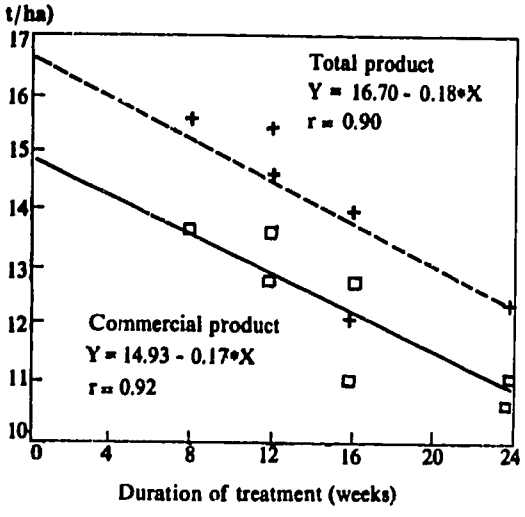

Figure 6. Cassava production related to duration of treatment with Diazinon. Based on 4 replications of 40 plants/plot.

The variety Valencia used in this study is typically columnar and late branching, with 3 or 4 main branches. At Turrialba average branching height of plants protected from attack by the shoot fly for 24 weeks was 137 cm. A moderate shoot fly attack stimulated earlier branching and apparently created more foliar area for photosynthesis, resulting in increased production. This may conflict with results obtained at CIAT (2-3) but can, perhaps, be explained on the basis of attack incidence. If the attack had been more severe at Turrialba, branches formed by the stimulation of attack would in turn have been attacked, causing brooming and stunting of the plants. This did not occur during the present study. The effect of shoot fly attack observed was comparable with the cultural practice of topping or pruning cassava to stop apical dominance and induce branching when the plants are 0.75 to 1 m high. This practice is common among small farmers in some areas of Central America.

Cock (4) has stated that leafy varieties can lose foliage continuously when they have "excess" foliage (based on the leaf area index for the ideal cassava plant) without any significant yield loss whereas nonleafy varieties cannot. He showed that removing leaves of improved varieties reduced yield whereas in leafy varieties it increased yield substantially. He concluded that a lower leaf area index increased production and that excess foliage is related to heavy branching.

In Costa Rica, insect attack increased branching, foliage and production. This apparent contradiction can perhaps be explained on the basis of leaf distribution relative to time. Branching stimulated by insect attack increased total foliage distributed over a wider crown area at an earlier age, thus providing more leaf area for photosynthesis during the earlier growth period.

Acknowledgments

Thanks are expressed to P.A. Blau for assistance in conducting this study and to Dr. P. Oñoro for statistical guidance and suggestions.

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Grasshoppers (*Zonocerus* spp.) on cassava in Africa

George A. Schaefers*

Abstract

A general review is presented on the life cycle, host range, economic losses on cassava, control of *Zonocerus variegatus* and *Z. elegans*, as well as factors affecting their incidence in Africa. The insects cause defoliation and feed on young shoots. It seems that HCN content of leaves may be related to grasshopper incidence, but further research is required. No information is available concerning yield losses when the attack occurs at the later stages of plant growth. Apparently there are no biological control agents for *Zonocerus variegatus*, except some rodents and birds; studies on pathogens are recommended. Chemical control is recommended for the early nymphal stages. Further investigation on varietal resistance is advised.

Cassava *(Manihot esculenta* Crantz) and locusts have been intimately associated in Africa since the crop was introduced in the 16th century. Fact an legend reveal that cassava was valued as a locust-resistant (nonhost) crop by the early inhabitants of Central Zaire and Zambia (14). Because of its resistance, as well as other attributes, the British encouraged, and in some instances mandated, the production of cassava in Nigeria and British East Africa. Similar programs were promoted by the French in West Africa. Following World War I, the Belgians tackled the problem of drought- and locust-induced famines in the Rwanda-Burundi area by ordering each adult male to grow five acres of nonseasonal foodstuffs including cassava. It is thus evident that locust resistance played a major role in the establishment and spread of cassava in Africa.

In the foregoing instances, it is apparent that the locusts involved were the African migratory locust, *Locusta migratoria migratorioides* R. and F. and/or the desert locust *Schistocerca gregaria* Forskal. Outbreak areas of the African migratory locust range from south of the Sahara to the Republic of South Africa, overlapping most of the cassava-growing areas of the continent. The desert locusts are found mostly north of the equator but still overlap much of the cassava-growing areas of Africa. The oligophagous *Locusta* feeds almost entirely on grasses and a few other monocots. Dicots are eaten only in the complete absence of other hosts and then usually only in small quantities. However, large numbers taking small bites can occasionally cause severe damage on hosts such as cassava (4, 18). A similar relationship pertains to the more polyphagous desert locust.

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Although preferring cereals, it has been reported to feed occasionally on cassava (18,23,25). Resistance to these locust species, although functional during times of outbreaks, is of much less concern since the development of international locust control programs.

Among the Acridoidea feeding on cassava in Africa, the variegated grasshoper, *Zonocerus variegatus* (L.) is without question the most important. This gregarious, somewhat migratory species also has a widespread distribution. Investigations on its biology have been conducted in Ghana, Camaroons, Ivory Coast, Nigeria, Sierra Leone and Gambia. It occurs from Senegal to south of the Gulf of Guinea in West Africa, ranging across Africa through southern Chad and Zaire to Kenya (7). The distribution of *Z. variegatus* largely parallels those regions most suited to the production of cassava, except for the extreme east and areas further than 5° south latitude. A closely related species and also a pest of cassava is the elegant grasshopper, also referred to as the stinking grasshopper, *Z. elegans* Thunb. This species occurs in the East, from the Republic of South Africa north to Kenya.

Biology and host plants

The active life span of the variegated grasshopper is about 9 to 10 months (2). Eggs remain in the soil from 4 to 6 months, and it takes 4 to 5 months for development from nymph to sexually mature adults. They undergo a single generation per year, but in some areas there exist two distinct populations which are out of phase. In Nigeria, the major dry season population emerges during October and November, while the lesser rainy season population emerges from late February to April. The literature indicates a wide variability in the time of hatching throughout its range. Undoubtedly this is due to variations in temperature, rainfall and possibly river effects.

Zonocerus spp. are also polyphagous, but in contrast to the acridids mentioned previously, they do not feed on grasses. This is a general characteristic of the pergomorphids (6). Furthermore, they have adapted well to the introduced cassava. Bernays et al. (3) studied the survival of the early instars of this species on 102 different host species. Only 11 of these permitted survival of better than 50 percent to the third instar. Of these hosts, all were herbaceous except *Citrus* and *Manihot*. They tested 30 host species for survival of the late instars; of these, 6 provided survival to adult, all of which were herbaceous except for *Manihot*. After a series of feeding preference tests, Kaufmann (15) concluded that cassava was perhaps the most preferred food plant for this species. It has been noted by several authors, however, that while all instars survive with optimum development when fed on cassava in the laboratory, only the later instars feed on cassava in the field (5). Host species of economic importance other than cassava include cocoa, cowpeas, yams, cotton, maize, bananas, citrus, coffee, tobacco and sorghum.

Damage and economic losses

Feeding damage is for the most part restricted to defoliation. This may be followed by feeding on the young tender bark and seed coats. Bernays et al. (3) concluded that cassava is badly damaged only late in the dry season when the herbaceous hosts dry up. However, the devastating effect of *Zonocerus* on this host in Kumasi, Ghana during October before the start of the extreme dry season, has been reported (15). Terry et al. (20) observed the nearly complete failure of certain varieties planted at the end of the rainy season in Nigeria. Damage was noticeably more severe on immature plants while mature plants were better able to withstand the defoliation and had a successful regrowth. Except in extremely high rainfall areas, cassava is usually planted at the beginning of the rains. However, cuttings are generally planted whenever the parent plants are harvested and in some areas they are planted during the dry season because of their drought tolerance. Further study is needed on yield effects of grasshopper feeding on cassava, particularly relative to time of planting and maturity of the plants. Qualitative effects may also result. It has been reported that natives in Ghana have found the roots of defoliated plants to be inedible due to excessive hardness (15). In addition to these direct effects of feeding on cassava, it has been found that the grashopper is capable of transmitting bacterial wilt (Terry, unpublished data). It does not appear, however, that this means of spread is of major importance.

Due to its polyphagous nature, this species can cause "enormous economic losses" (2) but is perhaps less important economically than other acridids (15). Extensive damage was experienced in Western State, Nigeria, where it is apparently increasing in abundance perhaps due to an increase in *Eupatorium*, a preferred alternate host (22). No studies have been conducted on the effects of feeding on yield, nor are there any estimates of loss available.

Control

Mechanical

When the wide range of economic plants and extensive damage caused by *Zonocerus* spp. are considered, surprisingly little information concerning their control has been published. As with many other pest species, early attempts involved various methods of mechanical removal. Hargreaves (9) was able to produce a noticeable effect on the population by digging up eggs from hopper breeding places. Most recommendations, however, involved collection of the adults prior to oviposition. This approach was modified by placing sticks among low-growing plants and collecting the nymphs as they ascended them to roost (8).

Chemical

Early use of chemicals involved the use of various inorganic insecticides as foliar sprays, ground sprays or as baits (26). Taking advantage of the gregarious nature of this grasshopper. Hargreaves (8) used *Aegeratum* as a trap plant and treated it with Paris green bait. Mallamaire (17) reported the apparently successful use of BHC against the bands of nymphs in 1948. In 1967 an official campaign for its control was initiated in Mozambique (1). In that instance, over 35,000 foci of spread were treated in the Inhambane District with a 6% BHC dust. The success of the program is not reported, but the practicality of such an approach throughout most of Africa is not encouraging even if modern organic insecticides were readily available and free of their environmental problems. However, the gregarious nature of this insect does facilitate focal treatment, particularly of the nymphs; and further investigation in this area seems warranted, at least in the more developed agricultural regions. Preliminary studies have been conducted by the Centre for Overseas Pest Research, London.

Biological

Zonocerus is particularly free from natural enemies (8). One small rodent, birds and chickens have been reported to feed on this grasshopper (26); however, Hargreaves (8) concluded that poultry would not eat it. Taylor (19) found 3 percent of the adults sampled to be infested with the dipterous parasite *Blaesoxipha filipjevi* Rohd. Although the parasite restricted ovarian development of the female host, he considered it to be of negligible importance because of its low incidence. Toye (21) also reared only small numbers of this species and an unidentified mermithid from adult hoppers. Dipterous parasites have also been reported from South Africa, and Hargreaves (10) found 30 percent of a grasshopper sample infested in Sierra Leone. Among the pathogens, *Coccobacillus acridiorum* d'Herelle, although fatal to hoppers in laboratory tests, was ineffective in field tests (16). Harris (11) in Tanzania and Hendrickx (13) in Zaire found adults killed with the fungus *Empusa grylli;* nevertheless, the latter author felt that there was little prospect of its being of value as a means of biological control. To date, it is apparent that no single agent is capable of suppressing *Zonocerus* populations adequately. Further study on the relationship with *Blaesoxipha* is indicated, however.

Resistance

Varietal resistance of cassava to this grasshopper species has not been investigated thoroughly. However, it has been observed for some time that the grasshoppers tend to select out individual plants in a field or apparently certain cultivars in a mixed planting. Whether this is due to the precise location of the plant relative to the direction of migration, true preference, or differences in plant height, as suggested by Kaufmann (15), is not clear. Terry et al. (20) studied population levels and feeding damage on three cassava cultivars in a replicated planting at IITA in Nigeria. These

included cultivars 60444 and 53101 and the variety Isunikankiyan. As previously discussed, the early instars fed on low-growing leguminous plants and only the later instars caused damage to the cassava. When the nymphs moved into the planting, they noticeably selected out 60444 and persisted on the replicates of this cultivar, even consuming the bark. The second cultivar defoliated was Isunikankiyan, leaving only 53101. Ultimately, nearly all plants were completely defoliated while in an identical planting, out of the line of march, virtually no damage was observed. When the adult grasshoppers finally left the planting, 60444 and Isunikankiyan were almost completely destroyed while over 60 percent of 53101, although bushy after regrowth, survived. The utility of the nonpreference observed for certain varieties remains to be tested in no-choice (i.e., single variety) plantings.

HCN content

Henderschott et al. (12) repeated the generalization that the absence of serious insect problems on cassava is thought to be associated with high HCN content. Continuing research on *Zonocerus* and other arthropod problems is more and more invalidating the "lack of seriousness thesis." The role of HCN in resistance becomes a matter of real concern, however. Although breeding for acyanogenic clones would be of value in terms of reduced hazard for mammalian consumers, it could lead to an increase in susceptibility to certain insects (Chapman, Centre of Pest Research, personal communication). Conversely, it would be obviously ill-advised to select for insect resistance if HCN content were the mechanism involved.

Jennings (Scottish Horticultural Research Institute, personal communication) conducted some preliminary investigations on the relationships of *Zonocerus* and HCN content in various clones at IITA. He offered adult hoppers paired varieties in caged choice tests. Rating was based on the number of days required for defoliation. The results of this particular experiment indicated some evidence for an association between low grasshopper preferences and high HCN content.

Bernays et al. (5) investigated the possible relationships between cyanogenic glucosides in cassava and *Zonocerus* resistance in greater detail. They concluded that it was unlikely that the glucosides themselves were distasteful to the grasshoppers. Their findings indicated that leaf damage, such as occurs during feeding, frees an enzyme that hydrolyzes the glucoside; release of HCN then results in feeding deterrence. They found that wilted leaves, which were preferred over turgid ones, lost the capacity to produce detectable quantities of HCN rapidly. Moreover, it was noted that senescent leaves, which were preferred over young leaves, produced little or no HCN. They further reported that feeding by fifth instar nymphs deprived of food for 48 hours was inversely correlated with total HCN content and hence with the rate of HCN production. When a direct jet of HCN was directed at the mouthparts of feeding insects, however, no deterrence resulted. They further suggested that perhaps HCN in solution with plant fluids and latex resulted in the production of hydrocyanic acid which was deterrent. Although the relationship remains somewhat obscure, these workers feel that HCN production is implicated in the unpalatability of cassava. They noted, however, that a number of secondary plant substances, other than cyanogenic glucosides may well be involved.

The question of whether HCN plays a role in resistance is an extremely critical one; and although evidence indicates a probable relationship, further study is indicated. For example, Umanah (24) reported that 53101, found to be the least preferred variety by Terry et al. (20), had a lower HCN content than did 60444, the most preferred variety. If the role of HCN is not verified, it would then be of interest to determine other factor(s) accounting for the resistance noted. If the role is verified, it then becomes of importance to determine whether some intermediate level of HCN might be adequate to provide the resistance desired. If acyanogenic varieties are highly desired and justified, then alternate resistance mechanisms should be sought. Finally, HCN content varies markedly with growing conditions (i.e., soil, moisture, temperature, potassium, nitrogen sources, etc.), as well as plant maturity. Any manipulation of these factors in crop management might ultimately influence the crops susceptibility to *Zonocerus* and other pests.

Cultural practices

Among the considerations for cultural control, it is well established that mature plants suffer much

less severe damage as a result of hopper attack than do young, undeveloped plants. As a means of reducing losses, therefore, it would appear advisable to continue the practice of planting the crop in such a manner as to assure that a fair percentage is in a mature or nearly mature stage of growth at the time of population peaks. No information is available concerning the effect of mixed plantings and the role of various weed species or mulches on hopper movement. Broad ecological studies are needed to understand the importance of these and other factors in the reduction of *Zonocerus* damage to cassava. It is not unreasonable to assume that this grasshopper has been under varying degrees of cultural control for several centuries of "back-door" cultivation. Of concern here is what we can expect when larger plantings of improved varieties, utilizing fertilizers, herbicides and pesticides become a traditional agronomic practice in Africa.

Recommendations for future research

Review of the literature, as well as personal experience, has revealed a fair amount of research and understanding of *Zonocerus* species in Africa. In spite of the ravages of this species, not only on cassava which is a staple crop for millions of people but also on many other agronomic crops as well, relatively little is known about it, particularly when compared to the amount of research devoted to the migratory African locusts. There is a great deal to be learned before adequate crop protection programs can be developed. A number of research activities may be suggested.

1. Assessment of crop losses. Although it is known that total destruction may result from attacks on young plantings, no reliable information is available concerning the effects on yield and quality when mature plantings are attacked. Such information is crucial in the estimation of crop losses by this insect.

2. Seasonal factors. More definitive information is required concerning the relationships between rainfall and other abiotic factors relative to population peaks.

3. Behavior. Investigations on the migratory behavior, aggregation, including possible pheromones such as "locustol," and selection of oviposition sites are inadequate.

4. Biological control. Findings on biological control agents for *Zonocerus* have, for the most part, been fortuitous. Basic studies are needed on pathology, as well as the overall effects of known and unknown parasites on population suppression. In this respect, particular emphasis might be placed on the sarcophagids.

5. Chemical control. In certain situations it may be practical to utilize pesticides to treat aggregations of early instar nymphs before damage occurs. Suitable insecticides should be investigated. In this regard, it may be possible to utilize aggregation pheromones to draw insects to trap plants or other devices.

6. Host plant resistance. The necessity of research on cassava resistance to *Zonocerus* is of highest priority because of the rapid advances currently being made with this crop The urgency of determining the mode of resistance, particularly the possible role of HCN, cannot be overemphasized A number of additional multidisciplinary research programs could be recommended, but those discussed would provide a basis for progress in the development of an at least intermediate cassava protection program.

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Biology, ecology and biological control of the cassava hornworm (*Erinnyis ello*)

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Abstract

The hornworm, one of the most important pests of cassava in the Americas, can defoliate plantations rapidly. More than 90 larvae/plant have been observed in Colombia. When populations reach this magnitude, they can consume up to 100% of the foliage; they also attack tender stem parts and lateral buds, killing young plants. Yield losses after a single attack can reach 20%; starch content can also be reduced. The 5 larval instars are described as well as the ecological factors that influence population fluctuations. Biological control is preferable to chemical control because pesticide application is costly and affects the equilibrium between parasites and pests. CIAT is conducting a biological control program to evaluate parasitism of eggs by *Trichogramma minutum* and *Telenomus dilophonotae*, parasitism of larvae by *Apanteles congregatus* and *A. americanus*, larval predation by *Polistes canadiensis* and *P. erythocephalus*, and a bacterial disease of larvae caused by *Bacillus thuringinesis*. Data related to these experiments are presented in tables.

The cassava hornworm *Erinnyis ello* is generally considered to be one of the most important pests of cassava in the Americas; its ability to defoliate cassava plantation rapidly has caused serious alarm among cassava growers. This pest is not found in Asia or Africa. The hornworm has been previously recorded as *Sphinx ello*, *Dilophonota ello* (2, 10) and *Anceryx ello* (1).*E. alope*, a less important species, has been reported from Brazil. Cassava and rubber are the principal hosts of *E. ello*, which appears to be confined mainly to the Euphorbiaceae (15).

Yield reductions in cassava of 10 to 50 percent have been estimated (13), depending upon plant age and intensity of attack; a decrease in starch content has also been suggested (9). Yield losses in farmers fields in Colombia have been measured at 20 percent after a single attack. Undoubtedly repeated attacks would cause greater yield reductions.

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Type of damage caused

The cassava hornworm is a voracious foliage consumer. Hornworm outbreaks with populations of more than 90 larvae per plant have been observed in Colombia (6). When populations reach this magnitude, 100 percent of the foliage is consumed and larvae will also feed on the tender parts of the stem, often consuming the upper 20 to 30 cm of stem tissue. Lateral buds may also be consumed and young plants may be killed. Damage simulation studies indicate that defoliation of young plants (2-5 months) reduces yields more than that of older plants (6-10 months). Laboratory and screenhouse studies at CIAT (3) show that a larva can consume 1 107 cm^2 of leaf area during its life cycle, 75 percent of which is consumed during the last (5th) instar. High larval mortality results when larvae are restricted to the basal leaves only, and no larva reaches the pupal stage. There is no indication that high or low cyanide content influences larval development greatly. (4). Some cassava varieties can tolerate high larval populations since under favorable environmental conditions there can be up to 80 percent defoliation with no reduction in root yield (4)

Biology and ecology

The generally gray nocturnal adult moth has five to six black bands across the abdomen, with gray forewings and reddish hind wings. The male forewing is a darker gray and brown with a black band from the base to the apex and is smaller than the female. Females live 5 to 7 days ;n the males ; new days less. Winder and Abreu (16) found that the nocturnal flight periodicity for both sexes was bimodal, for females from 2300 to 2400 hours and 0200 to 0300 hours and for males from 2400 to 0100 hours and from 0200 to 0300 hours. Oviposition occurs 2 to 3 days after emergence, usually on the leaf uppersurface but also on the petiole, stems and leaf undersurface (10). A female may deposit from 30 to 50 eggs which hatch in 3 to 7 days (6,8).

There are five larval instars with a total duration of 12 to 15 days (may be slightly longer in some areas). The first instar larvae consume the egg shell before moving to the leaf undersurface to begin feeding. Larvae prefer feeding on the upper leaves. All instars show color polymorphism, but it is more common during the third instar. Larval colors including green, greenish-blue, greenish-gray, tan, bluish-gray, brown red, black and yellow have been reported (15).

The fifth instar larvae may reach 10 to 12 cm in length; they migrate to the soil where they form chestnut brown, black-lined pupae under plant debris. Larvae may crawl considerable distances prior to pupation, which lasts 2 to 4 weeks. Pupal diapause of several months has been reported (14)

Population fluctuations of the hornworm are reported as occurring during different months of the year, depending upon locality. It is possible that these fluctuations are triggered by climatic or seasonal change, as well as being cyclic. In Colombia hornworm outbreaks generally occur at the onset of either rainy or dry periods, but attacks are sporadic and the insect can be virtually absent for several years. In Brazil they are found all year but are most abundant from January to March; several generations may occur.

Control

A biological control program that utilizes several of the natural enemies of the cassava hornworm appears to be the most effective method of controlling the pest economically. Several insecticides will reduce hornworm populations, trichlorphon (Dipterex) being especially effective. However, chemical control should be avoided as pesticide applications are costly for a long-season crop and also affect the equilibrium between parasites and pests (5, 10).

Many cassava growers do not notice a hornworm attack until considerable foliage has been consumed and most of the larvae are in the 4th and 5th instar. Pesticide application is not as effective against these instars as it is against the earlier ones. It has been observed that pesticide application will often induce 5th instar larvae into pupation. In addition insecticides also reduce natural enemies. Egg parasitism by *Trichogramma* sp. has been lessened in fields where insecticides have been applied (5). Hornworm outbreaks in certain cassava-growing areas of Colombia have increased in recent years. In these areas there has

been an increase in cassava acreage, as well as in the use of insecticides, especially to control thrips and fruit flies.

Biological control

A biological control program that combines parasitism of eggs and larvae, larval predation and the larval disease *Bacillus thuringiensis* is being studied at CIAT.

Egg parasitism

Natural hornworm egg parasitism by *Trichogramma minutum* (12), *T. fasciatum* (3) and *Telenomus dilophonotae* (10) has been reported to be as high as 94 to 99 percent (13). An average of 23 *Trichogramma* adults emerge per egg (4).

Two experiments were conducted at CIAT to evaluate the effectiveness of liberating *Trichogramma* in cassava fields to parasitize hornworm eggs. During a period of considerable hornworm oviposition, approximately 100,000 *Trichogramma* were released into a one-hectare field. A nearby field where there was no release of parasities was used as a control. Egg parasitism was measured prior to release and periodically afterwards. Results showed 22.1 percent more parasitism after four days in the field where *Trichogramma* had been released in the first experiment; in the second, there was a 23.2 percent increase during a similar period and a 32.6 percent increase after five days as compared to the field where *Trichogramma* had not been released. (Table 1).

Larval parasitism

Apanteles congregatus and *A. americanus* are important larval parasites in Colombia. These braconid wasps oviposit in the hornworm larvae where the parasite larvae develop. Mature larvae migrate from the host and pupate on the outer skin, forming a white cottonlike mass. These cocoons are approximately 3.8 cm wide by 4.1 cm long. Each cocoon will contain an average of 257 *Apanteles* pupae, about 80 percent of which will emerge (unpublished data).

In studies at CIAT we have twice released *Apanteles* adults into hornworm-infested fields to

Table 1. **Percentage of cassava hornworm eggs parasitized in fields where *Trichogramma* sp. had been released as compared to control (no *Trichogramma* released).**

Days after release*	% of eggs parasitized by liberated *Trichogramma***	Increase in parasitism %	% of eggs parasitized in control fields	Increase in parasitism (%)	Difference in parasitism between fields with liberated *Trichogramma* vs. control
Experiment no. 1					
0	48.3	-	52.6	-	-
4	73.1	24.8	55.3	2.7	22.1
7	67.9	19.6	67.3	14.7	4.9
10	91.0	42.7	95.7	43.1	0.4
Experiment no. 2* **					
-1	30.8	-	45.0	-	-
2	54.2	23.4	61.0	16.0	7.4
3	80.0	49.2	73.8	28.8	20.4
4	76.0	45.2	67.0	22.0	23.2
5	92.7	61.9	74.3	29.3	32.6

* *Trichogramma* released at a rate of 100,000/ha

** Sample of 50 plants/plot; av of 36.6 eggs/plant

*** Sample of 150 plants/plot

evaluate larval parasitism. Eleven cocoons were released in the first trial and 408 cocoons were collected after three weeks. At the same time 382 unparasitized larvae and 633 pupae were collected in the field, resulting in about a 35 percent parasitism of the larvae present. In the second trial 7 cocoons were released and 49 were collected 17 days later. No count was made of larvae or pupae.

A drawback in the use of *Apanteles* as a hornworm larval parasite is the high percentage of hyperparasitism observed. Seven hyperparasites have been collected from *Apanteles* pupae at CIAT. A study of 112 *Apanteles* cocoons collected on three separate occasions resulted in an average of 56 percent hyperparasitism (Table 2). An additional difficulty in the use of *Apanteles* for parasitizing hornworm larvae has been our inability to mass rear the parasite in the laboratory.

Larval predation

The paper wasps *Polistes canadiensis* L. and *P. erythocephalus* appear to be the most effective larval predators. Each wasp requires several larvae per day, for its own consumption as well as for its brood. Control is most effective when tentlike protective shelters are provided for the wasps in the center of cassava fields. A program using natural *Trichogramma* egg parasitism plus the *Polistes* wasp has been in operation at CIAT (50-60 ha cassava) since 1973, and there has been no major hornworm outbreak during this period. The *Polistes* wasp has been introduced onto several farms in a cassava-growing region of Colombia, and biweekly evaluations are being made of hornworm oviposition, egg parasitism, larval and wasp populations.

Larval disease

The adult hornworm moth is capable of lengthy flight, and large populations of adults may migrate into an area and oviposit numerous eggs, upsetting the equilibrium existing between biological control agents and the hornworm population. In addition, the somewhat cyclic occurrence of the hornworm often causes populations to increase rapidly and dramatically, also upsetting the equilibrium.

Bacillus thuringiensis, a commercially available bacterial disease of many lepidopterous larvae, was studied at CIAT for cassava hornworm control. In a cassava field with heavy hornworm attack, 50 plants/plot were sprayed with a suspension of *B. thuringiensis;* the larval population was measured before application and three days afterwards. Results showed that the larval population was reduced by 68 percent (Table 3). *B. thuringiensis* was more effective against the first three larval instars than the fourth and fifth

In a second experiment, one half of a 5-hectare field was sprayed with *B. thuringiensis* and 50 plants were sampled at random before application and at three and six days afterwards. The larval population in the treated field was reduced from more than six larvae per plant to one, whereas in the untreated field the larval population increased to more than 13 larvae per plant (Table 4).

A third experiment was designed to test the effectiveness of *B. thuringiensis* in controlling each hornworm instar under field conditions. Applications were made when there were high populations of the desired instar. Results indicated that *B. thuringiensis* is effective against the first four instars (the 5th was not tested) but most effective against the first (Fig. 1).

Table 2. Percentage of hyperparasites emerging from *Apanteles* sp. pupa parasitizing cassava hornworm larvae

Sample no.	Date of collection	No. of cocoons	*Apanteles* emerged	Hyper-parasites	% *Apanteles*	% Hyper-parasites
1	Aug. 1977	14	1034	1777	37	63
2	Sept. 1977	49	5543	2482	69	31
3	Oct. 1977	49	1190	5506	17.8	82.2
Totals		112	7767	9765	44	56

Table 3. **Number of cassava hornworm larvae before and three days after application of *Bacillus thuringiensis* on two-month-old cassava plants (var. Chiroza gallinaza).**

Developmental stage	No. larvae/instar* Before application	3 days after application
First Instar	1,520	114
Second Instar	4,449	982
Third Instar	3,375	1,207
Fourth Instar	1,192	850
Fifth Instar	320	298
Total	10,856	3,451

* Eight plots of 50 plants with center 15 plants of each plot sampled (total of 120 plants sampled)

Additional studies have shown that applications of *B. thuringiensis* will not affect *Trichogramma* egg parasitism adversely (6). Laboratory studies were conducted to measure the foliage consumed after leaves had been sprayed with *B. thuringiensis*, as compared to consumption of untreated leaves. Results showed that larvae can survive for 1 to 4 days after they begin to consume treated foliage; however, the leaf tissue that they are able to consume is reduced by 86% for the 3rd instar, 93% for the 4th instar and 98% for the 5th instar larvae (6).

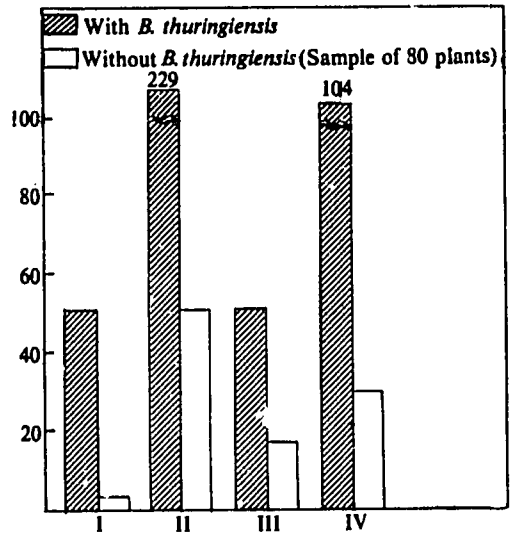

Figure 1. Effect of applications of *Bacillus thuringiensis* on hornworm population when in the 1st, 2nd, 3rd and 4th larval instars under field conditions.

Conclusions

A biological control program for the cassava hornworm appears to be a feasible control method. Several biological control agents were studied and found to be effective in reducing hornworm populations. These include the *Trichogramma* egg parasite, the *Apanteles* larvae parasite, the *Polistes* larval predator and *B. thuringiensis*, a larval disease.

Table 4. **Effects of *Bacillus thuringiensis* on a cassava hornworm population three and six days after application.**

	Days after application	No. of larvae* Instar I	II	III	IV	VI	Total larvae	Larvae/ plant
With *B. thuringiensis*	0	159	97	56	-	-	312	6.24
	3	84	80	39	1	-	204	4.08
	6	7	19	21	3	4	54	1.08
Without *B. thuringiensis*	0	311	160	63	-	-	534	10.68
	3	141	287	100	1	0	529	10.58
	6	127	254	227	51	20	679	13.58

* Based on a 50-plant random sample

There are several other natural enemies of the hornworm that could be employed effectively in a biological control program but that need to be studied in more detail. A viral disease of the hornworm has been identified, but no studies have been carried out. Larval predators that have also been identified are a pentatomid *Alceorrhynchus grandis* and a carabid *Calosoma retosum* (7, 9). Numerous other predators and parasites have been recorded as attacking *E. ello* (15). Larval parasitism by several tachinid flies is also reported (11, 16) and occasional tachinid parasitism has also been observed at CIAT. Studies with these parasites should be initiated.

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Miscellaneous pests of cassava

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Abstract

A description is given of several pests that may on occasion cause serious damage to cassava. Aspects dealt with include their biology and ecology, type of damage and control methods. Insects attacking planting material on young plants during the establishment phase include white grubs *(Phyllophaga* sp., *Leucopholis rosida)*, cutworms *(Prodenia litura, P. cridania, Agrotis ipsilon)* and termites *(Coptotermes* spp.). Pests attacking foliage include leaf-cutter ants *(Atta* spp., *Acromyrmex* spp.), gall midges *(Jatrophobia brasiliensis)* and lace bugs *(Vatiga manihotae)*. Among insects attacking stems and branches are the stemborers *(Coelosternus* spp., *Lagochirus* sp.).

The term "miscellaneous" for pests of cassava is perhaps misleading. In this paper it has been used to refer to pests that cause little or no economic damage to cassava, to those about which there is little scientific information; or to others that appear to be of secondary importance at present but that may become more important in the future as traditional cassava cultivation practices change.

High populations of general feeders (i.e., leaf-cutter ants, white grubs, cutworms and termites) can causs serious damage to cassava. During a recent armyworm attack in Malaysia, plants were defoliated and girdled, causing an estimated 25 percent yield reduction in a 3000-acre plantation.

Pests attacking foliage include gall midges and lace bugs; stemborers attack stems and branches. Other pests considered to be of minor importance and not discussed herein include leafhoppers, several leaf beetles, armyworms, certain species of mites and crickets. These pests were reviewed by Bellotti and Schoonhoven (2).

Insects attacking planting material or seedlings

Grubs, cutworms and termites attack planting material or damage plants during the important establishment phase (26). All can cause serious losses in germination.

Grubs

Grubs are pests in nearly all cassava-growing regions and are reported as a serious problem in

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Indonesia (22) Several species are mentioned in the literature (15, 34) but *Leucopholis rorida* (Indonesia) and *Phyllophaga* sp (Colombia) appear to be the most important. The adult stage of the grub is a beetle, usually of the family Scarabaeidae or Cerambycidae.

Damage

Grubs feed on the roots of young plants, causing considerable damage. Damage to planting material is characterized by the destruction of the bark and buds of recently planted cuttings and the presence of tunnels in the woody part. Affected cuttings may rot and die, and severely attacked fields have to be replanted. Larvae will also feed on the bark of the lower stem just below the soil, roots and swollen roots (1). When young plants (1-2 months old) are attacked, they suddenly wilt and die. In studies with *Phyllophaga* sp at CIAT, germination was reduced by 95% in experimental plots. Losses of 70% have been reported from Madagascar (17)

Biology and ecology

The biology of *L. rorida* has been described by Dulong (17). Adults become active after initiation of the rains and begin oviposition about 9 days after mating, laying up to 37 white eggs singly, 50-70 cm deep in the soil. Larvae hatch in about 3 weeks. The larval stage lasts about 10 months, with the 4- to 6-month-old larvae being the most destructive. Pupation takes place at a depth of about 50 cm, the prepupal stage is about 10 days and the pupal stage, 22 days.

Observations of *Phyllophaga* sp. in Colombia indicate a one-year cycle, with heaviest damage occurring at the onset of the rainy season. Attacks are often more severe if cassava is planted in lands previously used for pasture or in weedy abandoned fields. High populations can often be detected at the time of land preparation.

Control

Experiments at CIAT for control of grubs has centered around chemical soil applications and biological control. A muscardine fungus *Metarhizium anisopiae* is pathogenic to the grub, and experiments indicate that this may be an effective control method. Nevertheless, field experiments have not proven successful; the major drawback appears to be the method of application.

Successful control of the grubs was obtained with aldrin and carbofuran as a dust or in granular form, applied in the soil below the cutting. Germination with an application of aldrin was 80% and with carbofuran, 73% whereas only 4.4% germination of cuttings was obtained in the control.

Cutworms

Cutworms are a universal pest, attacking many crops. Attacks on cassava have been reported from the Americas (14,16) and Madagascar (18). The three species reported are *Prodenia litura, P. eridania* and *Agrotis ipsilon.*

Damage

Cutworm damage to cassava can be grouped into three categories: (a) Surface cutworms, such as *A. ipsilon* and *P. litura,* chew off plants just above, at, or a short distance below the soil surface, leaving the plant lying on the ground. (b) The climbing cutworms ascend the stem, feeding on buds and foliage. They may also girdle the stem, causing the upper part of the plant to wilt and die. Larvae of the southern armyworm *P. eridania* have been observed causing this type of damage to cassava. (c) The subterranean cutworms remain in the soil where they feed on the roots and underground parts of the stem, resulting in the loss of planting material. The bark and buds of recently planted cuttings may be completely stripped causing a loss in germination. We have observed *A. ipsilon* causing this type of damage at CIAT and nearby farms, where there have been losses as high as 50%, making it necessary to replant.

In experiments at CIAT, cutworm damage was simulated by removing shoots of recently planted cuttings. It was found that plants could recover from this type of damage so there was little or no yield loss. The most severe damage due to cutworms appears to be stem girdling, which can cause plant mortality and damage to cuttings, resulting in a loss in germination.

Control

Cutworm attacks are sporadic but often occur when cassava follows maize or sorghum or is planted adjacent to these crops. Longer cuttings (30 cm) will allow plants to recover from surface cutworm attack. Underground cutworms can be controlled with aldrin or carbofuran around the cuttings; it is, however, difficult to anticipate cutworm attacks and damage is not noted until cuttings fail to germinate. Aboveground attacks can be controlled effectively with poison baits (10 kg of bran or sawdust, 8-10 liters of water, 500 g of sugar or 1 liter of molasses, and 100 g of triclorfon for 0.25-0.5 ha).

Termites

Termites attack cassava mainly in the tropical lowlands, primarily in Africa. We have also observed them causing damage in the Americas and Asia. *Coptotermes voltkowi* and *C. paradoxis* have been identified from Madagascar (18) and *Odontofermes obesus* in India.

Damage

Termites will feed on propagating material, swollen roots or growing plants. Principal damage appears to be loss of propagating material. They attack cassava stems in storage, as well as cuttings after they have been planted, severely affecting plant establishment. Experiments on the North Coast of Colombia resulted in a 46% loss of stored cassava stems due to termite attack. Stems are stored during dry periods for planting at the initiation of the rainy season. Termite attacks will occur to stored material during the dry period and into the rainy season after planting. We have also observed swollen root damage and subsequent root rot caused by termite attack, primarily during dry periods.

Control

Treatment of stems with aldrin, chlordane or carbaryl prior to storage was effective in preventing termite attack.

Pests attacking foliage

Leaf-cutter ants

Several species of leaf-cutter ants (*Atta* spp. and *Acromyrmex* spp.) have been reported feeding on cassava in the Americas, especially in Brazil (9,11,29) and Guyana (4). There have been reports of *Atta* spp. attacking cassava in Africa; however, there is some doubt as to the presence of these ants there (Brown, personal communication).

Damage

Ant outbreaks frequently occur during the dry season in Colombia when normal food sources are limited since cassava is one of the few crops with considerable foliage. Plants can be totally defoliated when large numbers of worker ants move into a crop. A semicircular cut is made in the leaf, and during severe attacks the buds may also be removed. These parts are carried off to the underground nest and chewed into a paste, on which the fungus *Rhozites gongylophora* is grown (3-4). The ant nest is often readily visible by the piles of sand around the entrance hole. Attacks frequently occur during the early months of the crop, but yield losses are not known.

Control

Chlorinated hydrocarbons around the nest (11) or granular Mirex baits applied along the ant trails give effective control (33). Varietal differences to ant attack have also been mentioned (29).

Gall midges

Several species of gall midges (Cecidomyiidae) have been reported on cassava in the Americas (21, 32); *Jatrophobia brasiliensis* appears to be the most widespread (5-7).

Damage

Although gall midges are one of the most frequent pests found in cassava plantations, they are considered of little economic importance and control is usually not required. Reports from Peru and Mexico indicate that 6- to 7-month-old plants were totally deformed, measuring only 20-30 cm high as a result of gall midge attack. A severe attack causes yellowing of leaves, retarding plant growth; roots may become thin and fibrous.

Biology and ecology

Leaf galls on the upper surface are yellowish green to red, narrower at the base and often curved.

Galls are easily noticeable as they contrast against the green leaf surface. Eggs are laid individually by the fragile adults, 4 to 5 per leaf on the leaf undersurface. The emerging larvae cause abnormal cell growth and a gall is formed during the first larval instar. The second and third instars are also passed there. The larval duration is from 15 to 21 days and there is only one larva per gall. (21). Pupation, which occurs in the gall, is from 10-15 days. Prior to pupation, the larva enlarges the exit hole, through which the adult emerges.

Control

Varietal resistance to gall midges has been reported (36). Several larval parasites have been observed (6,30). The collection and destruction of affected leaves at regular intervals has been recommended to reduce pest populations.

Lace bugs

Lace bugs *(Vatiga manihotae)* damage is reported from Brazil (35), Colombia (9) and several other countries in the Americas (37). There are no reports of lace bugs from Africa nor Asia.

Damage

Yield losses due to lace bugs are not known but high populations can cause considerable damage to foliage. Leaves develop yellow spots that eventually turn reddish brown, resembling mite damage. Populations and damage have been increasing on the CIAT farm in recent years. There has been defoliation of lower leaves, but seldom has the whole plant been affected. Lace bugs are often observed as part of an insect complex involving mites, thrips and other pests attacking the plant. Alternate hosts have not been identified.

Biology and ecology

Lace bugs occur in high populations during the dry season and may attack the plant during any part of its growth cycle; however, populations at CIAT were highest during the first three months of plant growth (14). The gray adults, about 3 mm long, are generally found on the undersurface of the upper leaves. The whitish nymphs are smaller and prefer feeding on the central part of the plant (12). Laboratory studies at CIAT show five nymphal instars of 2.9, 2.6, 2.9, 3.3 and 4.8 days, respectively (totaling 16.5 days). Females deposit an average of 61 eggs; the egg stage is about 8 days. Adult longevity averages about 50 days.

Control

No control methods have been developed. but a germplasm screening program for varietal resistance has been initiated. It is suspected that this pest may become more important economically as new, efficent, high-yielding varieties are grown.

Stemborers

Numerous insect species have been reported feeding on and damaging stems and branches of cassava plants (2). They are mainly found in the Americas, especially Brazil (28) but have also been reported from Africa (23) and Asia (34). The most important stemborers belong to the orders Coleoptera and Lepidoptera. They appear to be highly host specific and few are reported to feed on alternate hosts. Approximately 17 species have been identified as successfully feeding on cassava; others reported attacking cassava appear to be only occasional feeders. Two species, *Megasoma elephas* and *Syllepta gordialis* have been observed feeding on swollen roots in Venezuela (20; Bellotti, personal observation). Seven species of *Coelosternus* are reported attacking cassava in the Americas (8-11, 19, 25, 27) and *Coelosternus manihoti* is reported as a pest in Africa (8). Only *Lagochirus* sp. is reported from Indonesia (34), and several lepidopteran and coleopteran stemborers are reported from Africa (24). Dissemination of stemborers was probably through infested planting material.

Damage

Larvae of the *Coelosternus* weevils and the *Lagochirus* long-horned beetles cause similar damage by penetrating the cassava stem and tunneling into the center or pith region. This weakens the plant, and stems and branches may eventually dry and break. Larvae of *C. sulcolutus* have been observed feeding on underground parts of the stem, but they have never been found attacking roots. Stemborers are suspected of reducing root production, but there is no sound data confirming this. We have observed stemborer-

infested planting material that had rotted and failed to germinate. Frass and exudate from stem wood, ejected from burrows by feeding larvae, can be found on infested branches or on the ground below the plants. Adults may feed on the tips of young shoots or stems, which may retard growth (28).

Biology and ecology

Female *Coelosternus* may oviposit on various parts of the cassava plant, but they prefer the tender parts (15) Oviposition is made by the proboscis near broken or cut ends of branches or beneath the bark in cavities. Adults of *Lagochirus* beetles also oviposit in stems and branches, and eggs hatch in 5 to 6 days. The full-grown larvae of *Coelosternus* vary in size, depending upon the species, but can range from 9 mm *(C. tarpides)* to 16 mm *(C. alterans)* in length. Most larvae are curved, with a yellowish white to pale brown body, a reddish brown head capsule and black mandibles. There may be one to several larvae in each stem depending upon the species. The larval period ranges from 30 to 60 days. The larval development period for *Lagochirus* is about 2 months and larvae measure up to 29 mm. They feed mainly at the base of the plant and many can be found in one plant. Pupation for both genera takes place in pupal chambers usually within the pith region of the stem and lasts about one month.

Adult *Coelosternus* range in length from 6 to 12 mm, depending upon species and are light to dark brown in color and may be almost completely covered with yellowish scales. Adult *Lagochirus* are rapid nocturnal fliers, brown in color, about 17 mm long, and feed on leaves and bark. Both genera are active throughout the year.

Control

Since adult stemborers are difficult to kill and larvae feed within the stems, pesticidal control is impractical. Resistance to *Coelosternus* spp. has been reported (31) Cultural practices that will reduce borer populations include removal and burning of infested plant parts (28) Only uninfested and undamaged cutting should be used for propagation.

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Summary conclusions and recommendations

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Integrated pest control

1. It is most important in the long term to maintain a holistic approach toward protection of cassava from the impacts of the total array of pests; i.e., insects, diseases, nematodes, weeds, rodents, etc. This approach is the core philosophy of integrated pest control.

2. Integrated pest control systems for cassava should place emphasis on combinations of the three fundamental tactics of (a) host plant resistance, (b) biological control and (c) cultural controls. The use of chemical pesticides and similar control measures should be resorted to only as a supplemental adjunct to the other three. It should be noted that this is not necessarily the case for weeds. The use of herbicides should be integrated with other control measures in the event they are required.

3. Pest interactions. It is important to observe the weed/insect/crop and weed/disease/crop interactions. Certain weeds may contribute to insect and disease problems, yet the possibility that beneficial interactions may also exist must not be overlooked. If such desirable relationships are observed, the methodology of maintaining noneconomic levels of the desired weed species should be worked out.

4. Integrated pest control systems for cassava can best be developed if they are guided by an intimate physiological knowledge of the cassava plant and its response to pests under varying environmental conditions.

5. Continual communication among all workers concerned with improved cassava production and protection is vital for applying the holistic approach. Integrated pest control systems will not result from the

separate development of several components that are later fitted together and offered to the cassava producers as a complete package. Integrated pest control systems will come from procedures that have a continual flow of communications in both directions— from the laboratory to experimental fields to the farmers, followed by effective feedback loops to guide and reorient ongoing research. Because of the critical role effective communication plays in this development, it is recommended that regularly scheduled workshops, similar to this one, be established on a triennial basis at different sites.

6. All concerned in the improvement of cassava production should be continually on the alert for any changes in pest status. These changes, usually danger signals resulting from changes in the agroecosystem, should be investigated immediately to determine their cause, as well as to find ways in which to rectify them. Previous experience in other crop agroecosystems suggests that these changes can come from many sources:

   a. Modification of fertilizer practices, moisture, other environmental factors, or other agronomic practices
   b. Changes in plant variety
   c. Introduction of a new pest
   d. Disruption of the natural enemy complex
   e. Rapid major expansion or change leading to monoculture over extended areas.

7. Any proposed protection system should be subjected to a careful cost/benefit analysis.

8. A mechanism for standardizing common names for diseases and pests should be established to avoid confusion.

Pest damage and yield loss

1. Pest damage to the cassava plant does not necessarily result in loss of yield or quality of the harvested crop because of the plant's tremendous capacity for recovering and compensating for damage.

2. Detailed studies should be made of the nature and quantitative aspects of damage caused by the various cassava pests, in addition to an economic analysis of their impact on final yield. These studies should reveal the seasons when the damage occurs, the significance of environmental conditions and the physiological state of the plant on the damage/yield relationship, the effect of agronomic practices on losses due to weeds, and the expected frequency of incidence. Where appropriate, injury thresholds should be established to guide protection programs.

3. A set of typical growth phases in the development of the cassava crop should be identified and the damage/yield impact of the more important pests fitted to these phases, thus making it feasible to gear the integrated pest control system to correspond to this series of phases. The period of stand establishment is clearly one of the most critical phases and should be considered high priority even though great progress has been made in developing integrated control procedures for this stage. There will probably have to be some adjustment for wet and dry seasons, leafy and nonleafy (vigorous and nonvigorous) varieties, and for mono- vs. mixed cropping systems.

4. Methods for analyzing and reporting damage/yield impact from pests should be standardized. Details should be given on the indices used for classifying damage, the conditions under which plants are tested and the procedures for evaluating pest impact on the plants.

5. A review should be made of all damage/yield impact information in order to rank pests into broad categories of significance to cassava production. This analysis should take into consideration the cassava plant's high tolerance and ability to recover, the distribution and abundance of pests, and the severity of the impact on yield

and quality. It may be appropriate to develop these analyses on a regional, national or climatic basis. Future research efforts should place emphasis on those pests that have the greatest potential impact on cassava production.

6. Postharvest problems must also be considered in an integrated approach. Fresh roots are damaged by physiological processes, microbes and insects; quality of the processed products is affected by storage insects and mold.

Breeding of new cultivars

1. Priorities in breeding must be established. Improved cultivars with increased yield and quality potential, coupled with characters for resistance to and/or ability to compete with pests will be a major component of integrated pest control systems.

2. New introductions of cultivars should be no more susceptible to pests than currently established varieties. New lines should be continuously exposed to the broad array of pests and potential pests over a wide range of conditions under various management practices.

3. Regional trials provide data for different climatic and edaphological conditions, making it possible to extrapolate results for another area with a good degree of accuracy.

4. A major question facing cassava improvement programs is the determination of breeding goals relative to the "ideal plant type." It is imperative that sound breeding objectives be established from the beginning because of the long time span between the initiation of cassava crosses and the delivery of improved varieties to farmers, plus the fact that there are only a few cassava breeding programs worldwide Determination of the leaf area index for an ideal plant type may have a negative impact on cassava pest control because by reducing excess foliage, the recuperative powers of the plant may be affected.

It was felt that an index should be used for evaluating pest damage under different cropping systems. It was reported that HI (harvest index=root wt/total plant wt) is the simplest way to relate to leafiness. This index must, however, be used carefully; for example, a very serious disease right before harvest might cause heavy defoliation, which would affect results. Work at CIAT by Irikura has shown that HI may be used to select varieties for different climatic conditions. For a climate that is slightly warmer than at CIAT, a variety with a slightly higher HI should be used than that at CIAT and vice versa. It is essential that realistic data be obtained on this question as soon as possible. Emphasis in breeding might best be placed on plant survival under stress conditions; i.e., pests, water, soil nutrients.

5. Total resistance to a pest is not necessary to make a new variety a useful tool in an integrated pest control system. When coupled with other control tactics, partial or incomplete resistance can be extremely valuable and often provides a completely satisfactory solution.

6. In the desire to make new high-yielding varieties available to wide areas or to test them in different regions, great care should be taken not to spread pests to new areas. The introduction of the green cassava mite *Mononychellus tanajoa* into Africa is a striking example of the need for strong quarantine restrictions and sanitary measures when transporting planting material from one area to another.

7. Efforts should be made to maintain or increase the inherent genetic variability of cassava varieties.

8. Information on the growing conditions under which new cultivars are tested should be standardized; e.g., soil fertility, altitude, meteorological conditions, cultural practices, etc.

9. The different breeding philosophies (i.e., development of homozygous lines,

breeding with wild species) should be reevaluated periodically to determine whether they are the most advisable.

Biological control (mainly with reference to insect and mite pests)

1. Cassava has a number of characteristics that make it especially suitable for biological pest control.

   a. It is a long-season crop, allowing time for insect an mite pests and natural enemies to establish an equilibrium.
   b. Few cassava pests will kill the plant outright, and since cassava has a great capacity for recovering, it has a high economic threshold for many pests; therefore, the level of biological control may not have to be very high.
   c. In general pesticides have not been widely used; thus existing natural biological control mechanisms have not been upset. Consequently, the natural regulating agents such as parasites, predators and pathogens offer a powerful tool in a pest management program. In the Americas, most of the pests are indigenous, and the natural enemies aid in the reduction of pest populations.

2. Research should seek to identify effective natural enemies and ascertain how they can be supplemented, augmented, or otherwise encouraged.

3. Intensive research leading to the introduction and rapid distribution of natural enemies of introduced pests should be initiated as soon as an exotic pest is discovered. Accurate identification of the pest is essential. Where these exotic pests have been identified (i.e., the green cassava mite *Mononychellus tanajoa* and the cassava mealybug *Phenacoccus* sp.), emphasis should be focused on identifying, studying, introducing and evaluating natural enemies in the target areas. The introduction of these pests points to the catastrophic consequence of ignoring established quarantine procedures for moving plant material from one area to another.

4. Indiscriminate use of chemical pesticides can disrupt the agro-ecosystems; an example of this is hornworm *(Erinnyis ello)* outbreaks following the application of pesticides to control thrips, a pest that can be rendered ineffective by the use of readily available resistant varieties.

5. Priorities for biological control must be established for different regions since key or major pests are not the same from one area to another.

Chemical control

1. Pesticides should be used only with extreme caution not only because of their potential for upsetting regulating mechanisms in the cassava agro-ecosystems, but also because of their relatively high cost and short-lived effectiveness when taking into consideration the long life and low unit value of the cassava crop. An exception to this is the preventive treatment of planting materials and their integrated use in weed control. Herbicides alone will not give adequate weed control in cassava.

2. As mentioned in no. 4 under Biological Control, application of pesticides for controlling thrips should be avoided, not only because this may induce an increase in hornworm attack but also because the agro-ecosystem is upset.

   As cassava production becomes of greater commercial value, great care should be taken to avoid intensive pesticide use, which has occurred on crops such as cotton and certain deciduous fruits.

Cassava protection in intercropping systems

For an integrated pest control program to be useful, it must take into account the planting practices that are prevalent in the different cassava-growing regions of the world. Small farmers in Africa and certain parts of Central America grow

cassava in association with other crops, whereas monoculture is the most common practice for both small and large operations in South America. That such practices affect disease and pest incidence, thus altering control methods and their effectiveness, is self-evident. At this workshop, for instance, it was reported that the incidence of cassava bacterial blight was 14 percent in intercropped areas of Nigeria, as compared with almost 100 percent in comparable areas under monoculture. These data probably represent extremes and may therefore not be representative of the average situation, but they may demonstrate why farmers practice intercropping in certain areas.

The reasons why intercropping may reduce pest incidence are not yet known. Possible factors involved are low populations of individual hosts per hectare, a change in microenvironment, and the influence of barrier crops. It is evident that there is a need to know precisely how pest control is affected under different crop combinations. The case of superelongation was cited where high populations are found not only when cassava is grown in monoculture but also when intercropped when highly susceptible varieties are used. Plant spacing and fertilizer regimes must also be studied. The methodology of an integrated control program will have to vary in accordance with pest populations which are intimately related to ecological conditions which, in turn, will vary under different intercropping systems. For these reasons, certain participants felt that it would not be feasible to develop a miracle cassava variety but rather varieties tailored to specific conditions, which would be the responsibility of national programs. As conditions at CIAT may not be realistic, aspects of cassava in intercropping should be investigated elsewhere, perhaps in Central America (i.e., CATIE in Costa Rica or ICTA in Guatemala).

Allelopathy

Studies should be initiated to ascertain whether cassava has chemical compounds that inhibit growth and development of weeds or microorganisms. If so, the influence of factors such as variety, plant part, plant age, weed species, etc. should be assessed, taking into account their possible significance in allelopathy.

Quarantine

There are three forms of cassava planting material: true seed, tissue culture and vegetative material (stem cuttings). Although seed can be treated for surface contaminants, CBB and other pathogens are seed transmitted. Little is known about tissue culture; and thus far, only apices have been obtained with success. This leaves vegetative material, which carries greater risks of disseminating pests. There is disagreement as to how strict quarantine measures should be in this regard because of the lack of proper facilities and expertise in some countries. Bans that are too strong would only have a highly negative effect. The case of Africa was cited, where only Nuguya (Kenya) can handle the introduction of planting material properly. On the other hand, it was felt that quarantine agencies in Latin America were fairly competent and that risks were not too high. When distributing material, great care should be exercised; cuttings should be selected from pest-free plantations only and treated with appropriate chemicals. Additional work on methods of obtaining, propagating, treating and shipping completely pest-free cassava germplasm is needed.

Recommendations

1. **Technical assistance.** This would be temporary, in the form of graduate students who would study specific problems, contracts with cooperating institutions, or temporary appointments. Areas where work is required include

   a. Nematology
   b. Taxonomy
   c. Nature and genetics of disease and pest resistance; the role and gene controlling HCN production in cassava. This work might be done outside the international institutes in some cases.

2. **Computer modeling.** Computer modeling can be an important tool for establishing, analyzing and determining the deficiencies of cassava pest management systems. Data used for computer modeling must have predictive value, which it will not have unless it has been submitted to statistical analysis.

3. **More intensive efforts to apply information from other crops.** Perhaps information available on other crops such as potatoes (i.e., storage of potato tubers) can be applied to cassava.

4. **Germplasm collection** to include species. A pool of resistant germplasm should be maintained and not allowed to disappear; this is a primary responsibility of a crop protection system.

It was mentioned that IDRC has a special project in collaboration with the University of Goiana in Brazil, where wild *Manihot* species are being collected. Seeds from this collection will be made available to other areas. In Mexico the National Agricultural Research Institute is also collecting the country's wild species. Although immediate application of resistance from related species is often difficult to visualize, such resistance may be invaluable in the future. Thus every effort should be made to collect and maintain collections of species related to cassava.

5. **Greater cooperation in research activities** among entomologists, pathologists, physiologists, breeders, etc., not only within institutions but between them.

6. **Epidemics as related to monoculture.** Several approaches to maintain genetic diversity in cassava, such as the multiline method, should be investigated. When only one genotype is used in a monoculture, the probabilities of an epidemic increase tremendously.

7 **Handling of breeding material and other propagating material.** There must be standardized methods for shipping material. It was strongly recommended that great care be exercised in selecting pest-free material and treating cuttings with appropriate chemicals.

8. **Statistical evaluation of data.** Where appropriate, research data should be analyzed statistically. Publishing research results in refereed journals is also recommended.

9. A technical committee was suggested to evaluate integrated control programs for cassava and to deal with specific problems as they arise. It is important that it also act in an advisory capacity at the different centers, working on outbreaks, etc.

It was generally felt that the interdisciplinary group had interacted well, coming up with some hitherto unforeseen ideas and problems and leaving some open questions. It is hoped that this workshop will make it possible to obtain the technical expertise required to solve the many problems cassava researchers face. Tropical researchers frequently feel discouraged because they are often isolated and out of contact with fellow workers in their own discipline, whereas developed country researchers can ussually interact with a far broader spectrum of expertise in a given discipline. This conference has been helpful in providing such interaction and thus building confidence that research objectives are sound and have the proper priority.