CHAPTER 12

Cassava Pest Management*

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Introduction

The management of cassava pests should be based on biological control, host-plant resistance, and use of cultural practices. These components of integrated control have played an important role in programs for managing cassava pests during the last 35 years. Thus, this management model should continue to be implemented to prevent environmental degradation and possible food contamination in the future.

One practical objective of entomologists is to maintain populations of insect pests at levels below economic importance. Stated like this, the objective is clear and easy to understand but, in practice, it becomes lost because its true sense is unknown.

When speaking of maintaining destructive insects at low levels of economic importance, it should be understood that the presence and damage caused by an insect pest does not always mean reduced production. Almost all crops can support a certain level of damage and still recover. Hence, the mere presence of a harmful insect does not necessarily mean that insecticides must be applied.

The cassava plant's ability to recover from pest damage is a significant quality that should always be taken into account before resorting to the application of control inputs, unless yield loss has been estimated.

Currently, accurate information exists on the pests that most reduce yields, the times and key stages of the crop when plants are more susceptible to pest attack, and the precautions or suitable management actions to be taken. Some pests are known not to affect production, even though symptoms appear severe enough to induce the application of what are, in fact, unnecessary control measures.

In controlling this crop's pests, costly inputs, especially pesticides, should be kept at a minimum. One way of achieving this objective is to increase basic knowledge on the biology and ecology of many of these pests and their natural enemies. Advantage must also be taken of the favorable factors involved in the insect–plant–environment interaction, so that developing a system for cassava pest management is both attractive and practical. Some of these factors are:

1. The cassava cropping cycle is 8 to 24 months long. Hence, continuous use of pesticides is costly and uneconomical with regard to profitability.

2. Because it is a long-cycle crop, cassava is ideal for biological control programs, especially in areas where it is continuously cultivated and over large extensions. Many biological control agents of many major pests have already been identified and studied in-depth.

3. The cassava plant often recovers from the damage caused by insects. During seasons with adequate rainfall, high levels of defoliation will cause little or no yield reduction.

4. Many pests do not disseminate widely and their incidence is often seasonal, with dry seasons

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favoring their population increase. However, the plant's ability to resist long dry periods usually enables it to recover when the rains start.

5. Cassava has a high threshold for economic damage by pests. Vigorous varieties may lose 40%, or even more, of their foliage without yield being significantly affected. Newly developed varieties may possess mechanisms other than defoliation, resulting in higher tolerance, because of the selection methods used for both vigor and resistance to biotic and abiotic factors.

6. Very few pests can actually kill the plant. Hence, the plant recovers from damage and can produce edible roots.

7. The selection of healthy and vigorous planting materials, together with treatment with low-cost fungicides and insecticides, permits fast and successful germination. The plant's initial vigor is thus ensured during this important early phase and yield is ultimately increased.

8. Cassava has been shown to possess adequate sources of resistance—at low, medium, and high levels—to prevent serious crop losses to certain pests.

9. Cassava is often cultivated on small farms, under mixed cropping conditions. This system not only reduces pest incidence, but also prevents outbreaks in large crop extensions.

10. Insects can reduce yields during specific periods of plant development. For many cassava pests, these periods have already been identified, permitting the intensification of control during these times.

Insect Pests

Insects have existed for more than 300 million years and have survived and evolved, despite all the drastic changes derived from the Earth's evolution.

Insects possess high reproductive capacity. A queen termite may oviposit 30,000 eggs daily. When dichlorodiphenyltrichloroethane (DDT)[4] appeared for agricultural use, its lethal effect on insects was of such a magnitude that many entomologists began collecting insect species to conserve them, as the belief was that the DDT would exterminate them. However, insects have survived much more difficult situations, and responded by developing resistance not only to DDT but also to most insecticides.

To date, 321 insect species resistant to several groups of insecticides have been recorded, meaning that the chemicals are no longer effective for reducing their populations. Hence, humans must seek other, more rational and economic alternatives that do not continue to increase insect resistance to insecticides or contaminate the environment at critical levels for humanity.

Many entomologists and scientists, past and current, have dedicated their lives to study beneficial insects and promote their use in pest control programs. These researchers are convinced that the use of insecticides only would augment biological imbalance, which would have catastrophic consequences for humanity. These studies are found in specialized books and bulletins that detail the methods and recommendations for programs of integrated pest management (IPM). Today, the situation has changed. It falls to entomologists, technical personnel, and people generally to practice these principles and use these experiences. Not only would production problems be solved, but environmental contamination would also be minimized.

The cassava crop may serve as a model for understanding some basic principles of integrated control, particularly biological control by means of beneficial insects.

Although pest outbreaks sometimes occur, the cassava crop does not permanently suffer severe attacks from insects. On the contrary, it maintains an excellent biological equilibrium. Mortality factors also function to maintain pest populations at levels of low economic importance.

This favorable situation should be conserved. The example of the cotton crop in Colombia illustrates this point: during 1977, pest control had arrived at a "situation of catastrophe". *Heliothis* larvae, the cotton crop's principal pest, had attained such a high degree of resistance to insecticides that its control was impossible. Yet, when the cotton crop was established in Colombia, more than 35 years ago, the pests that attacked it were few and their control was relatively esay.

4. For an explanation of this and other abbreviations and acronyms, see *Appendix 1: Acronyms, Abbreviations, and Technical Terminology*, this volume.

This situation is similar to that presented by the cassava crop 20 years ago. Thus, if cassava pests are not handled rationally and if insecticides continue to be indiscriminately applied, then, in the not very distant future, the same situation of despair affecting cotton growers will also develop for cassava growers.

Cassava pests have been studied in terms of their relationships with biotic and abiotic factors, crop management techniques, and production of varieties adapted to different ecosystems. Yet, increased awareness of the problem is still needed if the type of management that prevents epizootics happening on a regional or national scale is to be adopted.

One epizootic—an outbreak of the cassava stemborer (*Chilomima clarkei*)—occurred in the Atlantic Coast of Colombia in the 1990s. Quarantine standards had not been observed. That is, stakes were exchanged from one area to another, harvest residues were not destroyed, storage conditions for planting materials (stakes) were poor, stakes of poor quality and infested with the pest were used, and pesticides were inappropriately used. As a result, the pest became a social problem: the scarcity of asexual seed led many farmers—mostly resource-poor families who depended on cassava for sustenance—into precarious situations.

A similar situation has occurred with the cassava whitefly (*Aleurotrachelus socialis*) in northern Cauca, southern Valle del Cauca, Tolima, and some areas of the Atlantic Coast and Eastern Plains. This pest has become endemic. Its populations have increased dramatically, to the point of causing severe damage to the crop over prolonged periods and thus significantly affecting root production. In response, farmers indiscriminately applied insecticides, exacerbating the problem. The pest is now appearing at times and in areas where it had not previously been seen.

Currently, CIAT is searching for varietal resistance and biological control to manage these pests. Future results will respond positively to these problems (Bellotti et al. 1999).

Integrated Pest Management

Integrated management appears to be the most rational way of tackling insect pests. It consists of combining and integrating all available techniques and applying them harmoniously to maintain insect pests at levels where their economic damage to crops is not significant. Integrated management therefore consists of all available techniques, not only of biological control and insecticides. These, however, form two of its basic components.

Other techniques available are the use of plants that resist or tolerate insect attack, mechanical and physical methods that attract or repel, and compliance with quarantine standards. Although the available techniques are many, their successful application is more important. They must be understood and used correctly by technical personnel and farmers.

Biological control

Biological control may be defined as managing pests through the deliberate and systematic use of their natural enemies. Parasites, predators, and pathogens can help maintain population densities of pests at lower levels than would have occurred in their absence. This form of control has several advantages:

- It is relatively permanent
- It is economic
- It helps maintain environmental quality
- Food is less like to be contaminated by pesticides

The idea that an insect population may be reduced by other insects is ancient. For example, the use of predator ants to control certain citrus pests probably originated in China. This system is currently being followed in some areas of Asia. Insect parasitism was recorded for the first time by Vallisnieri (1661–1730) in Italy. He noted, in particular, the association between the parasitic wasp *Apanteles glomeratus* and the cabbage worm *Pieris rapae.*

Parasites for biological control in agricultural crops were first used in Europe, mostly in France, Germany, and Italy, during the 19th century. However, the science of biological control was developed in USA during the 19th and 20th centuries.

The project to control cottony cushion scale (*Icerya purchasi*) attacking citrus crops in California, USA, was the first successful example of biological control. The scale was accidentally introduced into Australia and, in 1888, entomologists brought in two of its natural enemies, one of which was the vedalia beetle (*Rodolia cardinalis*), a coccinellid predator. Scale populations declined rapidly. The technique for mass-rearing parasites and predators and releasing them periodically for pest control was developed in

California in 1919 during a project on the coccinellid *Cryptolaemus montrouzieri*, a predator of the mealybug.

Since then, more than 96 biological control projects have been evaluated and considered substantially successful. Another 66 or so, conducted in many parts of the world, have been evaluated as partially successful (DeBach 1964).

Describing pest management

Pest management can therefore be described as "a set of actions that results from understanding that, instead of eliminating insect pests, we should learn to live with them and to intelligently manage resources, not only economically but also ecologically".

Pest management is more inclusive than integrated control (defined on page 265, this chapter) because, in addition to the factors implicated by integrated control, several fundamental biological and ecological principles are also involved. Pest management recognizes that an insect can become a pest because of human activities such as taking pests to previously uninfested regions through the introduction of exotic plants and animals, producing varieties or races of organisms, simplifying ecosystems, or misusing pesticides. Such actions are usually a result of agricultural or industrial activities.

Controlling cassava pests

During the last 2 decades, collaborative studies of the cassava crop and the control of several of its major pests were carried out by institutions such as the Centro Internacional de Agricultura Tropical (CIAT), the International Institute of Tropical Agriculture (IITA), and the Brazilian Agricultural Research Corporation (EMBRAPA). They successfully used biological control, involving both insects and entomopathogens. Examples of achievements include:

- Mass release of the microhymenopterous parasitoid *Anagyrus lopezi* to control *Phenacoccus manihoti* in Africa.

- Controlling the cassava hornworm in Colombia, Brazil, and Venezuela by applying a baculovirus that attacks *Erinnyis ello*. This virus was found in hornworm colonies at CIAT in 1973. It was applied to commercial crops in Brazil in the 1980s and in Venezuela in the 1990s.

- Using predator mites of the Phytoseiidae family to control the cassava green mite (*Mononychellus* spp.) in Africa and Brazil.

Managing a Specific Pest: the Cassava Hornworm

Research conducted at CIAT on the hornworm *Erinnyis ello* may be used to develop an IPM program for this insect, using the different techniques offered.

The hornworm is attacked by several parasitic and predator insects, bacteria, fungi, and viruses. They can make control of *E. ello* feasible, without having to resort to insecticides that are likely to upset the balance that should exist between the hornworm and its natural enemies (Table 12-1). If insecticides are not applied, then, not only are entomophagous agents conserved, but the reduced number of applications will also help prevent the appearance of other pests, especially mites, that are more difficult to manage.

Natural enemies of *E. ello* eggs

Parasitism of *E. ello* eggs by *Trichogramma* spp. and *Telenomus* sp. helps reduce hornworm populations.

Trichogramma is a parasite of considerable importance, as it is present throughout the year in cassava fields and has a parasitism rate of more than 50%. Furthermore, it is easy to mass-rear in the laboratory. For release, 50 to 100 square inches per hectare should be used over 2 or 3 work days per week, as the parasitoids emerge. This amounts to releasing between 150,000 and 300,000 adults per hectare. During the growing period, 5 to 10 releases (established by previous evaluations) are carried out, costing about US$25/ha.

The moment at which *Trichogramma* adults are released must be determined by periodically evaluating cassava plots to detect the timing of the largest populations of *E. ello* eggs.

No pattern exists to serve as a basis for determining the number of *E. ello* eggs with the timing for release of *Trichogramma* spp. However, the experience of technical personnel and farmers indicates that if the parasite is released when the hornworm first appears, then the parasite can establish in time to control the *E. ello* populations that may suddenly appear.

Table 12-1. Parasites, predators, and pathogens of various stages of the life cycle of the cassava hornworm (*Erinnyis ello*).

Agent attacking	Habit	Order	Family
Eggs			
Trichogramma minutum	Parasite	Hymenoptera	Trichogrammatidae
T. fasciatum	Parasite	Hymenoptera	Trichogrammatidae
T. australicum	Parasite	Hymenoptera	Trichogrammatidae
T. semifumatum	Parasite	Hymenoptera	Trichogrammatidae
Telenomus dilophonotae	Parasite	Hymenoptera	Scelionidae
T. sphingis	Parasite	Hymenoptera	Scelionidae
Chrysopa sp.	Predator	Neuroptera	Chrysopidae
Dolichoderus sp.	Predator	Hymenoptera	Formicidae
Larvae			
Apanteles congregatus	Parasite	Hymenoptera	Branconidae
A. americanus	Parasite	Hymenoptera	Branconidae
Euplectrus sp.	Parasite	Hymenoptera	Eulophidae
Cryptophion sp.	Parasite	Hymenoptera	Ichneumonidae
Microgaster flaviventris	Parasite	Hymenoptera	Ichneumonidae
Sarcodexia innota	Parasite	Diptera	Sarcophagidae
Chetogena (*Euphorocera*) *scutellaris*	Parasite	Diptera	Tachinidae
Thysanomyia sp.	Parasite	Diptera	Tachinidae
Belvosia sp.	Parasite	Diptera	Tachinidae
Drino macarensis	Parasite	Diptera	Tachinidae
Polistes erythrocephalus	Predator	Hymenoptera	Vespidae
P. versicolor	Predator	Hymenoptera	Vespidae
P. carnifex	Predator	Hymenoptera	Vespidae
P. canadensis	Predator	Hymenoptera	Vespidae
Polybia sericea	Predator	Hymenoptera	Vespidae
Podisus sp.	Predator	Hemiptera	Pentatomidae
Zelus sp.	Predator	Hemiptera	Reduviidae
Alcaeorrhynchus grandis	Predator	Hemiptera	Pentatomidae
Bacillus thuringiensis	Pathogen	Eubacteriales	Bacillaceae
Baculovirus erinnyis	Pathogen	GV	Baculoviridae
Prepupae and pupae			
Calosoma sp.	Predator	Coleoptera	Carabidae
Pupae			
Cordyceps sp.	Pathogen	Sphaeriales	Hypocreaceae

Trichogramma spp. should be released when hornworm eggs are newly laid and are green or yellow. *E. ello* eggs should not be left to develop much before releasing the parasites, because once the larvae's cephalic capsule has started forming, the *Trichogramma* spp. will not parasitize them.

CIAT research demonstrates that *Trichogramma austrilicum* shows highly active parasitism on *E. ello* egg clutches (CIAT 1977).

Telenomus sphingis parasitizes the eggs of *E. ello* and *E. alope* and has a significant role in regulating their populations. The biological cycle of *T. sphingis,* from egg to adult, lasts 11 to 14 days. A female lays as many as 228 eggs, which give rise to an average of 99 adults.

Natural enemies of *E. ello* larvae

Five species of predators, several of parasitoids, and one pathogenic virus attack the larvae of this pest:

Predators. Two wasps and a bug are the most used:

- *Polistes erythrocephalus*, *P. canadensis*, and *P. carnifex*. The adults' capacity for predation depends on the number of their own larvae that they have in their nests. At CIAT, each *Polistes* larva was assessed as consuming 0.47 of an *E. ello* larva per day (CIAT 1977; Martín 1985).

- Cassava fields may be colonized with *Polistes* nests placed in stands or huts. To establish their colonies, adults prefer cool shaded places that are close to water. Hence, building bamboo and palm leaves are used to construct the stands. A hut every 4 ha and 20 nests per hut are recommended. The nests should contain more than 50 cells to ensure that the numbers of females and males are sufficient to favor the establishment of new colonies.

- *Podisus* spp. (Hemiptera: Pentatomidae). The most common species are *P. obscurus* (Dallas) and *P. nigrispinus.* Their importance lies in the ease of mass-rearing them and their capacity for predation. Throughout its life, a *P. obscurus* bug can consume between 339 and 1023, with an average of 720, first- and second-instar larvae. The biological cycle lasts from 65 to 119 days, averaging 97 days (Arias and Bellotti, 1989b).

Parasitoids. Several species have been used with good results:

- *Apanteles = Cotesia americanus* and *C. congregatus*. These braconids attack the larvae, ovipositing their eggs within the hornworms' bodies. The eggs hatch and the tiny larvae develop inside the host hornworms until they pupate in the host's epidermis, forming a white cottony mass or cocoon.

- The releases of *Apanteles* carried out at CIAT resulted in increased parasitism of hornworm larvae by more than 50% (CIAT 1977). On a field scale, the environment influences the effectiveness of the parasitoids. For example, in the Atlantic Coast of Colombia, in samplings carried out by CIAT, *Apanteles* spp. and *Telenomus sphingis* were found to be more effective than in the country's hinterland (Valle del Cauca and Quindío). In contrast, *Trichogramma* spp. are less effective in the Atlantic Coast than in the hinterland (Gallego, 1950; B Arias 1990, unpublished data).

The parasite can be mass-reared for use in biological control programs.

- *Drino* sp., *Belvosia* sp., and *Chetogena (Euphorocera) scutellaris* are dipterans (flies) that parasitize *E. ello* larvae. *Chetogena scutellaris* is particularly important, as it can be mass-reared in the laboratory and possesses a rapid biological cycle.

Other biocontrol agents

Hornworm larvae are also attacked by the granulosis virus *Baculovirus erinnyis* (EeGV) and by the bacterium *Bacillus thuringiensis*. The latter is available commercially (thus facilitating its use) under the trade names DiPel®, Thuricide, Bactospeine, and Biotrol.

Bacillus thuringiensis. Trials conducted at CIAT showed that this bacterium is effective against all larval stages (particularly the first and second instars). It is applied in doses of 3 to 4 g of commercial product per liter of water for soil applications, and of 800 to 1000 g/L for aerial applications. This product has the advantage of not affecting natural enemies of *E. ello* or other insects (Arias and Bellotti 1977).

Baculovirus erinnyis *(EeGV).* This virus is both highly specific and virulent for the pest. Egg parasites such as *Trichogramma* sp. are more abundant in areas where *B. erinnyis* is used. These two beneficial agents are the most efficient controllers of *E. ello* (Arias et al. 1989a; Torrecilla et al. 1992).

The baculovirus can be obtained from infected insects found in the field, or a base solution, maintained in the freezer, can be used. The latter is prepared from *E. ello*, that is, larvae that have died from the disease (Arias and Bellotti 1987; Torrecilla et al. 1992).

The baculovirus begins to act on hornworm larvae when these ingest contaminated leaves. After 4 days, the sick larvae start to lose their capacity for locomotion and feeding, their bodies becoming white and bleached. Death occurs from day 7 onwards when they hang, head downwards, from the leaves (Torrecilla et al. 1992).

Findings obtained from different studies conducted with *B. erinnyis* point out its advantages over most biological control agents. The latter tend to decline in numbers when they do not have their hosts in the field. The virus, however, can be stored for several years when no pest is present, to be used when the opportunity arises (Arias and Bellotti 1987; Torrecilla et al. 1992).

Usually, larvae attacked by the virus become slow, permanently regurgitate, and present residues of excrement adhering to the anal area. The black larvae take on a shiny tone and become extremely flaccid, finally hanging from their anal pseudopodia. Green and yellow larvae also develop brown spots in the folds of some segments or on the central parts of these, as if they had been burnt with a cigarette. Finally, the dead larvae dry up (Arias and Bellotti 1987; Torrecilla et al. 1992).

In the field, the larvae affected by this virus break apart, thus spreading the pathogen and triggering a disease that becomes endemic and able to wipe out the pest. After the larvae have died, they decompose through the joint activities of other microorganisms, especially bacteria, and give off repugnant odors. Hence, larvae collected for use to prepare base solutions or to process or purify the virus must be refrigerated (Torrecilla et al. 1992).

A base solution is prepared with macerated dead larvae. The solution is sprayed directly on the plants. To distribute the virus effectively throughout the crop, 20 to 70 cc in 200 liters of water is needed per hectare (Torrecilla et al. 1992).

To safely manage the virus, recommendations are to (Torrecilla et al. 1992):

- Keep *B. erinnyis* in the freezer either as dead larvae or in solution (liquefied mixture), using plastic bags or lidded glass bottles.
- Withdraw from the freezer only when it is needed and in the quantities required.
- In preparing the solution, avoid using live larvae, larvae that have died from other causes, or larvae that are already decomposing.
- Spray or pulverize only in the early hours of the morning.
- Avoid spraying when larvae are large.
- Visit the cassava plot periodically to detect the pest when it appears.

Recommendations for controlling cassava hornworm

During the first stages of their life cycle, larvae remain hidden under the lower sides of terminal leaves. Hence, when passing through the fields, these parts of the plants must be closely examined. When 5 to 7 first- or second-instar larvae per plant are found, the product should be applied. This level is flexible, depending on the abundance of natural enemies, climatic conditions, cassava variety, and plant age and vigor.

The number of plants to check per hectare depends on the area planted to the crop and on the availability of time. A minimum of five plants per hectare would be acceptable. For plantings of more than 15 ha, having as a trained worker, known in Spanish as a *plaguero*, to permanently check the fields is most advisable.

We emphasize that the success of integrated control depends on the timely application of the different techniques. Insecticides, for example, are valuable components of that control but should be resorted to only when strictly necessary.

Sometimes, beneficial insects are not sufficient to control the hornworm or its larvae when these have reached third instar or larger. In this case, applications of microbial insecticides would not have the expected effectiveness. In such a case, Dipterex 80 SP (trichlorfon) can be applied in doses of 3 g of commercial product per liter of water for soil applications, and 600 to 800 g/ha for aerial applications.

Ultraviolet light traps, particularly black-light lamps (BL type) and blue-black light lamps (type BLB) can be used to attract and capture adult hornworms (Bellotti et al. 1983). Although light traps do not constitute a control method, they allow researchers to discover the fluctuations in population sizes of *E. ello* adults and, hence, better plan the application of IPM.

Preliminary experiments led to the capture of as many as 3094 adults in one night, with the largest number of individuals being trapped between midnight and 2 a.m. This information is important because, in sites where energy is not available, the traps need only work between midnight and 2 a.m., using batteries or combustion motors (Bellotti et al. 1983).

In fields where the pest is only beginning to attack, manually collecting larvae and pupae is highly effective for reducing hornworm populations.

Options for Controlling Cassava Pests

Table 12-2 summarizes the control options currently available for managing the principal cassava pests. Insects normally appear as pests when the plant's levels of resistance either do not exist or are very low. However, for these pests, a large number of biological control agents may exist. The situation may also arise in which natural controllers are limited. Fortunately, highly acceptable levels of resistance have been found.

In most cases, the two control tools are available, with one being more efficient than the other. For successful control in this crop, the two should, ideally, be combined, together with adequate agronomic practices, thus minimizing pesticide use.

A successful program of IPM for cassava should harmonize with the environment. Pest management technologies should be available at low cost to farmers in developing countries (Bellotti 2000).

Table 12-2. Options to control principal cassava pests.

Pest	Control option	References
Hornworm	Biocontrol: Baculovirus as pesticide; monitoring adult populations with light traps and egg count in the field.	Arias and Bellotti 1987; Bellotti et al. 1992, 1999; Braun et al. 1993; Schmitt 1988
Mites	HPR[a]: Moderate levels of resistance available in cassava clones; an effective program for incorporating resistance into commercial cultivars is needed.	Bellotti and Riis 1994; Braun et al. 1989; Byrne et al. 1982, 1983; CIAT 1999;
	Biocontrol: A major complex of Phytoseiidae predators that can reduce mite populations is available; other entomopathogens (e.g., *Neozygites* and viruses) have been identified and evaluated.	Bellotti et al. 1999; Yaninek et al. 1991
Whitefly	Resistance: High levels have been found in some clones and hybrids. Biocontrol: Enemies, especially parasitoids, have been identified and are being evaluated; some entomopathogens give possibilities of control.	Arias 1995; Bellotti and Riis 1994; Bellotti et al. 1999; Castillo 1996; CIAT 1999
Mealybugs	*Resistance*: No adequate levels have been found in *M. esculenta* germplasm. Some wild *Manihot* species have potential for resistance. Biocontrol: three parasitoids (*Acerophagus coccois, Aenasius vexans,* and *Apoanagyrus diversicornis*) provide good control for *Phenacoccus herreni*.	Bellotti et al. 1999; Bento et al. 1999; Van Driesche et al. 1990
(*Phenacoccus manihoti*)	The parasitoid *Anagyrus lopezi* provides very good control in most cassava-growing areas of Africa and Brazil.	Herren and Neuenschwander 1991; Neuenschwander 1994
Thrips	HPR[a]: Pubescent cultivars have very good resistance and are available to farmers.	Bellotti and Kawano 1980; Bellotti and Schoonhoven 1978c
Subterranean burrower bug (*Cyrtomenus bergi*)	HCN contents in cassava: Cultivars with high contents in roots present less damage. Biocontrol: Natural enemies such as fungal and nematoid entomopathogens have given promising results. *Intercropping*: Intercropping cassava with *Crotalaria* reduces damage.	Barberena and Bellotti 1998; Bellotti and Riis 1994; Bellotti et al. 1999; Caicedo and Bellotti 1994; Riis 1997
Stemborers (*Chilomima clarkei*)	Farming practices: Keeping fields clean and destroying infested stems. Transgenesis: Possible use of transgenic plants (*Bt*) is being studied.	Bellotti and Schoonhoven 1978a, 1978b; Gold et al. 1990; Lohr 1983
Lace bug	HPR[a]: Research indicates some level of resistance present in landrace varieties. Biocontrol: Natural enemies have been identified, but research on their effectiveness is lacking.	Bellotti et al. 1999; Cavalcante and Ciociola 1993; CIAT 1990; Farías 1985

a. HPR = host-plant resistance.

SOURCE: Bellotti 2000.

Biotechnology

The biotechnology tools available usually offer a potential to develop improved varieties resistant to pests, thus increasing the effectiveness of natural controllers, including the parasitoids and other entomopathogens mentioned here. The new generation of genetic technologies for pest management is currently being integrated with traditional IPM. It offers alternative technologies for controlling stemborers, leafcutting ants, grasshoppers, white grubs, and other pests difficult to control. This research is already under way and may be available to farmers in the near future (Bellotti 2000).

Pesticides

Few pesticides are used in traditional cassava agroecosystems, because of their high cost and the crop's long cycle, which would make several applications necessary. Some farmers in the Neotropics respond to pest outbreaks with pesticides (Bellotti 2000). For cassava production in large plantings, the trend is to increasingly apply more pesticides to control outbreaks, as in certain areas of Colombia, Venezuela, and Brazil (Bellotti 2000).

The possibility is real that chemical pesticides can be replaced with bioplaguicides in cassava pest management. One example is the effectiveness of the baculovirus against the hornworm and its successful implementation, especially for large plantings (Bellotti 2000).

Entomopathogens are being found for mites, mealybug, whitefly, hornworm, white grubs, subterranean burrower bug, grasshoppers, and others. Research must also be conducted to develop bioplaguicides and other methodologies for their effective implementation. Such activity requires collaboration with the bioplaguicide industry, a process that has already started in Colombia with the production of *Baculovirus erinnyis* (Bellotti 2000).

Agronomic practices

Traditional farmers in most cassava-growing regions have depended on a set of cultural practices that enable them to effectively reduce pest populations (Lozano and Bellotti 1985). Intercropping is a common practice among small farmers. It reduces both the populations of whitefly, hornworm, and subterranean burrower bug, and the damage they cause (Bellotti 2000).

However, farmers may be reluctant to adopt these practices if the intercrop species are not commercially acceptable or if the cassava crop yield is considerably reduced. In large plantings, where mechanization is a production practice, intercropping may not be adoptable. Other cultural practices that may reduce pest populations are varietal mixtures, burning of harvest residues, crop rotation, planting time, and use of high-quality, pest-free, planting materials (Bellotti 2000).

Use of natural enemies

In Africa, classical biological control has been highly successful for managing introduced pests. The management of many cassava pests in the Neotropics requires greater commitment from farmers to effectively implement solutions (Bellotti et al. 1999). Numerous studies in cassava fields in several Neotropical regions have revealed that complexes abound of natural enemies of pests important to that crop. CIAT maintains a taxonomic reference collection, with a systematized database of cassava pests and their natural enemies. The information is available to growers, agricultural researchers, outreach programs, taxonomists, and museums (Bellotti 2000).

Results from explorations and research indicate that natural biological control frequently occurs in the Neotropics. This phenomenon was expected because the diversity of cropping systems and perenniality of the cassava crop would induce a balanced association among pests and their natural enemies (Bellotti 2000).

Disruption of this system (e.g., through pesticide use) may cause pest outbreaks. As described above, populations of the green cassava mite (*M. tanajoa*) in northern South America are regulated by a complex of phytoseiid predator mites. Once this complex is disturbed, yields drop (Bellotti 2000).

The virulence of natural enemies can be increased through genetic engineering, thus permitting use of this abundant complex (Bellotti 2000).

Host-plant resistance

The germplasm bank held at CIAT offers entomologists and breeders more than 6000 cassava varieties in which a group of genes for pest resistance may be found. As mentioned above, variable levels of resistance to mites, whitefly, thrips, subterranean burrower bug, lace bug, and stemborer have been identified (Bellotti 2000).

The innovative biotechnological tools that are available allow efficient and easy access to resistant genes and faster manipulation of molecular levels. Numerous materials from the germplasm bank are continually planted in the field and systematically evaluated for pest resistance (Bellotti 2000).

CIAT has various techniques for mass-rearing most of the principal cassava pests. Also available are damage descriptions and population scales for identifying susceptible and resistant germplasm. Field evaluations of germplasm for resistance need to be carried out, regardless of whether infestations are natural or artificial, because certain symptoms of damage caused by cassava pests are not truly expressed by plants maintained in the screenhouse or greenhouse (Bellotti 2000).

Varieties that possess multiple resistance (i.e., resistance to more than one pest) have been identified. For example, M Ecu 72 contains high levels of resistance to whitefly and thrips, and moderate resistance to mites. One challenge that geneticists and breeders may face is to include resistance to both diseases and arthropods within the one variety (Bellotti 2000).

The principal sources of resistance to pests may be found in the more than 100 wild *Manihot* species so far identified (Allem 1994). Small collections of these are held at some institutes, including CIAT, EMBRAPA (Brazil), and IITA (Bellotti 2000).

The genetic molecular cassava map is being developed (Fregene et al. 1997). This will become a very useful tool for developing, using other *Manihot* species, transgenic cassava plants with resistance to pests (Bellotti 2000).

Projects on IPM in cassava are few. Guides and strategies for the appropriate implementation of alternative controls are not available for small farmers in traditional production systems (Bellotti 2000). Such a lack is also strongly felt in large cropping systems, where the implementation of an effective IPM system, based on biological control and resistant varieties, is decisive in maintaining high yields. This is especially true in the Neotropics, where a large complex of arthropod pests and diseases exist (Bellotti 2000).

An effective proposal for cassava growers is one that overcomes the slow dissemination of technology, for example, use of participatory methods with farmers and inclusion of the private sector in planning research and determining its objectives. The successful implementation of a pilot IPM project in a cassava crop developed with traditional farmers in Northeast Brazil is a real example where such methodology was successfully applied (Bellotti 2000).

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The following acronyms are used to save space:

CIAT = Centro Internacional de Agricultura Tropical
SOCOLEN = Sociedad Colombiana de Entomología

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