Bananas for ever

Nobody has failed to hear about the announcement of the end of bananas in the next ten years. This outrageous prospect upset all the stakeholders in the export dessert banana production sectors and in local consumption sectors as well. In this set of articles, CIRAD-FLHOR wishes to calm the debate and clearly set out the position with regard to a number of notions such as genetic diversity, the genetic improvement of banana, pest and disease control, etc. Reflection on an overall approach to banana growing with the aim of sustainable production is also proposed. Solutions do exist. Bananas will not disappear. But there is no doubt that research on this crop deserves more attention and funding in the light of the food and trade issues that it represents.

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Contributing CIRAD researchers:
C. Abadie, F. Bakry, J. Carlier, M.L. Caruana, F. Cote, J. Ganry, T. Lescot, P. Marie, J.L. Sarah
Co-ordination: C. Sanchez, D. Lœillet
Photo: T. Lescot, Cirad

Banana and the rational agriculture concept

The technical development concepts widely disseminated in intensive banana growing are based on the perfecting of increasingly high-performance rational agriculture. The objective announced is clearly that of maintaining or improving yields while limiting pesticide and fertiliser inputs. Beyond the ordinary approach of wishing to justify each application of fertiliser or pesticide (reducing inputs by eliminating systematic application), CIRAD-FLHOR has developed agricultural diagnosis tools, technologies and cultural techniques that can be used at field or production area scale.

This set of facilities makes it possible to progress towards sustainable cropping systems and even sometimes to correct situations with seemingly inexorable falls in yield: solving soil exhaustion problems (physical problems and/or accumulation of soil pests), preventing or correcting acquisition of resistance of a pest to a pesticide and developing integrated or alternative control methods in the case of the limiting of the range of pesticides available.

The combining of these technologies is aimed at making progress in cropping systems that are varied because they rigorously match the environmental conditions (e.g. soil + climate and farm structures) in the context of a search for economic performance. The implementation of the cultural techniques and the associated control and diagnosis techniques should lead to savings in labour and inputs and/or gains in productivity compatible with the competitiveness objectives.

The scientific orientations aimed at improving cropping systems are such as to manage agricultural risks or may be in the precautionary principle category.

To give just one example of this, the creation of crop management sequences based on the use of healthy plant material in land cleansed by fallow or crop rotation is founded on the development of tissue culture plants, with the abandoning of the other techniques for obtaining healthy plant material: rebrotes, plants grown from buds, puddled suckers, etc.. The initial objectives of control of *Radopholus similis* and the solving of soil exhaustion problems caused by the accumulation of the pest, and the limiting of the use of nematicides, etc. are better attained. The technically difficult tissue culture plant option has made it possible to develop cropping systems in which the risk of introduction of new diseases or of the spread of existing diseases via plant material can be avoided. This concerns all viruses and soil pests and diseases—nematodes, fungi and bacteria—and combines laboratory and nursery technologies in each case, forming a quality chain.

In this context, the replies to the key questions of the banana profession concerning crop sustainability do not form a magic solution of just seeking a high-performance pesticide or even just the development of a resistant banana variety, but consist rather of a change in cropping systems with the improvement of complete crop management sequences, possibly including these innovations. Three out of a fair number of examples are shown here.

Panama disease

It has been shown that Panama disease is spread by the transfer of plant material or soil. The condemning of the intensive cultivation of Gros Michel, replaced by resistant Grande Naine, was the result of the intensive dissemination of FOC Race 1 (*Fusarium oxysporum* sp. *cubense*, the causal agent of Panama disease) during transfers of suckers or corms, the only material available for replanting at the time. In fact, susceptible varieties such as Petite Naine and Grande Naine are still grown in cultivation areas in which FOC race 4 is present, in the Canary Islands since 1931 for example. The spread of the disease is controlled by a temporary halting of use (fallow) of infested sites. Here, crop management sequences based on using tissue culture plants on land cleansed by fallow and whose economic competitiveness has been widely demonstrated can control the disease and hence stabilise production.

Sigatoka leaf streak diseases

The crop management sequence developed by CIRAD to control leaf streak diseases consists of a battery of complementary measures:

- elimination of necrotic areas of leaf laminae in the field (to control inoculum);
- spray decisions taken using a biological warning system. The growth rates of the plant and of the fungus are compared schematically;
- in some cases (for Yellow Sigatoka), the decision to spray is completed by a climatic warning

(periods favourable for the development of the fungus);

- alternating of pesticides to prevent enhancement of resistance in the fungus;
- regular monitoring (control of the effectiveness of the substances used to limit the use of the products to which resistance could appear until a return to normal susceptibility levels.

This system must be combined with rapid striking force performing high-quality spraying. Its effectiveness has been demonstrated for many years, even in zones with very high pest pressure. It has also made it possible to overcome critical situations of acquisition of resistance to triazoles. However, it is essential to apply it at the scale of the production area. Furthermore, its economic performance is achieved by a considerable decrease in the number of sprays, which might be contrary to the interests of the spraying companies. The system is therefore difficult to set up in established banana plantations but it is an essential step towards sustainability in this domain.

Improvement of bananas

The banana genetic base currently used in intensive production is very narrow. CIRAD has worked for many years on breeding conventional hybrids with a better response to the imperatives of sustainability within the context of present knowledge. The first generations of dessert and cooking banana hybrids are thus being validated at the moment. The most keenly sought-after resistance is to Sigatoka leaf spot diseases but we have succeeded in breeding resistance to several diseases.

This method gives polygenic resistance that is difficulty for pathogens to overcome. The varieties will be introduced in cropping systems specifically adapted to prevent the circumventing of resistance. These new varieties should give better economic competitiveness in terms of a response better suited to consumer expectations and segmentation of a market currently dominated by a single variety. In contrast, the genetic base of bananas for local consumption in the southern countries is fairly varied. Improvement of bananas is of prime importance. This research is well advanced but must be continued by the breeding of numerous hybrids for the varied requirements of users and sustainability and diseases resistance requirements. Making this innovative material available should be the occasion for improved phytosanitary security during transfers of plant material in the countries concerned.

Responses to the question of the sustainability of banana cultivation are complex. Few research centres have the capacity or the critical mass required to conduct these overall approaches that are nonetheless necessary. The funding awarded for research on banana is tiny in relation to its food and economic importance. Awareness of the sector and of development donors should be constant and intensified to stabilise this very important crop ■

The main banana groups and subgroups

Group	Subgroup	Cultivar	Fruit type	Distribution
AA				
	Sucrier	Pisang Mas, Frayssinette, Figue Sucrée	dessert-sweet	World-wide
		Pisang Lilin	dessert	Indonesia, Malaysia
		Pisang Berangan, Lakatan	dessert	Indonesia, Malaysia, Philippines
AAA				
	Cavendish	Lacatan, Poyo, Williams, Grande Naine, Petite Naine	dessert	World-wide, exporting countries
	Gros-Michel	Gros-Michel, Highgate, Cocos	dessert	World-wide
	Figue-Rose	Figue-Rose rose, Figue-Rose verte	dessert	World-wide
	Mutika Lujugira	Intuntu, Mujuba	beer - cooking	Central and E. Africa, Colombia
	Ibota	Yangambi km5	dessert	Indonesia, Africa
AB				
	Ney Poovan	Safet Velchi, Sukari	dessert - acidulous	India, East Africa
AAB				
	Figue-Pomme	Maçà, Silk	dessert - acidulous	World-wide
	Pome	Prata	dessert - acidulous	India, Malaysia, Australia, W. Africa, Brazil
	Mysore	Pisang Ceylan	dessert - acidulous	India
	Pisang Kelat	Pisang Kelat	dessert	India, Malaysia
	Pisang Rajah	Pisang Rajah Bulu	cooking	Malaysia, Indonesia
	Plantain	French, Horn, False Horn	cooking	Central and W. Africa, Latin Am., Caribbean
	Popoulou	Popoulou	cooking	Pacific
	Laknao	Laknao	cooking	Philippines
	Pisang Nangka	Pisang Nangka	cooking	Malaysia
ABB				
	Bluggoe	Bluggoe, Matavia, Poteau, Cacambou	cooking	World-wide
	Pelipita	Pelipita	cooking	Philippines, Latin America
	Pisang Awak	Fougamou	dessert	India, Thailand, Philippines, E. Africa
	Peyan		cooking	Philippines, Thailand
	Saba	Saba	cooking	Philippines, Indonesia, Malaysia

Source: Cirad

The genetic diversity of banana

Over a period of thousands of years, population migrations and movement of plant material have placed banana in very different ecological contexts in the various continents. Farmers have succeeded in profiting from the natural mutations resulting from vegetative multiplication. This combination of natural reproduction and selection by man since ancient times results in the present genetic diversity.

Bananas originated in South-East Asia as wild seminiferous plants. Natural crosses built up a large base of genetic diversity that still exists today. These crosses were the origin of the seedless varieties. These bananas have food qualities that soon interested man, who incorporated them in agriculture using their vegetative multiplication potential.

From the botanical point of view, the genus *Musa* is divided into seminiferous species with inedible fruits and parthenocarpic varieties with fleshy seedless fruits. The Eumusa section includes *Musa acuminata* (genome symbol: A) and *Musa balbisiana* (genome symbol: B). These are wild species at the origin of the cultivated varieties.

The latter are classified according to their ploidy level and their genetic make-up. Some 1 200 varieties have been counted and classified around the world.

The inedible wild species with seed-containing fruits can be used for purposes other than human foodstuff (fibre, livestock feedingstuff, etc.). They are all diploid (AA and BB). About 180 have been counted to date, all from South-East Asia, but the census is not definitive (especially for the BBs). These fertile varieties are nonetheless important since they possess different levels of resistance to pests and diseases. They therefore form base material for the various present and future conventional genetic improvement and varietal creation programmes. Numerous cultivars have been bred by man. They are classified in groups according to their genetic make-up and then in subgroups assembling the various cultivars derived from each other by natural mutation starting from a common genetic ancestor. Distinction is made between the following groups:

- diploid groups: AA (such as Figue sucrée or Frayssinette) and AB. These total about 290 cultivars grown mainly in South-East Asia where they originated;
- three triploid groups (650 cultivars): AAA, AAB and ABB. The subgroups of each of these distinguish between the dessert varieties richer in sugar at maturity, cooking varieties with fruits that are firm and not sweet even when ripe, and sometimes bananas for beer-making by fermentation of the pulp (East Africa).

Even if the plants within the same subgroup display only weak genetic diversity, they do have a great range of phenotypes, resulting essentially from mutations and many centuries of selection by man. This is the case of the Cavendish (more than 20 cultivars), East African highland bananas (more than 50) and central and West African plantain (more than 150) subgroups.

Although the intensive cultivation system used for approximately 25 percent of world production favours monovarietal production, it is important to remember that most production is based on less intensive family farming with stress on varietal mixing. This contributes to the continuing of selection and hence ensures the diversity of banana ■

A few definitions

Conventional breeding: improving plants by sexual reproduction.

Cultivar: a cultivated banana.

Genetic improvement: improving plants with regard to a given character.

Parthenocarpy: the spontaneous development of a fruit without stimulation of flowers by fertilisation.

Phenotype: a set of individual properties of a plant expressed in conjunction with a given environment.

Ploidy: number of sets of basic chromosomes:
diploid: 22 chromosomes
triploid: 33 chromosomes
tetraploid: 44 chromosomes

Seminiferous: fruits containing seeds more or less encased in pulp.

Vegetative multiplication: in contrast with sexual reproduction (by seeds). It means multiplying or reproducing a plant by suckers or *in vitro* multiplication.

Genetic improvement of banana

The genetic improvement of banana and plantain is made necessary today as a result of pest pressure and consumer demand in both the north and the south. However, the sector needs not only new cultivars but also good cultural practices.

New dessert banana and cooking banana hybrids are required.

The genetic base of export dessert bananas is narrow and the plant is subject to many diseases. The development of disease-resistant bananas is a major objective and new varieties will also make it possible to broaden the variety of supplies on the main import markets through market segmentation.

The need for new varieties of plantain (local varieties for cooking) also responds to a search for resistance to diseases. But the cultivation problematics are different. Plantain is not an intensive crop. A large number of varieties are grown and the problems met are not only related to pests and diseases but also to the agronomic management of the plant and distribution to local markets.

Long and complex techniques

Present varieties display special biological characteristics, and in particular marked flower sterility that is a handicap for breeders. However, sterility is not total and some clones can produce seeds when they are pollinated manually. In spite of these obvious difficulties, hybrids have thus been bred by sexual means. After selection screening, the latter have been multiplied vegetatively under natural conditions (from suckers) or by *in vitro* multiplication for rapid distribution to growers.

The implementation of complex crossing strategies first led to the distribution of new disease-resistant cooking varieties with good production potential. The plants bear larger bunches, display better sucker production and have a smaller habit. The fruit quality of most of the hybrids is very acceptable but progress remains to be made in the culinary and taste qualities in comparison with the traditional varieties. Work is continuing to take better account of these criteria and to specify the nutritional value of these new varieties.

The improvement of export varieties consisted of going back to ancestral varieties to reach the present hybrids in a similar way to what has happened naturally since the origin of bananas until today. This procedure is based on good knowledge of the evolution of *Musa* (the generic name of banana) and of the biology of the plant. The breeding of new varieties was slowed at first by the appearance of hybrids infected by a virus in the progeny. It was found that these infections resulted from the activation by crosses of virus sequence incorporated in the genome of one of the parents. This difficulty was overcome by concentrating work on the species *Musa acuminata*, whose genome does not incorporate activable sequences. New varieties resistant to the major diseases have recently been bred by crossing. Their potential for the domestic and export markets is being studied.

It is not because the so-called 'conventional' breeding techniques are long and complex that they should not be considered as being operational. Several teams have distributed improvement plant material bred using these techniques and new dessert and cooking banana hybrids are expected shortly.

GMOs form a possible approach for the improvement of banana as a complement to breeding using sexual methods. Among other things, it would make it possible to create virus-resistant plants as such genes are unknown naturally in the genus *Musa*. The approach is not yet operational, however. As for other transgenic plants, a set of conditions is required before the obtaining of results that can be taken over by users and that are satisfactory for consumers. The first condition concerns the degree of mastery of the method. Effective resistance strategies that are sustainable during transgenesis require the testing and validation of many technical approaches for which we have very little perspective for appraisal. The second condition involves bio-safety and is common to all genetically engineered plants. Finally, it must not be forgotten that the product must first and foremost be accepted by consumers.

The overall approach

Finally, responding to the pest threats to which bananas are exposed requires not only new, more resistant bananas but also good cultural practices based on in-depth knowledge of plant agronomy and the biology of these pests and diseases. Research in these fields receives less public attention but is just as essential as work on genetic improvement. It is clear that the development of bananas truly matching the requirements of growers and consumer expectations will be delayed unless an overall improvement approach is used ■

Pests and diseases of banana

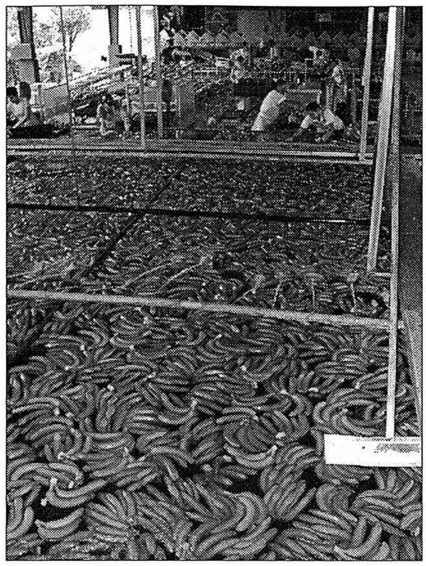
Like all agricultural crops, bananas are subjected to strong pressure from pests and diseases. Sigatoka diseases (especially black leaf streak disease) are the best-known but not the only ones. Control of soil pests (nematodes), banana borer, viruses and Panama disease mobilise all the attention of the research sector.

Panama disease

Panama disease or Fusarium Wilt was first identified in 1874 in Australia. It is now observed in almost all tropical and subtropical banana production zones. It is caused by a soil fungus of a very common genus, *Fusarium oxysporum* sp. *cubense* (FOC).

Different races have been identified. Under certain conditions (soil type, climate, crop intensification, drainage, etc.) each can cause serious vascular damage to the different banana varietal groups, making them practically non-productive.

- Race 1 originated in Asia and spread widely via movement of plant material in the form of suckers when the major export banana cultivation areas were established in the early twentieth century. It caused by the progressive disappearance of intensive production of the Gros Michel variety in Latin America and Africa in the 1940s and 1950s, when the variety formed the basis of international trade. Gros Michel was replaced in the industrial plantations by the resistant Cavendish varieties discovered in South-East Asia and that are now the fruits traded internationally. It should be noted that Gros Michel is still the reference for dessert banana consumption in most African and Latin American countries; production is still substantial at approximately 6 million tonnes per year. It appears that race 1 is not active in the areas in which it is cultivated extensively and combined with other varieties and other crops (hence at low density). Experiments conducted in Colombia have shown that Panama disease gains importance when the growing of Gros Michel is intensified (density greater than 1 000 plants per ha).



- Race 2 affects the Bluggoe subgroup (ABB, cooking bananas).
- Race 3 affects *Heliconia* spp. and sometimes Gros Michel.
- Race 4, identified in the Canary Islands in 1931, affects the Cavendish group sporadically and under certain environmental conditions but only in subtropical zones (Canary Islands, South Africa, Taiwan, Australia) where it is relatively well controlled by the appropriate cultural techniques (buffer zones, fallow, etc.).
- Race T4 was described recently (1995) and also affects Cavendish group varieties but only in a few tropical areas—Indonesia (Sumatra and Java) and Malaysia.

All the specialists agree that the main cause of the spread of the disease is the movement of plant material (suckers and corms) from susceptible, infected plantations. Contamination via the soil from an infected area is very slow.

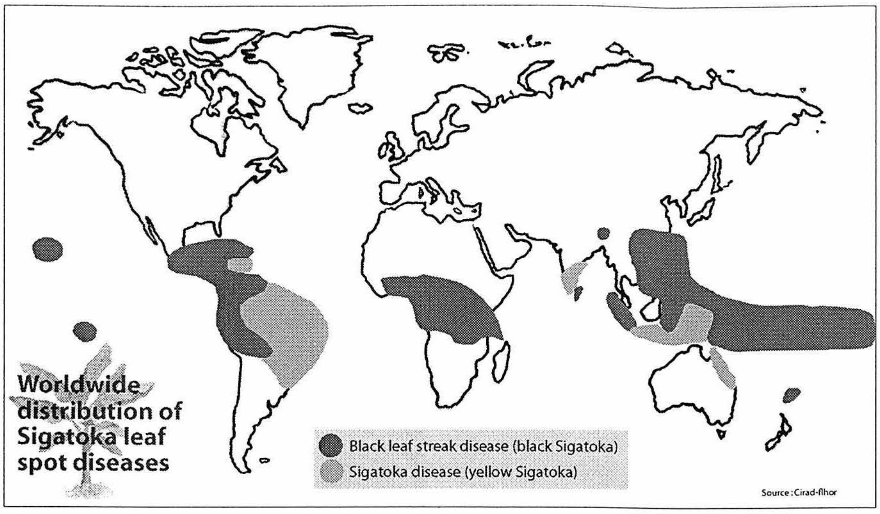
As for numerous soil pathogens, control methods are limited and consist essentially of keeping areas containing the outbreaks in quarantine. Not much international work is performed on this disease whose study is complicated. Control methods are not specific to bananas and are and will remain very limited. Conventional genetic improvement remains an important and as yet little-explored pathway.

International awareness of the importance of respecting rules for the movement of germplasm and the wide adoption of tissue culture plants by the banana industry should limit the present risks. The dispersion of race T4 is under surveillance. However, with strict control of germplasm movement and the surveillance and eradication of infected plants, the prospect of rapid spread of the disease is very improbable.

Sigatoka leaf streak diseases

Two main types of leaf streak disease endanger the banana industry: Black Sigatoka and Yellow Sigatoka. A new species called *Mycosphaerella eumusa* is even more aggressive than Black Sigatoka and seems to be spreading in Asia and the Indian Ocean.

Black Sigatoka (also called black leaf streak disease or BLS) is



Worldwide distribution of Sigatoka leaf spot diseases

caused by the fungal leaf parasite *Mycosphaerella fijiensis*.

Spread is from plant to plant in continental zones. The sea is a natural obstacle. Although the risk of natural dissemination of the spores of the fungus by wind cannot be ruled out, the spread of the disease from one zone to another is generally the result of uncontrolled movement of plant material.

The disease is present in all the producer countries in Latin America, Africa and Asia. The Caribbean countries were long protected by their island geography. The new feature that strongly increases the risk for the Lesser Antilles is the spread of the disease in the Greater Antilles in Cuba, Jamaica, the Dominican Republic and recently in Haiti.

The fungus destroys the foliage of banana plants. The disease appears in the form of small black streaks that soon develop into necrotic patches. These spread and finally all the leaves of the plant are destroyed.

The pattern is exactly the same as that induced by another fungal disease, Yellow Sigatoka, that has been present in the Lesser Antilles for about 40 years. This is caused by the fungus *Mycosphaerella musicola* and led to rational chemical control set up by professionals in Martinique and Guadeloupe (the only zones of intensive cultivation for export affected). Spraying is performed in relation to surveillance of the disease. Today, Yellow Sigatoka is controlled with a small number of sprays (five to seven per year).

There are fundamental differences between the two leaf streak diseases. Unlike Yellow Sigatoka, Black Sigatoka can infect both export banana and plantain. As it spreads rapidly, it is also more difficult to control. Depending on the country and control facilities and techniques, control requires from 12 to more than 50 sprays per year.

Two control strategies

The export banana plantations in the major Latin American producer countries form vast agro-industrial complexes in alluvial plains. Given the size of plantations (several hundred or even several thousand hectares), contamination from outside is weak. There are no nearby centres of infection. The agroclimatic homogeneity makes it possible to organise and rationalise crop spraying for large complexes. The low cost of labour facilitates essential control work (regular deleafing).

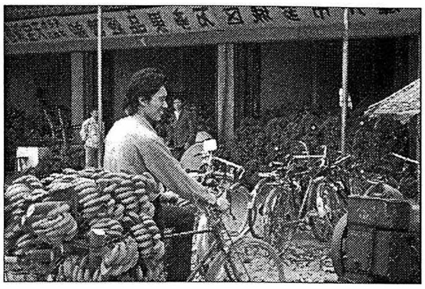
In this context, the impact of spraying as a nuisance is not always taken into account by the large companies that do not hesitate to use systematic control strategies leading to more than 50 sprays per year. Application is at regular intervals and generally consists of contact fungicides (chlorothalonil, dithiocarbamate, etc.) that by definition are of low efficacy—treatment every 10 to 15 days—requiring a large number of sprays to control the disease. Systemic fungicides are sometimes used but always as a water-based emulsion.

The importance of host-pest relations

CIRAD puts forward the importance of research on host-pathogen relations for addressing levels of efficacy and durability of resistance (creation of new varieties) to guide breeding and to define the management of resistance in space and time. The aim is the integrated, sustainable management of banana and plantain production. Recent studies performed on the genetic structure of populations of the fungus *Mycosphaerella fijiensis* (Black Sigatoka disease) using modern techniques (molecular analysis of DNA and measurement of aggressiveness) combined with studies of epidemiology show that:

1. the parasite populations are genetically very diversified (high diversity index) partly because of their mode of reproduction, and display a variable degree of aggressiveness. This suggests that they have substantial capacity for adaptation. These pathogen populations can thus evolve according to selection pressure such as the resistance of banana or fungicide pressure resulting from a large number of fungicide sprays;
2. dispersion between countries and large banana production zones may result partly from the movement of infected germplasm and/or limited dispersion of spores over long distances;
3. the spread of the disease in plantations results from the transport of spores in the air and in water (dew and rain).

Studies on the characterisation of partial resistance have shown that resistance has different components according to the variety. The efficacy and durability of some of these components are currently being studied in the laboratory and in the field (Cameroon).



CIRAD has developed a rational strategy using warning methods based either on disease monitoring in the plantation or on the observation of climatic descriptors (evaporation, temperature, etc.). It has been applied in particular in Guadeloupe, Martinique, Cameroon and Côte d'Ivoire.

It consists of performing spraying only at the appropriate moment. The main objectives are:

- improving control efficacy while decreasing the number of sprays per year;
- reducing production costs;
- limiting the risks of the selection of fungicide-resistant races;
- reducing pollution and increasing respect for human health and the environment (urban centres, rivers, water bodies, reservoirs, etc.).

The strategy is also based on the rational alternate use of systemic fungicides (benzimidazoles, triazoles, etc.) that are effective for a long time. Mixing them with a low volume (13 to 15 litres per ha) of petroleum oil (also fungistatic) extends the efficacy of each spray and therefore helps to reduce the number of sprays per year.

These two types of leaf streak control strategy have similar efficacy. However, the consequences are totally different with regard to the appearance of resistance in the fungus.

The first systemic fungicides put on the market were benzimidazoles. Their single-site action on the pathogen induced resistant parasite strains all the more easily as they were applied excessively. In Central America, resistance to benzimidazoles was observed only two years after their first utilisation. This led to greater use of contact products, with 15 to 40 kg active substance per hectare per year. Warning techniques and a reduced number of sprays resulted in the appearance of resistance phenomena in Guadeloupe, Martinique, Cameroon and Côte d'Ivoire only after 10 or even 15 years of use.

Triazoles, another group of fungicides, used to control races resistant to benzimidazoles were first used in the various production zones from the 1980s onwards. Rational management of these fungicides (alternative and warning) now enables very good control of leaf streak diseases with the application of 0.5 to 2 kg active substance per hectare per year.

Sometimes high levels of resistance have nevertheless been observed. The use of new fungicides is beginning. These belong to the new strobilurine family, which has the advantage of displaying similar efficacy to that of triazoles, without cross-resistance.

New control methods

Present control strategies cannot be used indefinitely. Thought should soon be focused on the adopting of an overall approach combining new hybrids resistant to the leaf streak diseases and cropping systems that make it possible to conserve this resistance.

Virus diseases

Virus diseases of banana (dessert and cooking fruits) have spread increasingly in recent years as a result mainly of the ease of plant movement and demand for diversification. They consist of banana bunchy top disease and mosaic diseases including banana mosaic, banana streak disease and bract mosaic. The economic damage varies, affecting all cultivated bananas and both large estates and village plantations. Banana bunchy top disease (caused by the banana bunchy top babuvirus, BBTV) can cause losses of 90 or even 100 percent of production, as in Pakistan. Banana streak disease (caused by the banana streak badnavirus, BSV) causes losses of 40 to 60 percent, as in Rwanda and banana bract mosaic (caused by the banana bract mosaic potyvirus, BBrMV) results in losses of more than 40%, as in the Philippines.

Spread is either by vector from outbreaks or by the use of infected germplasm—suckers or tissue culture plants—or, in the special case of BSV, from so-called 'silent' bananas with a virus sequence incorporated in the genome of the species *Musa balbisiana* and capable of producing viral particles as a result of stress.

Banana bunchy top disease

The plants are markedly stunted and rosetted at the top. The narrow, erect, brittle leaves display strongly chlorotic borders. The characteristic symptom is the appearance of discontinuous dark green streaks along the pseudostem, the main leaf vein and the secondary veins. When

A few definitions

Transmission in persistent mode: the virus circulates in the body of the insect as far as the salivary glands. The insect is virulent for its entire lifetime.

Transmission in non-persistent mode: the virus is on the surface of the insect, which remains virulent for only a short time.

Transmission in semi-persistent mode: the virus is fixed on the anterior part of the digestive system. The insect is virulent for one or two days.

the mother plant is infected, so are all the suckers. The most effective vector is the banana aphid *Pentalonia nigronervosa*, in a persistent manner

Mosaic diseases

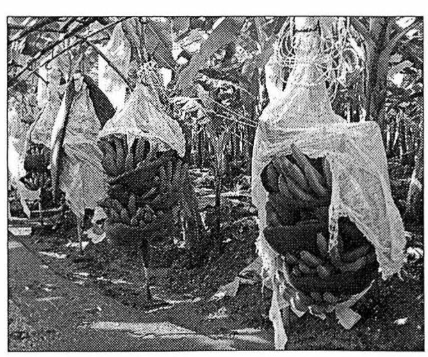
Banana mosaic caused by cucumber mosaic cucumovirus (CMV)

Infected plants display leaf chlorosis and mottling of the main vein and the pseudostem. The leaves are deformed and the cigar-tip necrotic in severe attacks. Secondary infections may appear in the form of bacterial rots in the sheaths forming the pseudostem. Distribution of the virus is uneven and not all suckers may be contaminated. The virus can be spread by a broad range of aphids such as *Aphis gossypii* and *Myzus persicae* in a non-persistent manner. The disease can also be spread by pruning tools. Necrotic patches have recently been described as associated with CMV type mosaic. This atypical CMV symptomatology is in fact related to the presence of a CMV + Banana mild mosaic virus (BanMMV) complex.

Banana streak disease

The leaf lamina displays discontinuous yellow streaks that rapidly become necrotic. The main vein is unaffected. In severe forms of the disease, the cigar tip becomes necrotic and the plant dies. If the mother-plant is infected so are all the suckers.

The disease is transmitted by mealybugs—*Planococcus citri*, *Saccharicoccus sacchari* and *Dysmicoccus brevipes*—in semi-persistent mode. In recent years, BSV infections unrelated to external contamination have been described in various parts of the world. There are two different causes: tissue culture plants derived from micropropagated healthy interspecific hybrid varieties of banana and the hybrid progeny of crosses between healthy *Musa acuminata* (genome A) and *Musa balbisiana* (genome B) parents. Various abiotic stresses cause the appearance of the disease in these hybrids, correlated with the presence in the genome of the *M. balbisiana* parent of endogenous viral sequences (endogenous pararetrovirus, EPRV) of BSV containing all the information required to synthesise the infectious virus.



Banana bract mosaic

The first stages of infection consist of greenish yellow streaks turning into brownish red necrosis on the leaf lamina and veins. Yellow mottling or whitish streaks are seen on the pseudostem according to the variety infected. Bract mosaic is the final symptom. The disease is transmitted to all the suckers by aphids (*Ropalosiphum madiis*, *Myzus persicae*) in non-persistent mode.

Prevention and control

The only control method available today to fight these banana virus diseases is control of the vector and the use of healthy plant material. Indeed, there are no bananas with natural resistance to these diseases and no cure other than eradication after a virus attack.

The procedure to be followed is based mainly on the use of disease-free germplasm—suckers or tissue culture material screened for viruses—and the cutting back of weed growth where aphids multiply.

Nematodes

Numerous nematode species parasitise banana roots and corms. Root knot nematodes (*Meloidogyne* spp.) and spiral nematodes (*Helicotylenchus* spp.) are found all over the world in all kinds of crop. However, the most damage is caused by the migrating nematodes *Pratylenchus* spp. and *Radopholus similis*. The latter species is found everywhere in the hottest banana growing zones and especially in intensive plantations where it arrived via germplasm movements during the spread of the crop during the past two centuries. *Pratylenchus coffeae* is also present in the hottest zones but is generally indigenous and found mainly on plantain crops. *Pratylenchus goodeyi* prefers cooler areas and originated on the Africa plateaux. It is observed in certain subtropical zones such as the Canary Islands, for example.

Underground enemies!

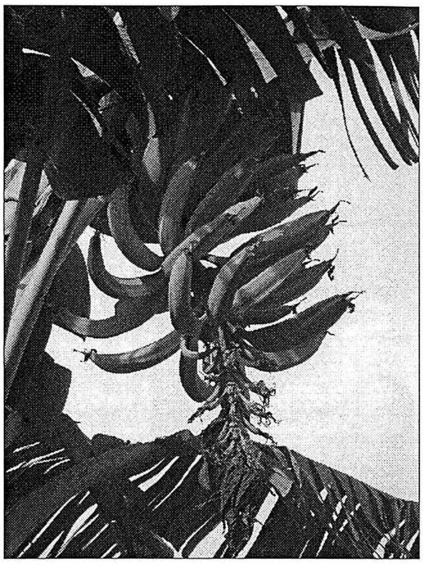
Pratylenchus spp. and *Radopholus similis* are migratory endoparasites whose full biological cycle lasts for 20-25 days in root and corm tissues. Juvenile forms and females are always mobile and can leave the roots when conditions are no longer favourable. These migratory forms can then colonise other roots. As they move within and between cells, these nematodes feed on parenchyma cell cortical cytoplasm, destroying cell walls and creating tunnels that become necrotic and can extend to the whole of the cortex. Root and corm necrosis is accentuated by other pathogens (fungi and bacteria). In particular, fungi of the genus *Cylindrocladium* are strongly pathogenic and can cause lesions similar to those made by nematodes. The combination of the two pests causes very serious damage. The destruction of underground tissue leads to a decrease in water and mineral nutrition resulting in slowed plant growth and development. This can lead to severe decrease in bunch weight and lengthen the period between harvests. Furthermore, destruction of the roots weakens the anchorage of the plants in the ground and increases the risk of toppling, especially during hurricane periods, with a strong economic impact.

Control methods in intensive plantations are still largely dominated by application of chemicals (mainly organophosphorus compounds and carbamates) that carry substantial sanitary and environmental risks. For this reason, in spite of their efficacy and very easy application, their use will be increasingly limited in favour of alternative control measures. These include cultural practices improving fertility (tillage, irrigation, organic ameliorators, etc.) that indirectly improve plant tolerance to pest pressure. More direct methods such as the use of fallow and the planting of micropropagated bananas are now in common use and lead to a strong decrease in nematode populations.

Operations involving biological antagonists, root symbionts (mycorrhizal fungi) and especially genetic resistance may allow the setting up of increasingly effective integrated control strategies in the fairly near future. However, it is necessary to be aware that the great complexity of nematode populations makes delicate the development of these more closely targeted techniques. To be effective, they must be able to handle the diversity of cultural and ecological situations.

Banana borer

Originating in South-East Asia, the banana borer has spread to all subtropical and tropical banana and plantain production regions. The insect (*Cosmopolites sordidus*) is 9 to 16 mm long and 4 mm wide. It moves freely in the soil at the feet of banana plants or in plant debris. It is nocturnal and very sensitive to drying. The pest is spread mainly via infested plant material. The adults do no damage. The females lay eggs in the banana rhizome and



the larvae feed on this, driving tunnels. These tunnels disturb water and mineral supply of plants, lengthen the production cycle, cause serious decreases in yield and weaken the anchorage of the plants, making them more sensitive to wind. Strong attacks can lead to the death of the plant.

In addition to classic chemical treatment, the use of healthy planting material (tissue culture plants) used in clean soil (after fallows) is an effective method of borer control. New pheromone trapping techniques seem to be promising ■

Estimated world banana production in 2000

Tonnes	AAB group plantains	Highland bananas + ABB group + other cooking bananas	Cavendish bananas	Gros Michel + other dessert bananas	Total
South America	4 873 156	270 328	10 354 370	4 969 088	20 466 942
Central America	803 500	89 950	5 953 040	154 010	7 000 500
Caribbean	830 500	415 654	1 379 995	91 410	2 717 559
West and central Africa	8 478 041	1 107 861	1 974 997	575 151	12 136 050
East Africa	705 842	12 954 880	1 971 300	755 552	16 387 574
North Africa – Middle East	20	3 010	1 219 159	1 030	1 223 219
Asia	1 125 120	9 245 529	18 369 381	5 027 150	33 767 180
Oceania	900	674 840	290 975	81 550	1 048 265
Europe	1	5	486 361	5	486 372
World total	**16 817 080**	**24 762 057**	**41 999 578**	**11 654 946**	**95 233 661**

Source: Thierry Lescot, CIRAD-FLHOR, after references, surveys, professional sources, FAO, etc.