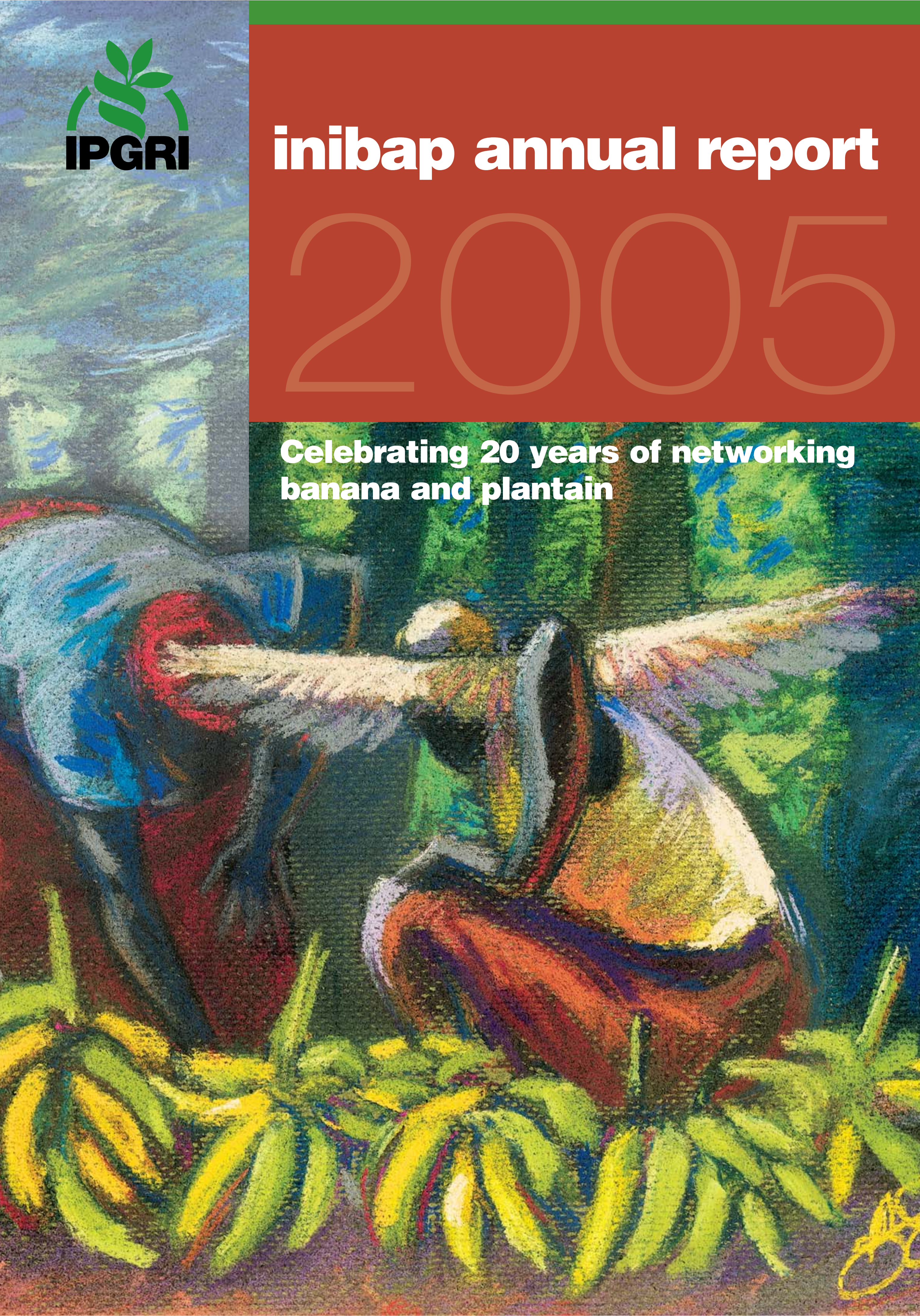
IPGRI

inibap annual report

2005

Celebrating 20 years of networking banana and plantain



The mission of the **International Network for the Improvement of Banana and Plantain (INIBAP)** is to enhance the livelihoods of small-scale *Musa* producers by working with partners to:

- Conserve, characterize and disseminate genetic diversity
- Develop (by conventional and molecular methods) superior cultivars and test them with farmers
- Develop sustainable production systems and identify opportunities for adding post-harvest value
- Support research-and-development efforts by disseminating information and raising awareness of key issues
- Assess regional and national needs, develop a coordinated response and encourage the adoption of promising solutions

INIBAP is a network of the **International Plant Genetic Resources Institute (IPGRI).**

The International Plant Genetic Resources Institute (IPGRI) is an independent international scientific organization that seeks to improve the well-being of present and future generations of people by enhancing conservation and the deployment of agricultural biodiversity on farms and in forests. It is one of 15 Future Harvest Centres supported by the Consultative Group on International Agricultural Research (CGIAR), an association of public and private members who support efforts to mobilize cutting-edge science to reduce hunger and poverty, improve human nutrition and health, and protect the environment. IPGRI has its headquarters in Maccarese, near Rome, Italy, with offices in more than 20 other countries worldwide. The Institute operates through four programmes: Diversity for Livelihoods, Understanding and Managing Biodiversity, Global Partnerships, and Commodities for Livelihoods.

The international status of IPGRI is conferred under an Establishment Agreement which, by January 2006, had been signed by the Governments of Algeria, Australia, Belgium, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Chile, China, Congo, Costa Rica, Côte d'Ivoire, Cyprus, Czech Republic, Denmark, Ecuador, Egypt, Greece, Guinea, Hungary, India, Indonesia, Iran, Israel, Italy, Jordan, Kenya, Malaysia, Mali, Mauritania, Morocco, Norway, Pakistan, Panama, Peru, Poland, Portugal, Romania, Russia, Senegal, Slovakia, Sudan, Switzerland, Syria, Tunisia, Turkey, Uganda and Ukraine.

Financial support for IPGRI's research is provided by more than 150 donors, including governments, private foundations and international organizations. For details of donors and research activities please see IPGRI's Annual Reports, which are available in printed form on request from ipgri-publications@cgiar.org or from IPGRI's Web site (www.ipgri.cgiar.org).

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Reflecting on twenty years of achievements

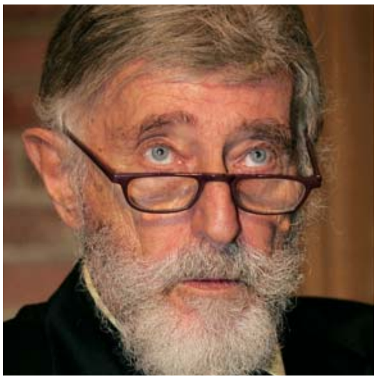
Dr Denis Kyetere, Chair of the INIBAP Support Group, opens the itinerant exhibition No end to the banana as part of the 20th anniversary celebration in Leuven.

It is a special pleasure to bring you this 20th Anniversary edition of the INIBAP annual report – and, with it, to have the opportunity to reflect a little on what has changed and what has remained the same over these two decades of networking for banana and plantain research.

In line with our philosophy as a learning organization – to hold on to what is good, but always be ready to evolve – this Annual Report has a similar 'look and feel' to the last three. It has four articles which explore different subjects in some depth, followed by an institutional summary of our current research agenda, governance and finances. It will be available in all three of our working languages: Spanish, French and English. We also complete our artistic tour of the regions with a cover from Africa. However, the content of the articles are rather different in that, instead of looking at a particular project experience, we have tried to draw together a reflection on the current 'state of the art' in each of our main areas of concern: conserving *Musa* diversity, understanding that diversity (especially through molecular studies), using both genetic diversity itself and our knowledge of diversity in crop breeding, and managing diversity for more sustainable production and more profitable post-harvest market links.

For the core of each article, we are indebted to four specialists who came together to offer the keynote addresses at a special "Symposium on the Conservation and Use of *Musa* Diversity for Improving Livelihoods" that we convened in Leuven, Belgium, as part of our 20th Anniversary celebrations. Rony Swennen of the *Katholieke Universiteit Leuven* (the institution that hosts our international genebank) addressed the subject of conservation; Pat Heslop-Harrison of the University of Leicester explained some of the mysteries of genomics; Michael Pillay of IITA highlighted the challenges of breeding bananas; and Franklin Rosales, INIBAP's Regional Coordinator for Latin America and the Caribbean, reviewed our work, with partners, on the ecology of production systems and post-production. Our science writer and editor, Anne Vézina, while preserving the substance of the original presentations, has given them a coherent voice and enriched them with additional insights of her own.

So, what have we learned in these twenty years of often frenetic effort? The founding Director of INIBAP, Prof. Edmond De Langhe, wrote in the introduction to the first INIBAP Annual Report that "the main thrust of INIBAP's mission in this first phase, as the network establishes its presence throughout the developing regions, is to interact with as many concerned people and institutions as possible. It is by forging harmonious links, at human and institutional levels, that we will evolve successfully toward the creation of a dynamic research network…". Banana researchers are perhaps not the scattered and beleaguered band that they were twenty years ago. And perhaps INIBAP can take some of the credit for linking them together into a more potent force for constructive change. Certainly, promoting constructive exchanges between *Musa* researchers remains at the heart of our business and the Pro*Musa* Working Group convenors (who are drawn from partner organizations, not from INIBAP's staff) recognized this as one of the most appreciated achievements of the network, when they assembled in Montpellier in May 2005 to discuss the way ahead.



INIBAP's second Director, Nicolas Mateo, reflecting on the issues confronting the network some ten years ago, identified:

- The challenge of explaining, especially to donors, the concept and the implications of network economics. How could we convince skeptics that a networking approach to germplasm maintenance, cleaning, testing and distribution represented a more cost-effective instrument than investing in new and costly infrastructure?
- The promise of biotechnology (perhaps initially over-sold) as the key tool to solve most challenges in *Musa* production and in particular those of pests and diseases; and

- The need and the expectation of achieving impact at the level of farmers and consumers, in order to increase competitiveness, reduce rural poverty and contribute to the proper management of natural resources.

Certainly we still struggle to convince some research planners that our peer-networking approach offers a more effective solution than linear technology-development-and-transfer models; we still wrestle with decisions about how much to invest in the latest biotechnology advances and how much in the more down-to-earth technologies, like composting; and our latest major project funded by Belgium's Directorate General of Development Cooperation operates along the whole length of the impact pathway, from basic research into mechanisms of stress tolerance, through evaluation and deployment of productive varieties, to process and market links.

One vital ingredient that has not changed is the commitment of our staff. Dr Mateo noted that "facing the above challenges was possible and bearable due to a most important factor: a small group of individuals at INIBAP with a strong dedication and a clear sense of purpose!" Though INIBAP's staff has grown from just a half-dozen at the beginning to almost 40 in 2005, this still feels like a small group to tackle the many activities in our ever-broader agenda and all are prepared to 'go the extra mile' to fulfill our mission.

In the midst of so much continuity, what has changed? Certainly the threats from many of the same major pests and diseases continue to make the headlines (though sometimes with new recruits joining the battle, such as the bacterial wilt that is now decimating bananas in Central Africa). We still emphasize new varieties as an important part of the solution to many of these problems. However, if we seek to identify an over-arching theme it is perhaps that, with a growing appreciation of the complexity of the world in which the smallholder farmer must operate, we no longer expect to solve problems by providing a single new technology. We seek to offer farmers a range of options from which to choose. On the conceptual side, these are unified by a paradigm of managing diversity in the production system at various levels and for various positive outcomes.

The directors of INIBAP, from left to right: Edmond De Langhe, Nicolas Mateo, Emile Frison and Richard Markham.

Prof. De Langhe is still a very active member of the INIBAP family, participating in the Taxonomy Advisory Group and still helping us to round up new germplasm for the genebank, especially from the Congo basin.

Dr Mateo is now Executive Secretary of the Regional Fund for Agricultural Technology (FONTAGRO) of the Inter-American Development Bank, an organization that is an important partner of INIBAP's network for Latin America and the Caribbean, MUSALAC.

Dr Frison, who presided over the period of most active growth in INIBAP's history, is now Director General of IPGRI where he has led the development of the new strategy Diversity for Well-being.

Dr Markham is seeking to integrate our work on banana with that on cacao and coconut within IPGRI's Commodities for Livelihood *programme.*

Background image: INIBAP's budget growth, from 1987 to 2005, from US$ 0.5 to US$ 6.8 million.

We increasingly emphasize the importance of the various human dimensions involved in technology adaptation and adoption, including the market forces and policy environment that affect us all.

Above all, however, we continue to work with people. The INIBAP network has always been concerned with building human capital, through training and information dissemination, and has done its best to bring people in the banana research-and-development community together. As our agenda evolves, we increasingly emphasize the people who are the intended end-users of our innovations: the smallholder banana farmers and their communities in developing countries. It is fitting therefore that we enter this next phase of our development guided by the new strategy, *Diversity for well-being*, of our parent organization, IPGRI, that focuses explicitly on meeting the needs of people.

In December 2006, not long after this Annual Report is published, IPGRI and INIBAP will take a further important step by changing the name of the combined organizations to Bioversity International. The full implications of this change remain to be worked out as this report goes to press. However, when Bioversity releases its new logo, we shall take this opportunity to drop the use of a separate logo for INIBAP. For historical reasons and to benefit from the recognition of our 'brand' with donors and other partners, we shall retain the name of INIBAP but we shall apply it more strictly to the genetic resources networking that was our original 'core business'. And we shall recognize this step as symbolizing the completion of the process of integrating INIBAP and IPGRI.

Until such time as the French government concludes an establishment agreement with IPGRI, allowing for the legal winding up of INIBAP as a separate organization in France, we shall continue to publish separate accounts and an annual report. However, in future this is likely to be a much more modest and formal document. We shall, however, reallocate the resources that were previously tied up in this publication and use them to reinforce our efforts to serve the banana research and development community by providing other kinds of 'knowledge products' – published on paper and on the Internet. We therefore urge our readers to sign up for one or more of the Pro*Musa* Working Groups and to monitor our website more frequently for the latest development in networking banana and plantain research for the benefit of people.

Emile Frison | Richard Markham

Banking on the future

The genebank INIBAP created is now the foundation of an ambitious plan to conserve the diversity of the world's favourite fruit.

Although only a small fraction of the 250 000 known species of flowering plants have been domesticated, most of them currently play only a minor role in the human diet. Most of the burden of feeding the world falls on just a few crops, of which rice, wheat and maize are the most important. Bananas and plantains are not far behind.

Because the number of staple crop species is so small, their genetic diversity is disproportionately important to meeting the challenge of feeding future generations. The rationale is that the varieties created by farmers and their wild relatives provide a reservoir of variability from which solutions to existing and unforeseen problems can be drawn, hence the need to conserve them. But conservation is a complex task that requires answers to various questions, including which diversity to conserve and where best to conserve it (genebanks, field collections, farmers' fields and, in the case of wild species, natural reserves).

To address these issues and place diversity conservation on a secure, long-term footing, INIBAP is developing and implementing a Global Conservation Strategy for *Musa*. Building upon existing strengths at the international collection managed by INIBAP, and several regional and national collections, the strategy aims to rationalize the global effort to conserve the *Musa* gene pool and promote the safe use and distribution of a wide range of diversity, all the way to farmers' fields.

In contrast to other major crops, for which up to one hundred thousand varieties may exist, the banana is in the enviable position of possessing a manageable level of diversity. With an estimated one thousand varieties, the ambition of conserving the entire banana gene pool is not an unrealistic one.

A first draft of the strategy has been developed within the framework of the Global Crop Diversity Trust, an endowment fund established by the FAO and the centers of the Consultative Group on

Rony Swennen (left) and Ines Van den Houwe (right), shown handing over one of the first consignments of plantlets to scientists from the Taiwan Banana Research Institute, have been managing the INIBAP Transit Centre since its creation in 1985.
KULeuven

Training courses on how to use banana descriptors to characterize varieties have stimulated various efforts to harmonize banana nomenclature.
E. Arnaud, INIBAP

This paper is based on a talk given by Rony Swennen from KULeuven at a symposium on the *Conservation and Use of* Musa *Biodiversity for Improving Livelihoods* held in Leuven, Belgium, on 18 October 2005.

International Agricultural Research to support the long-term conservation of vital food crops (see their website at www.croptrust.org).

KNOW THY DIVERSITY

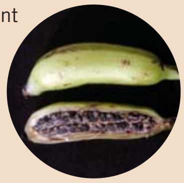
Because domesticated bananas and plantains are seedless, their genetic diversity must be conserved either in field collections as full-size plants, or in genebanks as plantlets derived from the culture of meristem tissue (actively dividing tissue from which all other tissues are derived) and kept in test tubes under slow-growth conditions. The world's largest collection of *Musa*, held at the INIBAP Transit Centre (ITC) and managed by the *Katholieke Universiteit Leuven* (KULeuven) in Belgium, currently contains 1183 accessions[1] (see *High-tech care*).

The maintenance of a central genebank is a necessary foundation for the conservation effort but provides only part of the solution. Field collections are also important for taxonomic characterization and evaluation. Currently there are some 60 collections, each dedicated to conserving part of the banana gene pool; however, there is growing concern about their long-term prospects. Numerous national collections, particularly those that are poorly resourced in Africa and in Asia and the Pacific, are threatened by poor management, natural disasters (flooding, drought, etc.) and diseases. Indeed, some accessions have already been lost from the field collections from where they originated and are now represented only by *in vitro* cultures.

Investment in genebanks is easier to justify if the genetic material being conserved is widely used by breeders and other researchers. But so far only a narrow range of genotypes is used and, even at the ITC, only a fraction of the accessions are regularly requested. Conventional breeding has traditionally rested on a rather narrow range of genotypes capable of engaging in fertile crosses, but other techniques, such as genetic transformation, should widen the range of materials from which useful genes can be accessed, underlining the need for more complete characterization. In that perspective, the ploidy levels of the accessions in the ITC collection have been determined by the Institute for Experimental Botany and

The domestication of the banana

Wild bananas are typically full of seeds. They became edible when some plants mutated to produce fruits that had more flesh than seeds, prompting farmers to propagate the offshoots (known as suckers) growing at the base of the plants. But since these edible diploids were still fertile, they could also be fertilized by wild bananas. Domestication went into high gear when, during such a crossing, one of the parents gave 'by mistake' all of its chromosomes, instead of half as sexually reproducing organisms normally do. What these new triploid varieties gained in productivity, they lost in fertility. From that point on, diversity was mainly created by farmers selecting advantageous mutations.



Fruit full of seeds of a wild Musa acuminata. R. Markham, INIBAP

The domestication of the banana plant for its fruits started with the appearance of fleshy parthenocarpic fruits – fruits produced without the need for pollination. S. Sharrock, INIBAP

Edible diploids are still eaten in certain parts of the world. In Papua New Guinea (below) the parthenocarpic fruits of Musa peekeli *are eaten despite the presence of seeds. In Thailand and India, semi-wild* Musa balbisiana *are similarly propagated by farmers and eaten when other foods are scarce.* S. Sharrock, INIBAP

The tallest banana plant on earth, Musa ingens, *grows in Papua New Guinea. Like all wild bananas, it is diploid, but unlike the others it has 7 pairs of chromosomes, instead of the usual 10 or 11 pairs.* S. Sharrock, INIBAP

Wild beginnings

Wild bananas belong to the genus *Musa*, which is native to the tropical and sub-tropical forests of Asia and Oceania that extend from India to the Pacific. Botanists have identified some 50 species of bananas, the exact number being subject to change as new specimens are collected and taxonomic arguments are settled. Like humans, wild bananas are diploid, that is they have two sets of chromosomes, one from each parent.

The majority of today's bananas are related to either Musa balbisiana *(right), or* Musa acuminata *(above) or both.* K. Tomepke, CARBAP

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[1] An accession is a species, a variety or a population registered at a genebank.

Cultivating diversity

The most well-known triploid bananas, at least in banana-importing countries, belong to the Cavendish group that dominates the international trade. These bananas trace their origin to *Musa acuminata* only, but many cultivars also have *Musa balbisiana* in their lineage. Other species have also left a trace in certain varieties, but their contribution is more limited, except in the Pacific, where another species gave rise to an unusual group of bananas that are rich in precursors of Vitamin A.

Plantains are a large group of cooking bananas that contain genes from Musa balbisiana *as well as* Musa acuminata. *They are at their most diverse in West and Central Africa.* K. Tomepke, CARBAP

Easily recognized by their erect bunch, Fe'i bananas are found only in the Pacific Islands. Their origin is obscure. J. Daniells, QDPI

By propagating the suckers of their favorite mutants, farmers created bananas of various colours and shapes to suit all sorts of tastes and uses. Clockwise: K. Tomekpe, CARBAP, S. Sharrock, INIBAP, M. Hakkinen, V. Lebot, CIRAD, J. Daniells, QDPI

characterization using morphological characters and genetic markers is under way.

Molecular characterization also holds the hope of contributing to a definitive taxonomy of bananas. The banana is notorious for the proliferation of names associated with a single variety or highly similar varieties. Although some names are clearly synonyms, others are more difficult to pin down because they correspond to morphological differences that depend on the conditions under which the plant is grown. Environmental influences on morphology need to be teased out and varieties distinguished on a sound genetic basis. Molecular markers capable of distinguishing between very closely related cultivars have yet to be found, but matching morphological characters with molecular profiles should serve as a springboard for harmonizing the taxonomy and rationalizing the *Musa* collections around the world. Indeed, one of the first major steps of the strategy is to coordinate a global effort to characterize *Musa* accessions and establish a working taxonomy by which all researchers on banana can understand one another.

Bananas originate from the tropical forests of Asia, where rates of deforestation are particularly high. R. Markham, INIBAP

STOPPING THE DIVERSITY DRAIN

The urgent need for a concerted strategy is underscored not only by the precarious situation of some genebanks and field collections, but also by the disappearance of traditional varieties from farmers' fields and the destruction of natural habitats harbouring wild relatives.

At present, the majority of banana farmers rely on only a fraction of the known diversity. Of the 105 million tonnes currently being grown, some 16 millions are accounted for by the export trade, which is represented by just a few, genetically very similar, cultivars belonging to the Cavendish group. The rest of the production is eaten or sold locally but increasingly tends to be dominated by a relatively small number of cultivars.

Many varieties are either no longer cultivated or found only in a few strongholds, frequently in remote or marginal areas where the tradition inherited from a bygone age, when crop diversity was the key to food security, still prevails. On-farm conservation can play a role in maintaining cultivated diversity (see *Reconciling modernity and tradition to conserve diversity* in the 2004 annual report) but the importance of that role will depend on the sustainability of the mechanisms put in place to foster it.

Field collections, such as the one managed by the Centre Africain de Recherches sur Bananiers et Plantains *(CARBAP) in Cameroon (left) are an important element of a global strategy for conserving the diversity of bananas, but staff may have to destroy infected plants in their fight against diseases (right).* R. Markham, INIBAP

Also at risk are the banana's wild relatives, which disappear when their natural habitat—the tropical and sub-tropical forests of Asia—is destroyed by logging, replaced by cities or transformed into cultivated land. Since conservation in genebanks and field collections puts a stop to their evolution, wild relatives also need to be conserved in their natural habitat where they can continue to change and adapt.

A better understanding of the diversity of bananas and more effective mechanisms for their conservation and exchange should lead to the development of healthier and tastier bananas for consumers everywhere, as well as providing novel solutions to the production problems that are inherent in agricultural systems based on a narrow range of varieties. Consumers in industrialized countries can expect to see more than the standard Cavendish banana in their shops. In developing countries, bananas could play a larger role in providing food security and fighting specific nutritional deficiencies. In the end, however, it is by demanding and using diversity that we, as a world community, will ensure its conservation.

Collecting the past to secure the future

Banana taxonomists tend to be real enthusiasts, who will always want to explore new areas, pose new questions and collect more plants. According to experts on wild bananas, more exploration is needed to refine the boundaries between species and sub-species and to ensure a complete coverage of the existing diversity—or what is left of it, given the rate at which natural habitats are being lost. However in the context of conservation, scarce resources have to be allocated strategically to surveying the areas of highest diversity or those whose diversity seems most at risk.

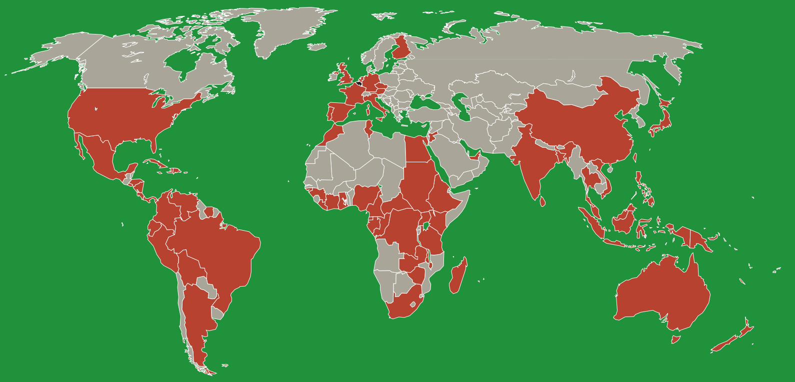
The same holds true for cultivated varieties, which are also disappearing fast. In India, for example, more than 90% of tribal hamlets are estimated to have halted cultivation of lesser-known traditional varieties. In Africa, which is a secondary centre of diversity for plantains and an endemic group of highland bananas, INIBAP is planning to return to the Democratic Republic of Congo and Tanzania, where previous collecting missions have uncovered varieties absent from genebanks.

The world's foremost expert on bananas, and INIBAP's first director, Edmond de Langhe was born in what was then Belgian Congo, a place to which he has returned many times to work on bananas. R. Stevens

Deborah Karamura of INIBAP is an aknowledged expert on East African highland bananas, a highly diversified group of some 80 varieties, used mainly in cooking and beer-making, which occupy the fertile mountains around the Great Lakes area and are found nowhere else. INIBAP

A former merchant marine ship captain, Markku Hakkinen embarked on a second career as a banana specialist some 30 years ago after becoming fascinated with a banana plant he had bought at a market in his native Finland. He is currently a research fellow at the University of Helsinki and close collaborator of INIBAP. He has conducted many collecting missions in Southeast Asia and has written over 30 articles on bananas. Mrs Hakkinen

High-tech care



Since its creation in 1985, the ITC has shipped more than 60 000 Musa *samples to 200 institutions in 88 countries.*

The fact that Belgium does not grow bananas played in its favour when, in 1985, the newly-created INIBAP opted for the university town of Leuven as the place to set up the INIBAP Transit Centre (ITC). As the name suggests, the genebank was meant to be a hub for germplasm movement. Locating it in a non-producing country facilitated the receipt of banana samples from anywhere in the world, due to the absence of quarantine restrictions. Distributing it, however, was another matter. Care had to be taken not to pass diseases along with the plant material, especially when the destination was a place still exempt from certain diseases.

Because cultivated varieties of bananas are seedless, they are conserved as plantlets in test tubes.

Since domesticated bananas do not produce seeds, scientists have used the plant's propensity for producing shoots to conserve bananas as small plantlets in test tubes. Because they are grown on a sterile medium, it is possible to ensure, through rigorous testing and culture procedures, that they are free of bacteria and fungi. This is not necessarily the case for viruses, which—as cell parasites—may need special therapy and intensive testing (carried out by certified 'indexing' centres) to be reasonably confident that the plantlets are virus-free and can be cleared for distribution. Indeed, the continued presence of viruses in 37% of the accessions means that this part of the collection is not available for general circulation, although therapies have recently been developed for some viruses and research is continuing to find ways of removing the others.

Deep-freezing meristematic tissue to the temperature of liquid nitrogen (-196°C) makes it possible to store viable plant tissues for thousands of years.
B. Panis, KULeuven

Even though the temperature and lighting are kept at a minimum to slow down the growth process, the plantlets eventually outgrow their test tube. As a consequence, each accession is re-cultured once a year. In addition, experience suggests that tissue-culture material should be replaced every 10 years to control for the risks of somaclonal variation, altered characteristics in plant tissues that have been kept in test tubes for an extended period of time. A programme to rejuvenate the collection was launched in 2001. For a given accession, plants are grown in greenhouses and 'decapitated' to supply suckers. From these suckers is derived material both to replace the tissue-culture samples in medium-term storage, and for sending into the field so that taxonomists familiar with the particular material can check for its trueness-to-type.

Research carried out at KULeuven has provided an extra level of insurance to the conservation effort by developing methods that allow all kinds of banana to be safely conserved in liquid nitrogen. At these ultra-low temperatures, so-called 'cryopreservation' arrests both the growth of plant cells and all processes of biological deterioration, so that the material can be preserved, safely and cost-effectively, and resuscitated into fully viable banana plants. So far, more than one-third of the banana collection has been safely stored away in liquid nitrogen and, as yet further insurance, a duplicate set is being prepared for safe-keeping at a separate location. The expertise developed in the process has led to the recognition of KULeuven as a centre of excellence in cryopreservation, not just for banana but for other crops as well.

ONE-SIZE-FITS-ALL CRYOPRESERVATION

As recently as three years ago, scientists trying to cryopreserve parts of plants would try something and if that didn't work, they would try something slightly different. This trial-and-error approach produced results but was not efficient when venturing into unexplored territory. A European project—CRYMCEPT, short for establishing CRYopreservation Methods for Conserving European PlanT germplasm collections—changed this when it set out to identify the crucial components needed for successful cryopreservation. The scientists from the Laboratory of Tropical Crop Improvement at KULeuven were part of a multi-national team of scientists working on different plants and analysing various parameters.

Contrary to what might be believed, the main key to success is not having plant tissues that are tolerant to freezing—otherwise, being tropical, banana plants could not be cryopreserved—but in having plant tissues that are tolerant to dehydration. The major concern when freezing living cells is avoiding the formation of ice crystals. Ice crystals are capable of puncturing the cellular membrane, which will then lose its capacity to control what goes in and out of the cell. Avoiding ice crystals by removing all the water is not an option, as the cell will surely die. The solution, known for some time, is vitrification, a solidification process that does not involve the formation of ice crystals and gives the tissue a glassy look.

The KULeuven researchers were already using vitrification to cryopreserve banana meristems. Prior to freezing, the cells are exposed to a vitrification solution high in compounds like sucrose and glycerol. Osmosis causes some of the water to move out of the cells into the solution, dehydrating the cells without killing them.

The vital new ingredient was to add a drop of the vitrification solution to a section of meristematic tissue placed on a small piece of aluminium foil and then plunging it into liquid nitrogen. Being syrupy, the solution sticks to the foil. Compared to the standard procedure, in which the tissues are placed in a small tube, this method more quickly freezes the tissues, which are now in direct contact with the liquid nitrogen (it is only after they have been frozen that the plant cells are stored in a tube). Rapid freezing and thawing turned out to greatly increase survival when the tissue is subsequently thawed.

After succeeding with bananas, the KULeuven scientists tried their cryopreservation protocol with taro, potato, strawberry, chicory, date palm and pelargonium. Their method worked almost immediately. When they have had to make adjustments, it was often in the part of the tissue-culture plant that was used or in the amount of time the meristematic cells are exposed to the vitrification solution.

Hungry for improvement

As INIBAP and its partners have learned, breeding better bananas takes time and determination.

Domesticated bananas are often taken to task for having given up the plant equivalent of sex and as a result lack the genetic diversity that would help them fend off pests and diseases. But too much genetic diversity can be as much a problem as a lack of it. Most crops are derived from the small group of wild plants that are either "selfers"—that have both male and female flowers and pollinate themselves—or that, like wild bananas, reproduce vegetatively as well as sexually. Cross-pollination is better at generating diversity but self-pollination or vegetative reproduction is more effective for fixing a desired genotype and reliably reproducing it.

The problem with bananas is that their capacity to produce diversity was drastically reduced by domestication (see *Banking on the future* in this report). Had all bananas lost the ability of exchanging genes with each other, the options for their improvement would be limited to selecting advantageous mutations, spontaneous or induced, and to introducing the desired trait through genetic modification. Fortunately for breeders, some varieties have hung on enough fertility to make hybridization a viable avenue.

Wild bananas are fully fertile but the seeds produced in the course of breeding usually have only a 1% chance of germinating. To increase the odds, breeders "rescue" the embryo, that is they pry open the seed and extract the embryo to grow it on an artificial culture medium.
M. Hakkinen

THE BANANA BREEDER: LONELY NO MORE?

Getting bananas to take up sex again was not easy. The first one to try gave up. When the United Fruit Company abandoned the idea of breeding a commercial banana in 1984, it donated its breeding programme to the *Fundación Hondureña de Investigación Agrícola* (FHIA), in La Lima, Honduras. When INIBAP came on the scene the year after with its mission to increase the productivity of the smallholder crop, it started channelling financial support to the Honduran breeding programme, which, capitalizing on more than 25 years of tinkering with bananas, was soon able to deliver disease-resistant hybrids.

Before they were released, the hybrids were field-tested in the newly-created International *Musa* Testing Programme (IMTP) set up by INIBAP in 1989 (see *Globe-trotting hybrids* in this report). One of the explanations offered for the slow progress of banana breeding had been that breeders were receiving little guidance from other disciplines. The IMTP addressed this by making the material they produced available for study by pathologists and other scientists under different environmental conditions.

Forging inter-disciplinary links was further encouraged with the creation in 1997 of the Global Programme for *Musa* Improvement (Pro*Musa*). At the origin, it consisted of six interlinked working groups, each focusing on a particular subject—genetic improvement, fusarium wilt, *Mycosphaerella* leaf spot diseases, weevils, nematodes and viruses—but all from the point of view of providing support to banana breeding efforts.

Although Pro*Musa* is perceived as a valuable forum for advancing research and addressing urgent questions, it is also felt that its operating mechanisms need to change, both to stimulate interaction among specialists and to take into account the difficulty of coordinating such a network with minimal financial support from donors. Indeed, it has proved increasingly difficult to attract the interest of donors to conventional breeding efforts as a whole. Funding for the IMTP dried up after the first phase and public-sector support to FHIA ended in 2004.

Of course, the lack of international donor interest in networking has not spelled the end of banana breeding. The field is not as crowded as for the other major crops, but a handful of centres are still working at it. In Latin America and the Caribbean, the veterans are the *Empresa Brasiliera de Pesquisa Agropecuaria* (EMBRAPA) which focuses on breeding bananas for the Brazilian market and

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This paper is based on a talk given by Michael Pillay from IITA at a symposium on the *Conservation and Use of Musa Biodiversity for Improving Livelihoods* held in Leuven, Belgium, on 18 October 2005.

Giving bananas a helping hand. To obtain enough seeds to evaluate, breeders may have to pollinate thousands of flowers (left). The fruits resulting from this forced coupling are pressed (middle) and sieved (right) in search of seeds, any seeds. R. Markham

the Guadeloupe research station of *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD), which is breeding mainly for export. Cuba has recently joined the fray when the *Instituto de Investigaciones en Viandas Tropicales* (INIVIT) started a banana breeding programme. In India, the National Research Centre on Banana (NRCB) and Tamil Nadu Agricultural University have created numerous hybrids, while in Africa, banana breeding is mainly conducted by the International Institute of Tropical Agriculture (IITA) and the *Centre Africain de Recherches sur Bananiers et Plantains* (CARBAP).

IMPROVING IMPROVEMENT

The approach honed by FHIA, which consists of crossing triploid varieties with elite diploids to obtain tetraploid hybrids (see *Breeding pains*), is still used but other methods have also been developed to avoid some of the drawbacks associated with tetraploids. Although these hybrids tend to be more productive, having a large bunch can be another example of 'too much of a good thing' when it causes the plant to topple over. Tetraploid hybrids also produce fruits that have a high water content and become soft fairly quickly. And some farmers find the large plants unwieldy—especially when it comes to disposing of the trunk and other vegetative parts after harvest. Finally, having an even number of chromosome sets can restore fertility and may lead

Breeding pains

At the beginning of the 20th century, breeders were mainly interested in improving the Gros Michel banana dominating the export trade of the time. This banana had many virtues—especially a great taste and a bruise-resistant skin ideally suited for long-distance travel—but its great weakness was a susceptibility to a rapidly spreading fungal disease, fusarium wilt, better known as Panama disease.

Fortunately for breeding purposes, Gros Michel can be stimulated to produce seeds when fertilized with the pollen of wild bananas. Since Gros Michel is triploid and its reproductive cells can contain anything between one to three sets of chromosomes, crossing it with a diploid will produce descendants that have two, three or four sets of chromosomes. Breeders were mainly interested in the tetraploid progeny since these hybrids had the biggest bunches. But few of them had both the fruit quality of the female parent and the disease resistance of the male. The burden of responsibility for the poor quality of the hybrids was put on the male parent. The solution was to create 'elite' male parental lines better equipped to express their resistance to disease and possessing improved fruit qualities.

Breeders crossed the most promising diploids with each other to produce elite male parents, an approach that turned out to be very lengthy. The elite diploid known as SH-2095 took more than ten years to develop. In the process, more than 10 000 plants had to be evaluated for their agronomic qualities and disease resistance. Once breeders had their elite parents, they used the pollen to fertilize seed-fertile triploid varieties, thus initiating another cycle of crosses and evaluations for the elusive improved hybrids.

Thanks to this strategy, traces of Gros Michel live on in some FHIA hybrids, such as FHIA-17 and FHIA-23, but, by the time the FHIA hybrids were released, Gros Michel had long been displaced in commercial plantations by Cavendish bananas, which are resistant to fusarium wilt. It was soon found out, however, that the new staple of the international trade was susceptible to another fungal disease, black leaf streak disease, better known as black Sigatoka. Even though FHIA hybrids tend to be resistant to these fungal diseases, as well as to some pests—and at least one, dubbed 'Goldfinger' in the Australian market, has shown that it can be successfully commercialized—none has managed to shake the hold that the Cavendish varieties have on the international trade.

Family resemblance. FHIA-26 (left) with its parents, an elite diploid (centre) and the cultivar Pisang awak (right). FHIA

FHIA breeders succeeded in created a disease-resistant hybrid using Gros Michel as one of the parents. K. Tomepke, CARBAP, A. Javellana

to the production of seedy fruits when the flowers are pollinated. But this feature is not only a disadvantage. Some breeders have exploited it, by crossing tetraploid hybrids with elite diploids, to obtain more reliably sterile triploids.

In the search for alternatives, CIRAD has devised an original strategy that comes closest to reproducing what appeared in the course of domestication. Since the ancestors of bananas are diploid, the first triploids appeared when one of the parents underwent abnormal meiosis (the process of cell division that reduces by half the number of chromosomes in the reproductive cells) and gave both copies of its genes instead of just one. But breeders don't have the luxury of waiting for mistakes to happen. What CIRAD breeders have done is to select diploids and double their number of chromosomes by using colchicine to produce autotetraploids. They then cross these tetraploids with diploids to obtain triploids that inherit half of each parent's genome by the normal process of meiosis.

Having four sets of chromosomes may sometimes be too much for the plant to bear if the bunch is too heavy (left). Tetraploid hybrids also sometimes produce fruits that contain seeds.

An advantage of this strategy is that all or most of the genes in the diploid whose genome was doubled end up in the triploid hybrid, while the use of more fertile parents usually translates into a larger number of progeny to choose from. This method also makes better use of the known diversity as more diploids can be recruited into breeding schemes.

While CIRAD relies on this strategy to breed dessert bananas, CARBAP has adopted it to produce cooking bananas that contain no trace of *Musa balbisiana*, the wild species that has contributed at least one set of chromosomes to most cooking bananas, including plantains. Some breeders stopped using bananas related to *balbisiana* as a parent when it was established that the genome of the banana streak virus was integrated in the genome of the wild species and its domesticated descendants. Under certain circumstances, and hybridization is one of them, the complete sequence of the virus is capable of reassembling itself and generating infectious viral particles (see *The accidental pathogen* in the 2004 annual report). To avoid this, CARBAP breeders took advantage of molecular studies that had traced the cooking qualities of a *balbisiana*-free group of bananas to the subspecies *M. acuminata banksii*. By carefully selecting the parents, they were able to produce triploid hybrids, with the typical starchy flesh of cooking bananas, but of purely *acuminata* origin.

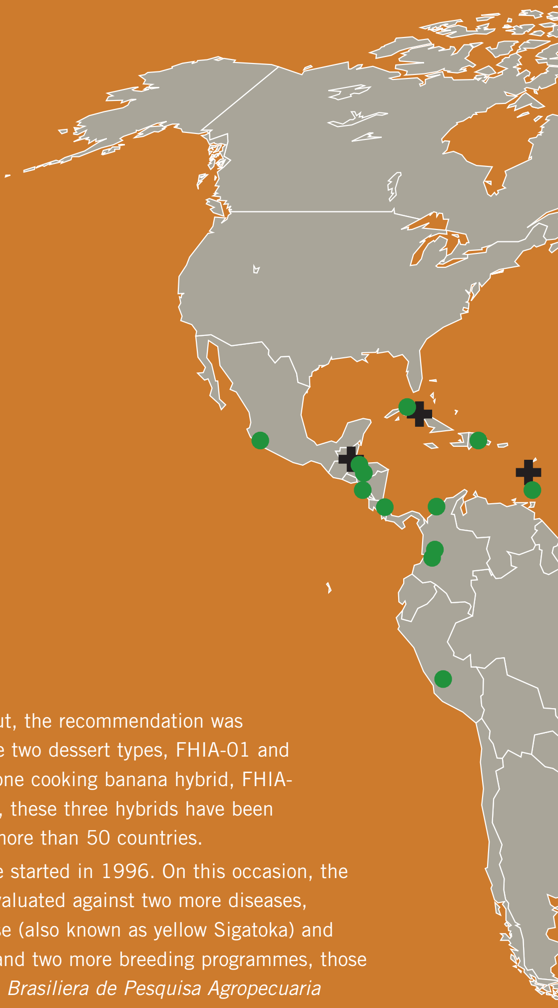
WHAT NEXT?

In their quest for new challenges and opportunities, breeders are now moving beyond breeding for resistance to pests and diseases to include such traits as tolerance to cold and drought, to help banana growers cope with climate change or extend to areas currently considered marginal for production. The drive to improve the nutritional quality of crops is also offering a new target for breeders. For bananas, the interest lies mainly in carotenoids, which the body converts into Vitamin A. Some banana varieties have been shown to contain high levels of these micronutrients. In Micronesia, bananas belonging to the Fe'i group are being used to fight Vitamin A deficiency, a source of debilitating health problems in the developing world. Research is under way under the Harvest Plus Challenge Programme to screen other cultivars for their carotenoid levels and to breed the trait into less well endowed varieties. Plantains, which are an important staple in many regions, are interesting candidates for this approach since some varieties, with yellow or orange flesh, are naturally high in carotenoids.

Given the difficulties inherent in breeding bananas and plantains, some scientists have turned their sights to genetic transformation as a way of introducing genes into bananas without disrupting their agronomic qualities. Moreover, the lack of cross-fertile wild relatives in many banana-producing areas and the sterility of most cultivated varieties reduce, to negligible levels, the risk of genes escaping from genetically-transformed bananas. Over the years, INIBAP has coordinated research projects that have contributed to advances in genetically modifying varieties important to smallholders (see *Gene power fuels an African agricultural revolution* in the 2003 annual report)

Compared to conventional breeding, genetic transformation has other types of obstacles to overcome before it can be used to create new banana varieties. Consumer acceptability is only one of them. But whether or not the future of banana breeding is biotech, it will surely be high-tech, as new technologies come to the aid of the ancient art of crop breeding. ❧

Globe-trotting hybrids



A plantain hybrid, FHIA-21.
A. Javellena

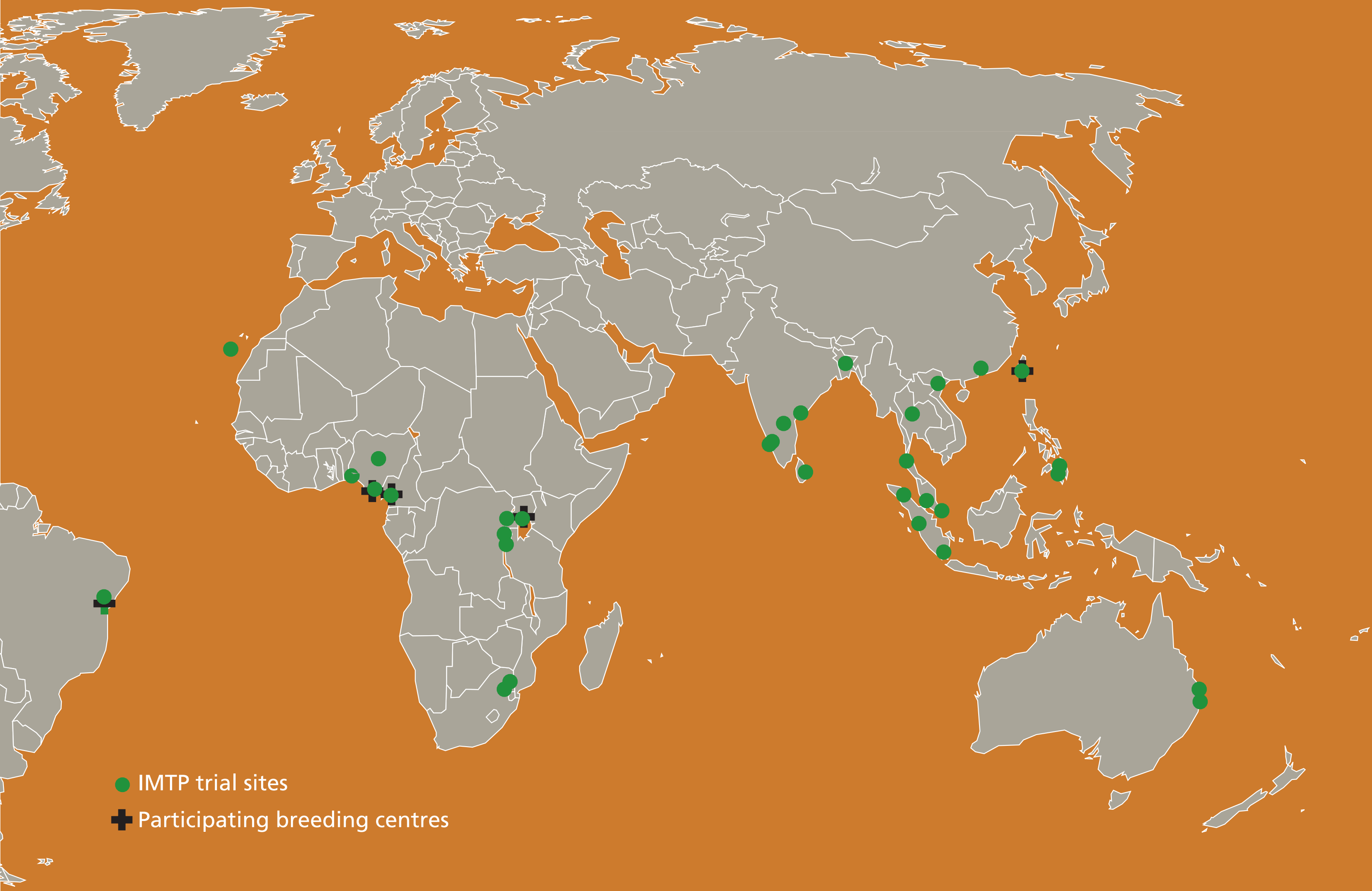
In 1989, INIBAP set up the International *Musa* Testing Programme (IMTP) to evaluate across a wide range of growing conditions the banana hybrids produced by breeders. The first phase of this collaborative effort focused on the evaluation in six countries (three in Latin America and three in Africa) of seven hybrids produced by the *Fundación Hondureña de Investigación Agrícola* (FHIA). Their resistance to black leaf streak (better known as black Sigatoka) was compared to several varieties known to cover the whole spectrum of possible responses, from highly resistant to highly susceptible. When the results came out, the recommendation was made to release two dessert types, FHIA-01 and FHIA-02, and one cooking banana hybrid, FHIA-03. Since then, these three hybrids have been distributed to more than 50 countries.

A second phase started in 1996. On this occasion, the hybrids were evaluated against two more diseases, Sigatoka disease (also known as yellow Sigatoka) and fusarium wilt, and two more breeding programmes, those of the *Empresa Brasiliera de Pesquisa Agropecuaria* (EMBRAPA) and the *Instituto de Investigaciones en Viandas Tropicales* (INIVIT), contributed some of their new varieties. The Taiwan Banana Research Institute (TBRI) also offered somaclonal variants for evaluation. The number of testing sites increased to 37, even though the participating institutes now had to finance their trials. The results singled out FHIA-23 and SH-3436-9 as the most tolerant to black leaf streak. The hybrid with the best overall performance was FHIA-23, although GCTCV-119 was also commended.

At present, 25 countries are participating in the third phase. In addition to FHIA and TRBI, the International Institute of

Breeders whose creations have been tested in field trials: the late Phil Rowe of FHIA (left) and Kodjo Tomekpe, current Director General of CARBAP (right).
D. Jones, R. Markham, INIBAP

Visiting an IMTP trial in India.
G. Orjeda, INIBAP

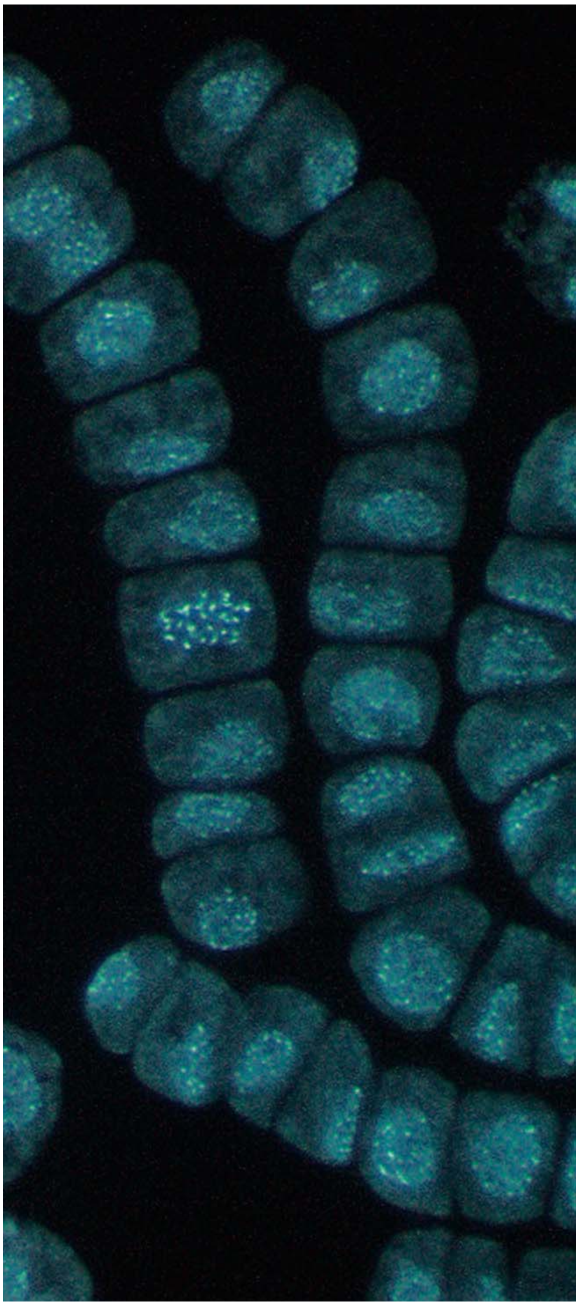


Tropical Agriculture (IITA), the *Centre Africain de Recherches sur Bananiers et Plantains* (CARBAP) and the *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD) have also volunteered hybrids for evaluation. For the first time, the partners were able to choose between carrying out an in-depth study involving epidemiological and ecological research, and a simplified performance trial against specific diseases. As in previous phases, partners used shared methodologies to ensure that results can be compared across sites.

One of the toughest tests hybrids have to pass is having their taste compared to that of local cultivars.
T. Hemelings, KCDP

Unlocking the secrets of the banana genome

Will genomics, the science emerging around the sequencing and deciphering of the functions of genes, change the way we grow food?



Genomics should help understand the processes that underlie the problems affecting bananas and, as a result, improve the lives of smallholders.
G. Orjeda, INIBAP

If all that mattered were the number of genes, we wouldn't be able to explain why humans, and not bananas, are the species who solved the genetic code, sequenced their own genome and are busy doing the same for other species. Humans and bananas both have about 30 000 genes. The challenge is to understand the similarities—and what makes us so different.

As genes are identified and functions are assigned to them—the goal of genomics—we shall come to understand how banana genes interact with each other and the environment to make a plant thrive or die. The hope is that this knowledge will translate into sustainably higher yields, especially for the smallholders who grow over 85% of the bananas harvested in the world.

Breeders have largely confined their search for genes to Musa acuminata *and* Musa balbisiana, *but other wild species might harbour agronomically-interesting characteristics, such as mechanisms for tolerance to cold, water-logging or drought. From left,* Musa campestris, Musa borneensis *and* Musa velutina.
M. Häkkinen

This paper is based on a talk given by Pat Heslop-Harrison from the University of Leicester at a symposium on the *Conservation and Use of* Musa *Biodiversity for Improving Livelihoods* held in Leuven, Belgium, on 18 October 2005.

One compelling motivation is provided by the fact that most of the existing varieties haven't changed substantially since the time they were selected from the wild and nurtured by farmers over thousands years, whereas the conditions—economic and agronomic—under which they are cultivated have changed spectacularly. Bananas are beset by a host of pests and diseases while the loss of agricultural land to urbanization and unsustainable agricultural practices is forcing many farmers to grow bananas in less than optimal settings. What smallholders need are bananas that can overcome these challenges and still possess the qualities that growers, traders and consumers have come to expect. This is a tall order, given the difficulty of crossing varieties which, for all practical purposes, are sterile (see *Hungry for improvement* in this report).

The same constraints that make breeding bananas a long and laborious process also limit the application of classical genetics to understanding the processes that underlie the problems afflicting bananas. Banana genomics is still in its infancy and its agricultural benefits are still largely theoretical. Like other branches of banana research, it remains relatively under-resourced, but a networking approach is helping researchers make the most of what they do have and this approach has certainly accelerated gene discovery. Since 2001, most of the genomics work on bananas is being done by scientists who are members of the Global *Musa* Genomics Consortium for which INIBAP provides the secretariat. What they are finding has implications not only for agriculture, but also for conservation and fundamental research.

A first glimpse into the genome

Since the vast majority of domesticated varieties of banana are related to one or two wild species, scientists have not one but two genomes to look at; *Musa acuminata* donated the so-called A genome and *Musa balbisiana* the B genome. As a prelude to sequencing the banana genome, the DNA of *acuminata* and *balbisiana* plants was duplicated and broken into smaller pieces that are easier to handle. These DNA fragments were inserted into bacteria for safe keeping as 'bacterial artificial chromosomes' (BACs). Consortium members have developed five BAC libraries: one of *balbisiana* and four of *acuminata*. The BAC libraries are freely available to the research community through the *Musa* Genome Resources Centre, hosted by the Institute of Experimental Botany in the Czech Republic (see *A resourceful centre* in this report).

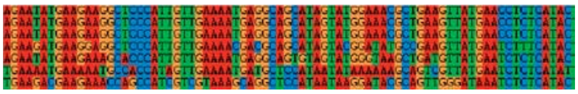
A first glimpse into the organization of the A genome was provided when the Laboratory of Gene Technology at the *Katholieke Universiteit Leuven* (KULeuven), in Belgium, sequenced two BAC clones from one of the *acuminata* BAC libraries (the wild diploid Calcutta 4). The gene density was, on average, one for every 8700 bases (8.7 kb). Less than 50% of the DNA in these clones was coding for genes. Like most plant genomes, the banana genome seems to comprise gene-rich areas that are separated by long stretches of repetitive sequences. And as scientists have known for some time, the B genome—and maybe the A genome as well—contains viral DNA from the *Banana streak virus*, which, in the course of the evolution of *balbisiana*, has found a niche in the banana's genome (see *The accidental pathogen* in the 2004 INIBAP annual report).

BAC clones have also been used to compare banana sequences with those of rice, a monocotyledon like banana, and *Arabidopsis*, a dicotyledon. By virtue of being sequenced, the genomes of these plants have become the yardstick against which genomes-in-waiting are compared, but their current prominence may diminish as other genomes yield up their secrets. A first round of comparison done at The Institute for Genomic Research (TIGR), in the United States, found less similarity with rice and more correspondence with *Arabidopsis* than anticipated. Banana's evolutionary position, relatively far from the major cereal crops and with similarities to various dicotyledons, may help to make it a useful point of comparison. (see *The comparative advantage of bananas*)

Mining the genome

To obtain the complete sequence of the banana genome, a representative genotype will be chosen and each clone in its BAC library will be sequenced. A computer programme will then match the overlapping ends to reassemble the entire sequence

Calcutta 4 is the common name given to the Musa acuminata *sub-species* burmannicoides. R. Markham



from the tens of thousands of clones in the BAC library. Identifying the genes buried in the litany of As, Cs, Gs and Ts that represent the four DNA bases of the genetic code is only a beginning. The next task is to find out their function.

Indeed, long before the entire genome sequence is available, there are other ways to search for useful genes. Since nature didn't start from scratch with each species, the genome can be mined for genes known to exist in other species, whereas ESTs (expressed sequence tags) and complementary DNA (cDNA) provide a short cut to discover commonly expressed genes and genes that are expressed in specific conditions, such as disease, infection or drought. The procedure starts with the harvest of messenger RNA (mRNA)—the molecule that carries the information encoded on the DNA to be translated into proteins. The presence of mRNA in a cell indicates that the genes for which they act as intermediary are active. But because of the transient nature of the RNA molecule, scientists transcribe it into the more stable cDNA. The sequence of a certain number of bases at either or both ends of the cDNA is an EST. It need only be long enough to act as a tag for the gene encoded in the cDNA.

What farmers need are cultivars that can grow in extreme conditions.
INIBAP, J. Daniells

The method is popular with scientists trying to isolate agronomically important genes, such as those involved in a plant's response to biotic or abiotic stresses. In these instances, the mRNA is collected from a plant submitted to the stress in question—be it a pathogen, extremes of temperature or drought—or from a normal or developing plant, when the goal is to zero in on genes involved in its day-to-day functioning or development.

A resourceful centre

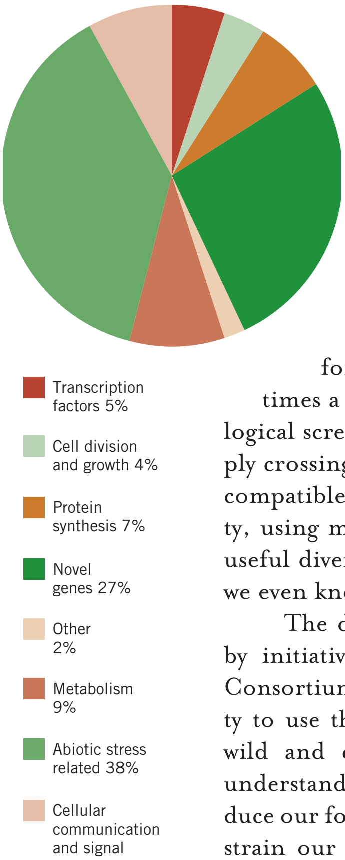
Whenever possible, the Global *Musa* Genomics Consortium is committed to placing the products its members have developed in the public domain. To do this it has set up the *Musa* Genome Resources Centre as its distribution arm. The primary aim of the Centre is to support the research activities of the Consortium by making available *Musa* genome resources to its members and by developing new resources. Under some circumstances, the Centre also distributes its resources to individuals and research organizations outside the Consortium. The main limitation is that users have to sign an agreement ensuring that the resources remain in the public domain.

Five BAC libraries are currently available. They include one *balbisiana* BAC library of the wild diploid Pisang klutuk wulung donated by the *Centre de Coopération internationale en recherche agronomique pour le développement* (CIRAD) and four *acuminata* BAC libraries: two are of the wild diploid Calcutta 4 (one from CIRAD and the other from Texas A&M University), one is of the wild diploid Tuu gai from the *Centro de Investigación Cientifica de Yucatán* (CICY), and the fourth is of the triploid cultivar Grande naine from CIRAD.

The Centre also provides libraries of expressed sequence tags (ESTs), insert DNA, repetitive DNA clones and molecular markers. Information about the Centre is available at http://www.musagenomics.org/index.php?page=resources

Jaroslav Dolezel of the Institute of Experimental Biology, which hosts the Musa *Genome Resources Centre.*
A. Vezina, INIBAP

Genome sequencing at The Institute for Genomic Research in the United States.
TIGR



Breakdown of the 22 candidate genes linked to drought stress identified by scientists from the University of Leicester.

In Brazil, scientists from EMBRAPA and the Catholic University of Brasilia, took samples of Calcutta 4 leaves exposed to temperatures as cold as 5°C and as hot as 45°C, to build two cDNA libraries, one for each type of temperature stress. About 10% of the sequenced cDNAs were present in both types of stressed leaves, while 42% were present only in the leaves exposed to cold and 48% only in the ones exposed to hot temperatures.

Meanwhile in the UK, a team from the Department of Biology at the University of Leicester has isolated candidate genes involved in the tolerance to drought in three dessert cultivars (AAA). The scientists gave one plant its daily share of water (200 ml) but withheld most of it from another. The expression profile of the cDNA led to the identification of 22 candidate genes. The scientists were able to show that 3 of the genes had been activated by the drought stress, 5 had been down-regulated and 14 had been turned off. The genes were then classified according to their putative function. Nearly 40% of them were genes that had never been identified before (pie chart, above).

Many Consortium members are similarly busy building EST and cDNA libraries of genes expressed in male flowers, young leaves, roots of *in vitro* plantlets, the peel of green fruits, leaves exposed to the fungus *Mycosphaerella fijiensis* (the causal agent of black Sigatoka) and plants wounded by weevils, to name only a few. The sequences, as they are elucidated, are posted on the website of the Global *Musa* Genomics Consortium so that others can join the effort of comparing and analysing them.

GETTING A HANDLE ON DIVERSITY

Even when the genes have been identified and their functions revealed, another challenge will remain: to document allelic diversity—which is the difference between knowing that a gene codes for eye colour, for example, and knowing which variant, or allele, codes for blue eyes and which one for brown. This is a crucial piece of the puzzle for breeders, who want to be able to recognise individual alleles in crosses to ensure that the new variety expresses the characteristic they want to impart. The same holds for scientists who want to genetically engineer bananas.

This level of knowledge would also help to ensure that collections capture the existing allelic diversity, which in turn is expected to increase the use of the diversity conserved in genebanks. At the moment, the search for useful traits is a laborious, or sometimes a rather hit-or-miss affair, involving biological screening in the field or glasshouse, or simply crossing the relatively few materials known to be compatible. Systematic screening for allelic diversity, using molecular methods, can help to pinpoint useful diversity and ensure that it is not lost before we even know what is there.

The development of powerful molecular tools by initiatives such as the Global *Musa* Genomics Consortium provides an unprecedented opportunity to use the mostly untapped diversity available in wild and cultivated *Musa*. Used wisely, a better understanding of the plants on which we rely to produce our food, and of the pests and diseases that constrain our ability to do so, would also allow us to increase the nutritional quality of our food crops and lessen the impact of agriculture on the environment. But improving agriculture and our food are not the only reasons to pursue genomics. Uncovering the hidden genetic diversity of bananas should remind us of our moral duty to conserve it. ❧

The comparative advantage of bananas

Even though it ranks next to rice, wheat and maize in terms of its importance as a food crop, the banana does not command the same kind of attention from researchers and the donors who fund their efforts. However, the banana's unusual genetic make-up could attract a whole new level of interest. The banana has many things to offer scientists interested in the power of comparative genomics to study fundamental questions of biology and evolution. For one thing, the banana provides an opportunity to analyse traits not found in the current model plants.

The reproductive system of bananas includes both sexual and vegetative modes of propagation, the latter being the result of various forms of sterility combined with parthenocarpy (fruit development without fertilization), which is relatively rare in monocots. What is more, Southeast Asia is unique in hosting sexually and asexually reproducing bananas, both of which have co-evolved with pathogens. Enlarging the scope of genomic studies to cultivars that, like plantains, diversified outside Asia in the absence of some key pathogens would provide a valuable tool to study how bananas evolved, with and without their original attackers.

The range of ploidy levels found in bananas also offers a special opportunity to gain insight into the greater-than-additive gains in crop productivity that often accompany polyploidy. More complex than cotton and sugarcane polyploids, which contain only one level of ploidy within the taxon, banana varieties include various levels of ploidy and mixes of the A and B genomes (AA, BB, AB, AAA, AAB, ABB, AAAA, AABB, AAAB). This creates opportunities to study not only the relationship between ploidy and phenotype, but also the causes and consequences of polyploidy for genome organization.

Enemies on the move

Like the banana itself, most of the pests and diseases attacking the crop can trace their origins to Asia. However, in natural forest habitats and diverse traditional farming systems they are often held in check by natural enemies or competing species—or simply do not encounter enough susceptible hosts to launch a real epidemic. Once they turn up in the large-scale commercial plantations of the banana exporters, on the other hand, it is a different story. Both pests and diseases can run rampant, sending researchers and plantation managers scrambling to find solutions. Meanwhile, small-scale farmers often suffer ‘collateral damage’ as new pathogens spread from the commercial plantations into nearby smallholdings, whose owners are poorly equipped to combat the invaders.

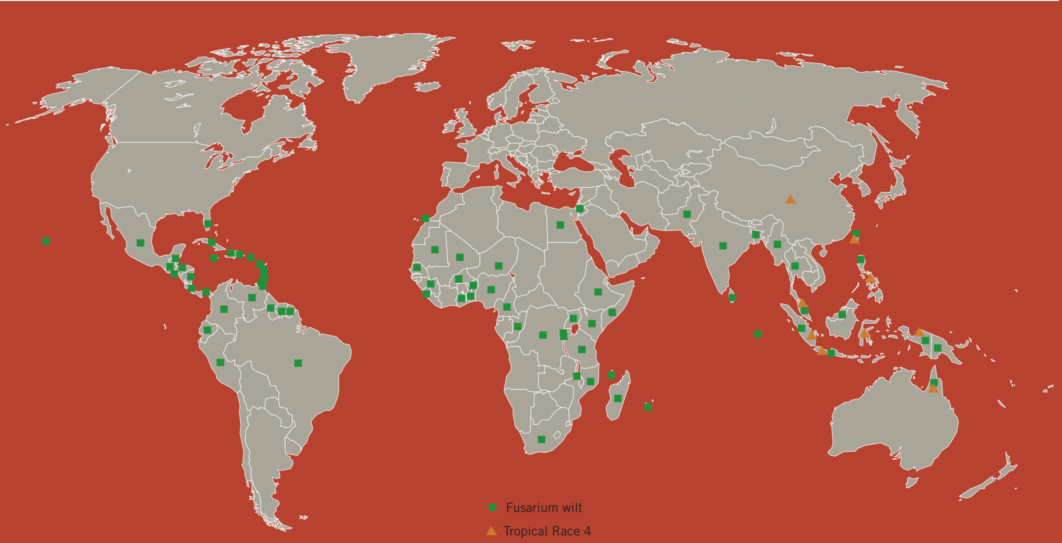
The first global epidemic to affect bananas was of fusarium wilt, or Panama disease, the fungal disease responsible for the demise of the dessert banana Gros Michel that had dominated the export trade since its early days. This soil-borne fungus cannot be controlled with chemical pesticides and eventually the tasty and hardy Gros Michel banana had to be replaced by varieties belonging to the Cavendish group, which are resistant to the fungus. However, a highly virulent strain of fusarium wilt (Tropical Race 4) is presently spreading through Southeast Asia, where it attacks a wide range of varieties, including the Cavendish ones.

In the Americas, the main threat is, and has been since the 1980s, a fungal disease called black leaf streak, but better known as black Sigatoka. In this case, the disease attacks the leaves and can be controlled by spraying fungicides on the plant. The large commercial plantations of Latin America are sprayed almost weekly to keep this disease in check. Moreover, new virulent isolates capable of overcoming the pesticides frequently appear. Now present throughout the humid tropics, this disease also reduces the productivity of bananas grown by smallholders who have few options for controlling it—the challenge that INIBAP was originally set up to meet. It had been preceded by the closely related Sigatoka disease, better known as yellow Sigatoka, which is also caused by a fungus belonging to the genus *Mycosphaerella*.

Nematodes and weevils damage the root systems and cause toppling of the plants. They too have travelled around the world

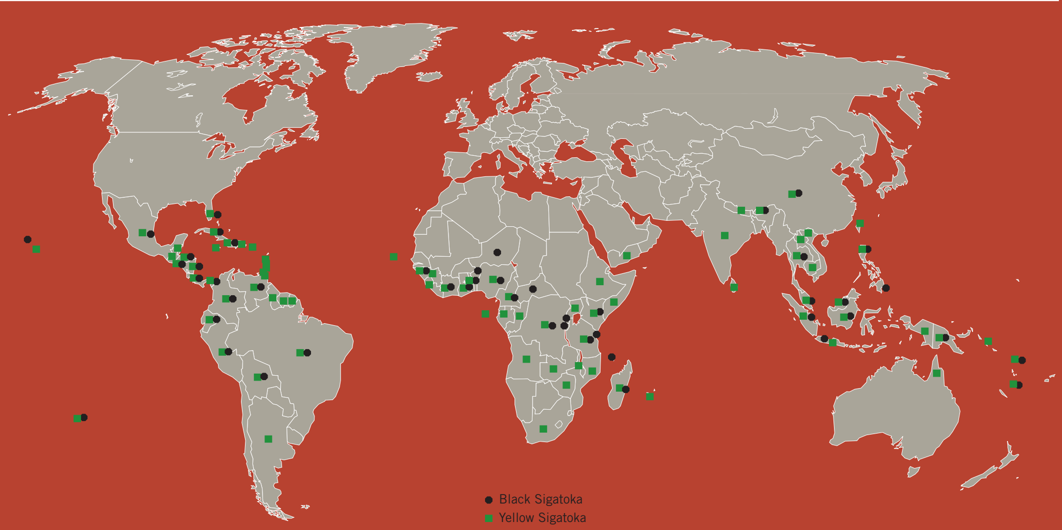
The fungus that never goes away

The soil-borne fungus that causes fusarium wilt invades the vascular system of the plant. A. Javellena



The banana’s No.1 enemy

By attacking the leaves, the Mycosphaerella *fungi disrupt photosynthesis, the process that feeds the growing bunch.* E. Fouré



with the banana and are, especially in the case of nematodes, sometimes subjected to environmentally damaging (and only partially effective) pesticide treatments. In Africa, nematodes and weevils are regarded as a growing problem, contributing to an ill-defined ‘banana decline’ syndrome which reduces productivity and the productive life of banana plantings.

In parts of Asia, one of the main threats is the *Banana bunchy top virus*, which stunts plant growth and has driven many farmers to stop growing bananas, for instance in parts of the Philippines. The disease is now on the move in Africa.

Bacterial diseases also threaten bananas. The same pathogen causes ‘moko’ when spread mainly by infected tools (especially in Latin American plantations) and ‘bugtok’ when it is spread by insects visiting the flowers of bananas (especially in Asia) while the related, but even more virulent, ‘blood disease’ is spreading through the area of origin of bananas in Southeast Asia, threatening traditional cultivars and wild relatives alike. Meanwhile, a new threat has surfaced more recently in East and Central Africa, where a bacterial wilt has long been a chronic problem in the enset crop of Ethiopia, but is now spreading like wild-fire through the staple food and beer bananas of Uganda and its neighbours.

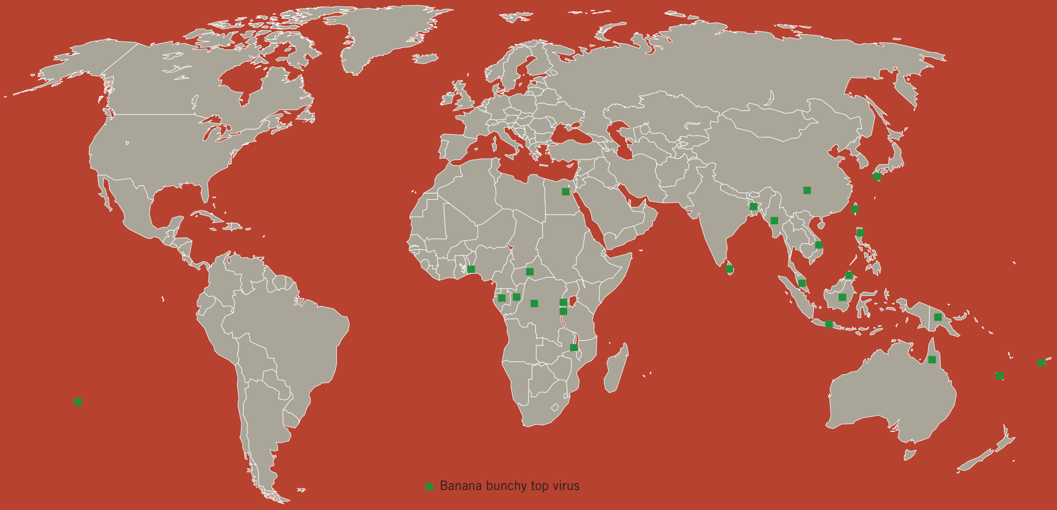
Researchers and banana farmers will have to continue to innovate and share best practices, in order to keep up with these new threats as they arise.

KEEPING TABS ON PESTS AND DISEASES

Ever since its creation, INIBAP has not only played an active role in monitoring the spread of the key pathogens, studying their diversity and promoting the use of the most effective diagnostic techniques available, it has also complemented the research effort with information exchange and capacity building. Between 1991 and 2004, for instance, INIBAP organized 21 research coordination workshops and training courses on black Sigatoka alone. Fifty-six articles on the disease have appeared in Info*Musa* and by the end of 2005 there were 1144 articles on this subject recorded in the *Musa*Lit database. Working Groups on the main pest and disease problems within Pro*Musa* have played an active role in organizing meetings and promoting other forms of information exchange. And currently the separate groups on Sigatoka, fusarium, nematodes and weevils are being drawn together into a unified Crop Protection Working Group, to promote the search for integrated solutions.

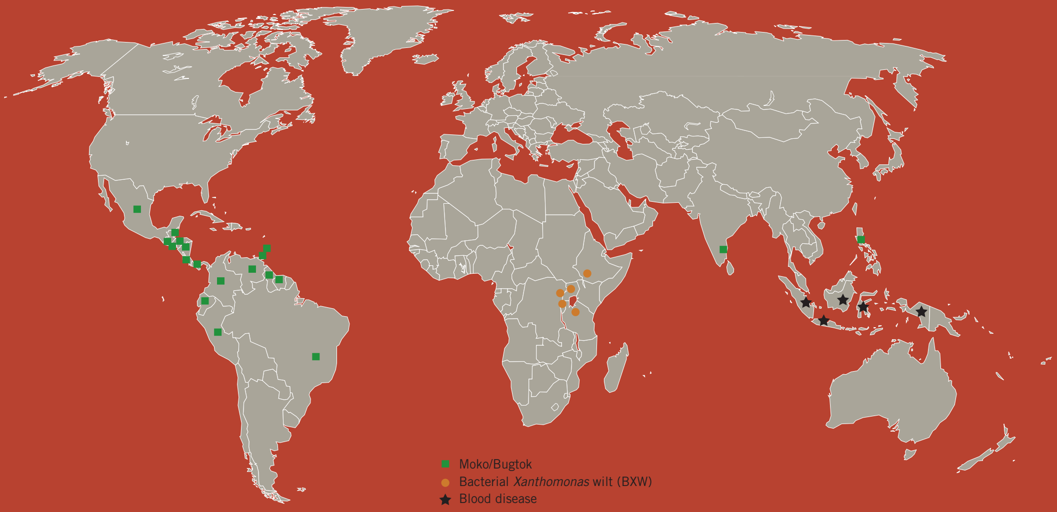
The virus that dwarfs plants

The Banana bunchy top virus *stunts growth and was named after the bunchy appearance of infected plants.* S. Sharrock



The bacterial trinity

The three pathogenic bacteria can spread through the entire vascular system of the plant and destroy the fruit. G. Blomme



Sources: Crop Protection Compendium - Global Module, 3rd edition. © CAB International, Wallingford, UK, 2001. Diseases of banana, abaca and enset. Edited by D.R. Jones. CAB International, Wallingford, UK, 2000.

I. Van den Bergh

Improved crop varieties have been considered an indispensable element in agricultural development, but do farmers have other priorities in seeking to improve their lives?

Learning to manage diversity

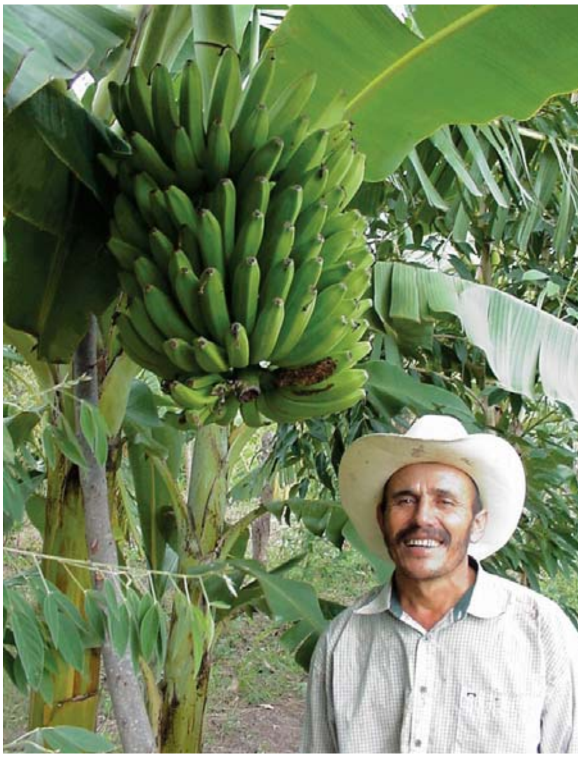
In the heady days of the green revolution, agricultural scientists believed that breeding highly productive varieties, and feeding them a steady diet of fertilizers and pesticides, could save the world from poverty and starvation. Banana breeders evidently had a harder time of it than their counterparts working on rice, wheat or maize (see *Hungry for improvement* in this report). However, the absence of banana hybrids has not prevented the export industry from delivering consistently high yields. Large-scale producers have sought to make up for any shortcomings of the Cavendish cultivars that dominate the international trade by investing heavily in their culture and protection and keeping an eye out for useful mutants. What lessons can we draw from this experience for smallholder producers of bananas and plantains? Are they best served by the conventional model of varieties and intensified production systems or are there other, more effective ways, to help small-scale farmers meet their objectives?

Over the last twenty years, INIBAP and its partners have looked at many dimensions of the challenge of producing slowly-evolving bananas in a rapidly evolving world—and this experience has been quite different in the parts of the world where INIBAP operates regional offices. In Latin America, where INIBAP first set up a regional office in 1987, researchers have worked with and around the dominant export banana industry, looking at various 'greener' production technologies, including purely organic production. Regional offices established in West Africa in 1988 and in East Africa in 1989, have focused mainly on deploying and evaluating new cultivars in the context of food security-focused African farming systems. Meanwhile in Asia, where INIBAP set up shop in 1990, the focus has been on developing systems to deploy disease-free planting material of superior varieties.

The emphasis in the networks that developed around each regional office has generally been on helping national partner organizations to identify and meet what were seen as the distinct challenges of banana production in each region. More recently, however, a new paradigm of 'managing diversity in production systems', using the principles of agro-ecology as a foundation, is providing INIBAP with a conceptual framework for drawing together these diverse experiences into a coherent whole.

Matching hybrids with farmers

In other crops, the conventional wisdom is that pest- and disease-resistant varieties provide a sound foundation for integrated crop management strate-



Honduran farmer evaluating FHIA hybrids on his land.
C. Staver

This paper is based on a talk given by Franklin Rosales from INIBAP-LAC regional office at a symposium on the *Conservation and Use of* Musa *Biodiversity for Improving Livelihoods* held in Leuven, Belgium, on 18 October 2005.

gies but in bananas this principle has been hard to establish. Perhaps because of the relatively limited diversity of bananas, farmers and consumers have tended to develop strong preferences for their familiar cultivars and, because of the complexity of banana breeding, the disease-resistant cultivars that have been developed rarely substitute directly for existing varieties.

The *Fundación Hondureña de Investigación Agrícola* (FHIA) has perhaps had the greatest success in using conventional breeding to generate highly productive, disease-resistant varieties but all of these differ to some extent in taste and other fruit characteristics from existing varieties. Much of the effort of INIBAP and its partners has been invested in disseminating and evaluating these 'FHIA hybrids' with farmers in Latin America, Africa and Asia. It was initially assumed that varieties, both dessert and cooking banana types, offering high levels of disease resistance and yields as much as five times higher than traditional cultivars would be welcomed by farmers with open arms. Certainly tens of thousands of plantlets of these varieties have been distributed to farmers, through various projects. However, the record on adoption has been at best mixed and the factors that favour adoption are still not fully understood.

The most enthusiastic adoption of FHIA's improved hybrids has been in Cuba. Since 1992, more than 16,000 ha have been planted. Economic analysis suggests that the new varieties offer farmers benefits of more than $400/ha/yr, mainly in reduced fungicide applications. But why isn't everyone following the Cuban example? Is there something unique in the Cuban situation? One factor appears to be that Cuban farmers were already accustomed to intensive banana production, with major use of 'inputs' (including pesticides, fertilisers, irrigation and labour). When foreign exchange restrictions and other economic forces sharply reduced access to pesticides, farmers were perhaps more ready to adapt to the different taste and other characteristics, in return for the high levels of disease resistance and production offered by the new hybrids.

Samuel Addo and his wife carrying a bunch of FHIA-21.
A. Nkakwa Attey

Experiences are still being digested from the TARGET project in Africa, which saw some 64,000 plantlets of FHIA hybrids and other highly productive varieties distributed in four countries (see *Improved hybrids up for adoption* in the 2003 annual report), and from a CFC-funded project that saw more than 31,000 plantlets distributed in three African and three Latin American countries. Evidently access to good quality planting material can be an issue limiting adoption of the new cultivars. Both these projects took care to ensure the quality of the initial planting materials, to set up nurseries to harden the plantlets, to provide farmers with training on how to handle tissue-culture materials and, to some extent, set up mechanisms to

Ghanaian farmers participating in the TARGET project were invited to vote on which new variety they liked best (right) after evaluating them in their fields (left).
A. Nkakwa Attey

For farmers to have access to improved planting material, 'clean seed systems' must be established. Commercial plantation may use plants derived directly from tissue culture (above) whereas for smallholders, plants propagated from corms (below) may be more useful.
R. Markham

encourage further propagation of the new materials by conventional methods. However, these experiences fall far short of establishing national systems to ensure the long-term availability of clean planting material.

INIBAP has come closest to institutionalizing such systems in Asia where 17 National Repository, Multiplication and Dissemination Centres have been established in 14 countries. These Centres maintain disease-free mother stocks of potentially useful varieties that can then feed into private- or public-sector systems for larger-scale multiplication. This has been achieved most successfully in the Philippines where a partnership between highly efficient private sector producers of tissue-culture plants (mainly for the export industry) and public sector providers of expertise have teamed up to supply large numbers of high quality plants to small-scale farmers at very competitive prices (see *Bringing back an old favourite, the capitalist way* in the 2004 annual report).

Lacking the foundation provided by the banana export industry, smaller-scale tissue-culture laboratories in East and Central Africa provide plantlets at approximately four times the price of their counterparts in the Philippines and, currently, without similar guarantees of quality (especially freedom from virus infection). Moreover, the upgrading of such systems to ensure quality plantlets at a competitive price represents something of a 'chicken-and-egg' situation—in so far as suppliers' ability to achieve economies of scale and quality control depend on an increased demand but it is hard for demand to grow as long as the supply is inadequate.

Creating demand

Part of the demand side of the equation, especially where highly productive but unfamiliar banana varieties are concerned, would appear to be the market for processed products. For instance, in East Africa there are indications that FHIA hybrids and others, such as those produced by the International Institute of Tropical Agriculture (IITA), can provide an acceptable and profitable supply of raw material for the traditional banana beer-brewing and wine-making industries, whether on a cottage industry scale or to supply more commercial breweries. In Latin America and elsewhere, the new varieties serve as raw materials for making banana chips, which have a limited but profitable market as a snack food. Meanwhile in India and Southeast Asia, bananas serve as a raw material for a wide range of flours, ketchups and various high-value confectionary products.

So far, these industries are small-scale and only locally important. Probably by their nature, processed banana products will always remain niche markets but in this case perhaps this is a virtue rather than a vice. For small-scale farmers there may be economic stability in supplying a series of local, regional and international markets, rather than large-scale commodity markets. Moreover, these are markets that can add value to the diversity of genetic resources that they hold (specifically if certain varieties are found to be better suited to particular products).

The role of INIBAP in the area of post-harvest marketing and processing is not one of leading innovative research but rather of promoting the exchange of experiences. By commissioning case studies of how banana-based enterprises have developed in different regions and analysing successes, INIBAP seeks to draw and share conclusions on how a rather limited public sector investment can help to catalyze the development of enterprises that offer positive opportunities for small-scale farmers and their communities.

ENSURING SUPPLY

Supplying factories or even urban markets with a dependable supply of bananas presents smallholder farmers with quite a different challenge from their traditional one of assuring household and community food security. Varieties remain an important consideration in this new market-oriented game but production systems that offer high productivity and predictability are also at a premium.

One approach that INIBAP has been experimenting with in both Latin America and Africa involves high-density annual planting of plantains and cooking bananas. By re-planting annually with tissue-culture plants—and, if necessary, rotating with other crops—farmers may be able to reduce problems of chronic, soil-borne pests such as nematodes, while increasing the productivity of limited land holdings. The dense shade that is established by the banana plants effectively excludes weeds while, through mechanisms that are poorly understood, a microclimate seems to be established that reduces the incidence of black Sigatoka. An added bonus in hurricane-prone areas is that the dense stands are much less susceptible to wind damage and, to minimise the risk of losing the whole plantation during hurricane season, farmers can stagger their plantings over the entire year.

Again, Cuba leads the way in adopting high density planting with over 4000 ha currently in production. Once more, the attraction here may be mainly in the reduced need for chemical inputs. However, workshops, training courses and pilot projects on high density production have now been conducted in some 13 countries and there are signs that this approach may be useful elsewhere in Latin America, as well as in West Africa (see *When West Africa meets Latin America* in the 2004 annual report). INIBAP and its partners will need to further analyse these various experiences to work out where and under what circumstances such approaches are most appropriate and most likely to succeed.

Using bananas in processed products opens up new opportunities for smallholders.
B. Favre

Most of the bananas grown by smallholders are sold in local markets.
Clockwise from left, D. Mowbray, A. Javellena, C. Lusty

LIVING WITHOUT PESTICIDES

The high cost of synthetic pesticides and growing resistance on the part of the fungi (especially the one causing black Sigatoka) to conventional products remain strong incentives for the development of new products and new approaches. Projects in Latin America have looked at a wide range of plant and compost extracts for their effectiveness in reducing pathogen attack, either by boosting the plant's defence mechanisms or through direct toxicity to the fungi. After extensive trials, two botanical products, derived from the plants *Momordica charantia* and *Senna reticulata*, have completed small-scale assays and moved to 'semi-commercial' production in Costa Rica. However, there is little reason to suppose that in the longer term such products will prove inherently superior to their synthetic counterparts.

A more radical approach, that has been developed largely empirically, is simply to do without pesticides and other synthetic inputs, with or without the official designation of 'organic' production. In principle, the trade-off here is to accept lower yields in return for the higher price that some con-

sumers are prepared to pay for a fruit that is certified as having been grown without chemical inputs. In reality, the trade off is a much more subtle one, determined by the demand and price differential for organic bananas on the one hand and the cost of production on the other. Organic farmers, by definition, do not have to pay the costs of pesticides but they may be applying (and sometimes preparing) other products that are allowed under the organic certification regime or they may have to invest extra labour in assuring soil fertility or pest management in other ways. In some places, farmers simply benefit from the lower production costs of non-pesticide production and accept a lower yield, without seeking the price advantage associated with organic certification.

Part of the strategy for organic banana production involves selecting conditions that are inherently less favourable for the fungal leaf diseases such as black Sigatoka. In particular this involves growing bananas in less humid environments, usually with ground-level irrigation. This was the strategy in Peru, where, in 1998, INIBAP took a leading role in establishing organic banana production as part of a post-El Niño recovery programme in the northern part of the country. The first 400,000 boxes were exported in 2001, with a value of $2.4 million dollars, and as more companies have joined the effort, exports are now at four times that level, placing Peru in third position among organic banana exporters in the world. Another project developed organic banana production in Bolivia, to supply a national urban market (see *The highs and lows of organic bananas in South America* in the 2003 annual report).

A dry climate (top left, G. Blomme) *makes it easier to grow organic bananas, as long as irrigation is available (right,* I. Van den Bergh).

In Ecuador, an organic producer (right) controls diseases through a 'special diet' of natural fertilizer (above).
R. Markham

In Alto Beni, Bolivia, INIBAP has helped farmers produce organic bananas.
A. Vezina

Working with nature

In the forests of South-east Asia, it's relatively easy to find the wild relatives of the cultivated banana—but it's very rare to find a sick one. Sometimes this is for reasons that are inherent in the situation of the wild plant, rather than the cultivated version, such as the sexual reproduction that allows it to evolve in parallel with its pathogens and the scattered stands of the plant that slow the spread of pathogens. But other features of the natural environment can perhaps be mimicked in banana plantation. Soils that are rich in organic matter support a great diversity of saprophytic organisms that may compete with potential pathogens, as well as biological control agents that may attack directly and keep in check the nematodes and fungi that would otherwise overwhelm the banana plants. Perhaps most interesting of all are bacteria and fungi that grow within the banana plant ('endophytes') or on the surface of its roots ('mycorhizae'), helping to protect it against pathogen attack. The more we can learn and understand about the processes that keep bananas healthy in their natural environment, the more we can hope to manage these same processes to ensure that bananas remain healthy and productive on farms as well.

A handful of soil contains millions of beneficial micro-organisms.
R. Markham

PARTNERS IN HEALTH

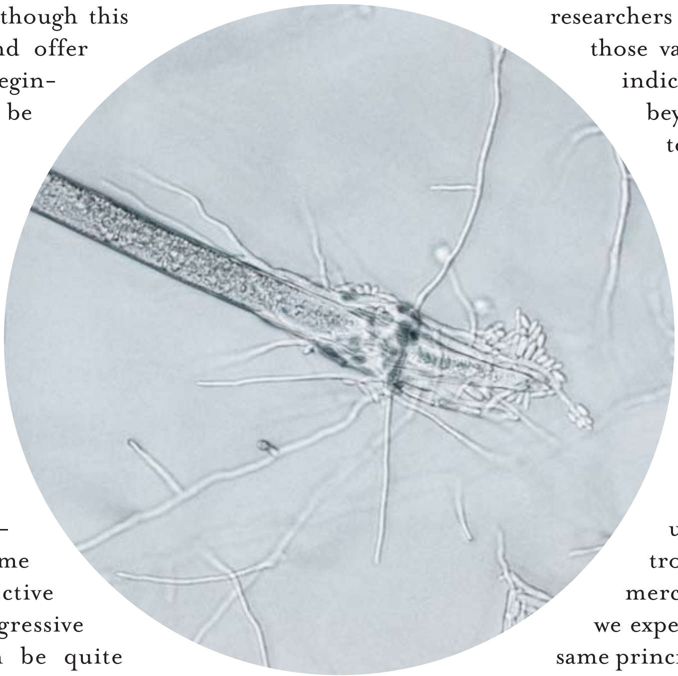
What INIBAP is now attempting is to draw together the knowledge gained in organic production projects and in specific studies of pathogens in order to learn more generally how to work with the living organisms that protect bananas in their natural habitat (see *Working with nature*). Although this approach may be more ambitious and offer greater technical challenges at the beginning, it should prove in the end to be more durable.

Researchers are finding, for instance, that bacteria and fungi living 'endophytically' within the tissues of plants without causing disease are a widespread phenomenon and that such organisms may help to protect the host plant against disease-causing agents. In some cases, the protective endophyte and aggressive pathogen can even be quite closely related, as in the case of endophytic fusarium species that can protect against both nematodes and perhaps against the aggressive fusarium strains that cause Panama disease as well.

The search for the most effective endophytes can be a painstaking process of screening and characterizing numerous samples of plants and microorganisms. However, the networking approach of INIBAP is ideally suited to mobilizing the complementary resources of partners in such a concerted global effort. Thereafter, cost-effective means of culturing, formulating and applying the chosen products to banana plants must be developed in the same way. Various organisms and approaches are currently under evaluation and there remains much work to be done to define the circumstances in which the extra cost of treating tissue-culture plants is justified by better establishment and yields. However, in Costa Rica, treatments with endophytic fungi are now proving their value on 22 ha of intensively produced bananas. If these trials are successful, the potential benefits in terms of reduced nematicide applications alone could be enormous.

Also in Latin America and the Caribeean, INIBAP and its partners are working with banana producers selling to the export and local markets to understand what constitutes a healthy soil for durable banana production. By comparing 42 farms of known history in four countries, the researchers involved are identifying those variables that will serve as indicators of soil health and, beyond that, will learn how to manage the crop and its inputs—especially organic matter—in order to restore ecologically damaged land and achieve low pest levels and a healthy, productive crop.

Once we understand the underlying principles of how soil health can be managed under the relatively controlled conditions of commercial banana plantations, we expect to be able to apply the same principles to managing the pest and soil fertility problems encountered by small-scale farmers everywhere. And, once more, INIBAP's trademark approach of sharing knowledge and sharing the task of testing new options will be ideally suited to identifying a range of solutions, tailored to the individual situations and aspirations of our ultimate clients, the small banana producers and their communities.



A 'good' fungus attacking a nematode.
A. Meneses

INIBAP in brief

Following consultations with partners and stakeholders, the International Plant Genetic Resources Institute (IPGRI), of which INIBAP is a part, implemented in 2005 a new organizational structure in which the institute's work on crops of great significance for the livelihoods of small-scale farmers, namely banana, coconut and cacao, are grouped under the 'Commodities for Livelihoods' programme. The new structure reflects a shift of emphasis from the conservation of crop genetic resources to improving the well-being of people through the deployment of agricultural biodiversity. Helping people benefit from biodiversity is expected to result in genetic resources being conserved for future use.

INIBAP's agenda now falls within two thematic areas:

- Conserving, understanding and improving *Musa* biodiversity
- Using *Musa* biodiversity to improve rural livelihoods

Conserving, understanding and improving *Musa* biodiversity

Activities focus on the effective conservation and characterization of *Musa* genetic diversity in order to increase its use and address problems posed by the plant's biology. As a parthenocarpic, vegetatively propagated polyploid crop, *Musa* is hard to improve by conventional means. Its cultivated varieties have a very narrow genetic base and even current breeding efforts are using only a small proportion of the existing diversity. Meanwhile, research on *Musa* is chronically under-funded despite its importance as a food crop. Genebanks are also poorly-resourced and not adequately linked to global efforts that could facilitate the more effective use of *Musa* diversity.

Conservation of *Musa* genetic resources

Representative materials from banana-growing regions are maintained in a state-of-the-art germplasm collection managed by INIBAP at the ITC[1] in KULeuven with the support of the DGDC of Belgium. Most of the collection is held 'in trust', under the auspices of the FAO for the benefit of the international community and is made publicly available through material transfer agreements. Research is carried out to eliminate pathogens and accessions are indexed to ensure that only disease-free material is distributed to users world-wide. Accessions are currently being rejuvenated, checked for trueness-to-type and replaced in tissue culture while a duplicate set is cryopreserved for secure, long-term storage. Some 30% of the *Musa* genebank is currently cryopreserved and half of the collection has been rejuvenated. About 70% of the rejuvenated accessions have been sent for verification in the field of their trueness-to-type.

In the Democratic Republic of Congo (DR-Congo), 20 plantain cultivars were collected and planted in the field collection of the University of Kisangani. A collecting mission in Tanzania identified 16 potentially new East African highland banana cultivars.

To place the conservation of banana diversity on a secure, long-term footing, a Global Conservation Strategy for *Musa* is being developed in the framework of the Global Crop Diversity Trust, the FAO-CGIAR-initiated endowment fund set up to support crops on Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture. Information has been gathered from 45 collections while experts and regional banana research networks have been consulted to establish a 'road map' for improving and rationalizing conservation of *Musa* on a global scale.

Understanding of *Musa* genetic resources

INIBAP's *Musa* Germplasm Information System (MGIS) provides access to information on accessions in various collections, including phenotypic and molecular characterization data. A major upgrade of MGIS, to include more illustrations and a wider range of information, as well as increasing its ease-of-use, is nearing completion under a CGIAR-wide genebank upgrade project, funded by the World Bank.

The Global *Musa* Genomics Consortium brings together expertise from 27 publicly funded institutions in 20 countries. As well as encouraging close collaboration, the Consortium enables research resources to be shared, including sequence data and enabling technologies. Members of the Consortium are active participants in the Generation Challenge Programme (GCP), which is supporting the development of a common set of markers for better characterization of banana genetic resources, as well as comparative genomics studies between banana and rice. In 2005, 304 accessions representing the range of *Musa* diversity were characterized using molecular markers (24 SSRs). Four types of markers/methods (SSR, IRAP, CpDNA, DArT) were used and compared in characterizing 48 accessions considered as the 'mini-core' collection. (For more information, consult the website at www.musagenomics.org)

The *Musa* Genome Resource Centre, hosted by the IEB, in the Czech Republic, provides DNA libraries, individual DNA clones, markers for molecular cytogenetics and high-density colony filters to the members of the Consortium. (For more information, consult the website at www.musagenomics.org/index.php?page=resources)

The International *Mycosphaerella* Genomics Consortium brings together seven partners from seven countries who have a shared research interest in *Mycosphaerella* species. In 2005, the Joint

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[1] See page 32 for acronyms and abbreviations in full.

Genome Initiative of the US Department of Energy announced the sequencing of the *Mycosphaerella fijiensis* genome.

Genetic improvement of *Musa*

Support to *Musa* breeding is provided by the Pro*Musa* network and its specialist working groups. The Pro*Musa* working group coordinators proposed a new structure and strategy for the network, focusing on developing global public goods based on using *Musa* diversity more effectively in the areas of crop improvement, protection and production. Trials for the third phase of the International *Musa* Testing Programme (IMTP) are being carried out in 25 countries. Complete datasets have been received from two test sites and progress reports from several other sites. An IMTP working group has been initiated to coordinate data collection and analysis.

Protocols for evaluating carotenes (Vitamin A precursors) and micronutrients (especially iron and zinc) in banana and plantain were developed under a grant from the HarvestPlus Challenge Programme. These will be used initially to identify higher-nutrient plantains and cooking bananas among those available in West Africa, with a view to promoting their wider use by sectors of the population vulnerable to malnutrition.

Projects	**Donors**	**Partners**
Rehabilitation of CGIAR global public goods assets	World Bank	BPI, ESPOL, FHIA, KULeuven, University of Gembloux
Improving the management of banana and plantain genetic resources for Africa	Gatsby Charitable Foundation	CARBAP, Infruitec-Nietvoorbij, KULeuven, Maruku Agricultural Station, NARO, University of Kisangani
Conservation and improvement of *Musa* germplasm	DGDC	KULeuven
Musa microarray platform	Austria	ARC, IAEA, IEB
Support distribution of reference germplasm	GCP (sub-programme 1: Genetic diversity)	CIRAD, IEB
Genotyping of composite germplasm set, *Musa*	GCP (sub-programme 1: Genetic diversity)	ARC, CARBAP, CIRAD, IITA, University of Leicester, IAEA
Validation of DArT as a platform for whole genome profiling in orphan crops	GCP (sub-programme 1: Genetic diversity)	DArT, CIRAD
Population structure, phenotypic information and association studies in long-generation crops	GCP (sub-programme 1: Genetic diversity)	CARBAP, CIRAD
Musa genome frame-map construction and connection with the rice sequence	GCP (sub-programme 2: Comparative genomics)	CIRAD, EMBRAPA, IEB, NIAS, University of Leicester
Validation of conserved orthologous markers	GCP (sub-programme 2: Comparative genomics)	University of Leicester
Exploring the structure of the *Musa* genome	USAID linkage funds	TIGR
Evaluating the potential of banana and plantain diversity to contribute to improved human nutrition	HarvestPlus Challenge Programme	CARBAP, IITA, KULeuven
Novel approaches to the improvement of East African highland banana varieties	Uganda with Belgium, Rockefeller Foundation, USAID	CIRAD, FABI, IITA, JIC, KULeuven, NARO, University of Pretoria, Makerere University

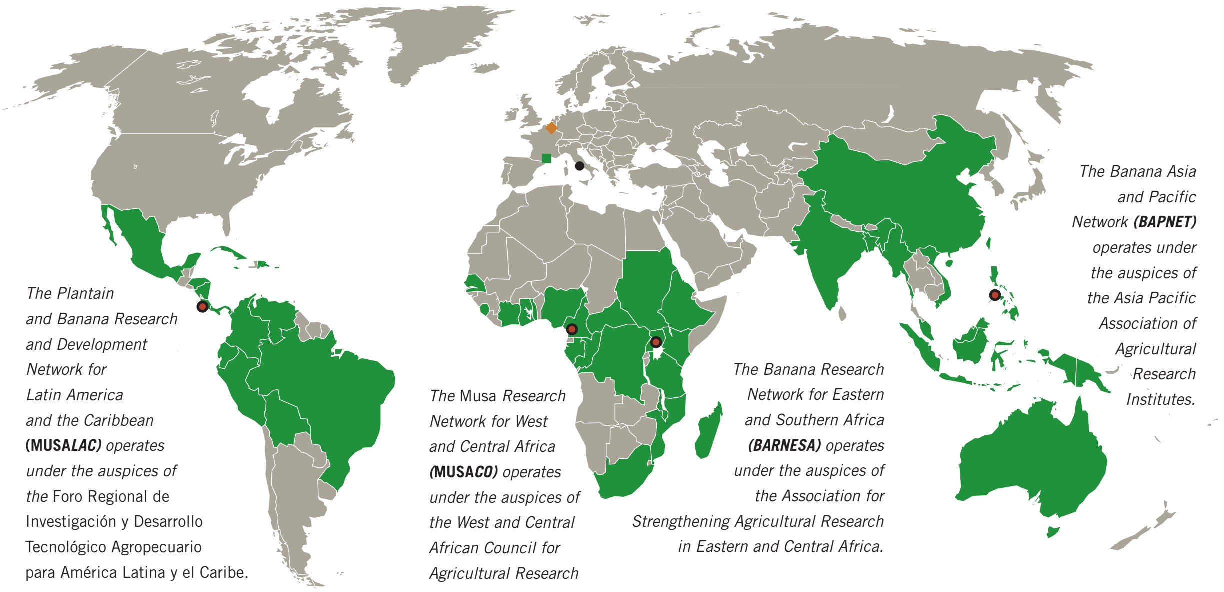
Using *Musa* biodiversity to improve livelihoods

Rural communities in tropical and subtropical regions, including those dependent on banana-based systems, face challenges of resource degradation, poverty, climatic change, globalizing markets, changing consumer preferences and costly external inputs. The ability of people to better manage the diversity in such systems, so as to improve their food security and increase their income depends on being able to enhance their skills in agro-ecological and business management as well as having access to useful genetic materials and new production and post-harvest technologies. In order to succeed, they need ready access to sources of such new information and skills – which are usually provided by field organizations, private sector services, educational institutes and mass media. This thematic area of INIBAP's work is directed mainly towards the groups, organizations and institutions that are involved in improving rural well-being through the use of banana and plantain diversity.

Targeted research topics include diagnosing soil, root and plant health, managing pests and diseases (such as fusarium, bacterial wilts, banana bunchy top virus and leaf spot diseases), and managing crop and crop-associated diversity to improve the productivity and sustainability of high- and low-input systems. In Central America, partners in a FONTAGRO-funded project have intensively sampled 40 fields in four countries and are analysing the data with a view to developing indicators of soil and root health. In the same region, botanical extracts are being evaluated on a semi-commercial scale as an option for black Sigatoka management.

The over-riding concern in East and Central Africa is the spreading epidemic of banana *Xanthomonas* wilt. As well as carrying out a study, funded by DFID, to evaluate the effects of the wilt epidemic on rural livelihoods, and another study, funded by IDRC, to see how farmers are coping with this challenge, INIBAP's team in Uganda helped to mobilise expertise from Latin America and Asia, where similar bacterial diseases are already well established; the experts, convened with the support of FAO and other international organizations, proposed strategies to mitigate the impact of the new disease outbreak.

Deploying improved varieties and improving systems for multiplying planting material are



The Plantain and Banana Research and Development Network for Latin America and the Caribbean (**MUSALAC**) operates under the auspices of the Foro Regional de Investigación y Desarrollo Tecnológico Agropecuario para América Latina y el Caribe.

The Musa Research Network for West and Central Africa (**MUSACO**) operates under the auspices of the West and Central African Council for Agricultural Research and Development.

The Banana Research Network for Eastern and Southern Africa (**BARNESA**) operates under the auspices of the Association for Strengthening Agricultural Research in Eastern and Central Africa.

The Banana Asia and Pacific Network (**BAPNET**) operates under the auspices of the Asia Pacific Association of Agricultural Research Institutes.

■ INIBAP HQ ● IPGRI HQ ● INIBAP Regional office ◆ International *Musa* germplasm collection

Although research activities funded by specific grants may be carried out with a relatively small number of national and institutional partners, the wider uptake of results and innovations is encouraged through the four regional networks coordinated by INIBAP. Discussion of national priorities and of the research results presented to the Steering Committees of these networks help to ensure that future collaborative research is well targeted to address issues of mutual concern.

regarded as key elements in addressing several disease problems, as well as other challenges faced by farming communities. Experiences in this area are most developed in Asia where a project funded by the Philippines government has mobilised private- and public-sector partners, with the technical support of INIBAP, to respond to an epidemic of BBTV. Such strategies will also be amongst those deployed in a new project being launched to revitalize the banana sector in Central Africa (specifically Rwanda, Burundi and eastern provinces of the Democratic Republic of Congo), with the support of DGDC and in collaboration with IITA and CIAT-TSBF.

If banana farmers and their communities are to derive maximum benefit from more productive new varieties and the diversity of traditional ones, they will need to link up with various stakeholders who are involved in adding value to *Musa* post-harvest, through diverse processing and marketing opportunities. Case studies on banana-based post-harvest enterprise development were conducted by partners in 9 countries and discussed at a workshop in the Philippines, with a view to distilling common lessons that can be applied elsewhere.

A continuing concern of INIBAP is to ensure that the products of research and development experiences are made available, in the appropriate form, to as wide a range of stakeholders as possible in the banana sector. Relevant information is disseminated through regional newsletters, question-and-answer services and increasingly as web-based products that can be downloaded and printed locally by would-be users.

Projects	**Donors**	**Partners**
Technological innovations to improve soil health and quality in banana plantations of Latin America and the Caribbean	FONTAGRO, IDB, CGIAR	CATIE, CEDAF, CORBANA, IDIAF, IDIAP, INIA, University of Bonn
Development of biological pest control products	FONTAGRO	IDIAF, INIA
Rehabilitation of banana industry devastated by BBTV in northern Philippines	DA-BAR	CAVSU, DA-BAR, DMMSU, ISPSC, MMSU, PCARRD
Developing a coherent regional response to BXW	FAO, IDRC	MAAIF, NARO
Assessing the impact of BXW on household livelihoods	DFID	EG Consulting, IFPRI, MAAIF, Makerere University, NARO, NIDA,
Community coping mechanisms in response to BXW	IDRC	Ssemwanga Group Ltd.
Development of BSV and CMV management strategies	STC-Peru	INIEA
Nematode studies	VVOB	CARBAP, IITA, IPB, NARO, Makerere University
Enset and banana project in Ethiopia	VVOB	SARI
Farmer-participatory evaluation and dissemination of improved *Musa* germplasm	CFC	CIRAD, FHIA, FUNDAGRO, IICA, INERA, IRAG, NARO, UNAN-Leon
Increasing productivity and market opportunities for banana and plantain	USAID TARGET	ADRA, AFRICARE, ARDI, Cameroon Gatsby Trust, CARBAP, CARE, Casa do Gaiatus, CSIR, FAIDA, INIA, Mozambique Ministry of Works, UEM, WV Ghana
Building impact pathways for improving livelihoods in *Musa*-based systems in Central Africa	DGDC	AgroBiotec, CIAT-TSBF, INERA, IRAZ, ISABU, ISAR, KULeuven, Université Catholique du Graben, WV Rwanda
Utilisation of *Musa* biodiversity to improve livelihoods in East Africa	IDRC	ARDI, FADECO, Farmer Associations from Bisheshe, Chanika, Ibwera, Bushenyi and Masaka, Makerere University, NARO, Ssemwanga Group Ltd, Uganda Biodiversity Network
Cultivar evaluation and deployment in Asia-Pacific region through the NMRDCs	EU, National Programmes	BAPNET member countries
Diversifying market opportunities (case studies and workshop)	Rockefeller and CFC	ARDI, MARDI, MoA, NRCB, NIHORT, PCARRD, UNAN-Leon

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UK

Financial highlights

Revenue	Unrestricted	Restricted	Challenge programmes	Total
Australia	144			144
Austria			47	47
Belgium	340	1 003		1 343
Canada	517			517
CFC		232		232
Challenge Programme - Generation			101	101
CTA		23		23
DFID		55		55
European Commission		648		648
FAO		34		34
FONTAGRO		75		75
France	165			165
Gatsby Foundation		48		48
Harvest Plus			50	50
IDRC		86		86
IFPRI		1		1
IITA		10		10
India	25			25
KUL		11		11
Netherlands	253			253
Organization of American States		82		82
Peru		9		9
Philippines	7	11		18
Rockefeller		36		36
South Africa	30			30
Thailand	3			3
Uganda		170		170
United Kingdom	348			348
USA	100			100
USAID		52		52
VVOB		414		414
World Bank	429	271		700
Total revenues	**2 361**	**3 271**	**198**	**5 830**
Expenditures				
Research programme	1 793	3271	198	5 262
General administration	684			684
Total expenditures	2 477	3 271	198	5 946
Recovery of indirect costs	-299			-299
Total	**2 178**	**3 271**	**198**	**5647**

As at December 31, 2005 – in US dollars ('000)

Staff list 2005

Name	Position	Nationality	Joined	Stationed
R. Markham	Director	UK	01-07-03	Montpellier
E. Akyeampong	Regional Coordinator WCA	Ghana	01-06-97	Cameroon
E. Arnaud	Officer in charge of MGIS	France	01-10-89	Montpellier
T. Aourai	Accounting Assistant	UK	01-07-03	Montpellier
S. Belalcázar	Honorary Research Fellow	Colombia	01-04-02	Costa Rica
G. Blomme	Associate Scientist, Assistant to Regional Coordinator	Belgium	01-01-00	Uganda
R. Bogaerts	Technician	Belgium	12-02-88	ITC, Belgium
K. Borromeo	Communication Assistant	Philippines	16-06-04	Philippines
G. Boussou	Info/Doc Specialist	France	07-09-00	Montpellier
H. Calderón	Administrative officer	Costa Rica	06-09-04	Costa Rica
A. Causse	Programme Assistant	France	22-11-99	Montpellier
H. Doco	Info/Com Specialist	France	15-09-98	Montpellier
C. Eledu*	GIS Expert	Uganda	01-06-00	Uganda
L. Er-Rachiq	Assistant Documentalist	France	19-08-02	Montpellier
J.V. Escalant	Senior Scientist, Coordinator *Musa* Genetic Improvement	France	01-04-99	Montpellier
S. Faure	Senior Programme Assistant	UK	01-06-88	Montpellier
E. Gonnord	Accountant	France	17-08-98	Montpellier
K. Jacobsen	Associate Scientist, *Musa* Technology Transfer	Belgium	01-05-01	Cameroon
J. Kamulindwa	Administrator of the Ugandan Biotechnology Project	Uganda	03-05-01	Uganda
D. Karamura	*Musa* Germplasm Specialist	Uganda	01-01-00	Uganda
E. Karamura	Regional Coordinator ESA	Uganda	01-04-97	Uganda
E. Kempenaers	Research Technician	Belgium	15-10-90	ITC, Belgium
K. Lehrer	Programme Assistant	USA	06-01-03	Montpellier
C. Lusty	Strategy Development Specialist	UK	05-06-00	Montpellier
S.B. Lwasa	Programme Assistant	Uganda	01-08-97	Uganda
M.A. Maghuyop*	Technical Assistant	Philippines	01-07-00	Philippines
D. Masegosa	Assistant Accountant	France	16-08-04	Montpellier
H. Mbuga	Accounting Assistant	Uganda	15-04-02	Uganda
J. Mertens	Technician	Belgium	01-01-05	ITC, Belgium
B. Metoh	Programme Assistant	Cameroon	07-01-03	Cameroon
A.B. Molina	Regional Coordinator ASP	Philippines	20-02-98	Philippines
A. Nkakwa Attey*	Supervisor Plantation Technology Transfer Project	Cameroon	01-11-02	Cameroon
M. Osiru	Associate Scientist	Uganda	01-07-04	Uganda
C. Picq	Coordinator, Information/Communications	France	01-04-87	Montpellier
L. Pocasangre	Associate Scientist, *Musa* Technology Transfer	Honduras	01-07-00	Costa Rica
G. Ponsioen	Info/Doc Specialist	Netherlands	12-04-99	Montpellier
V. Roa	Programme Assistant	Philippines	01-01-91	Philippines
F. Rosales	Regional Coordinator LAC	Honduras	01-04-97	Costa Rica
M. Rouard	Bioinformatician	France	01-11-04	Montpellier
N. Roux	Senior Scientist, Coordinator *Musa* Genomics and Genetic Resources	Belgium	26-05-03	Montpellier
M. Ruas	Computer Technology Specialist	France	28-02-00	Montpellier
G. Sempere	Senior Scientist, MGIS consultant	France	17-05-05	Montpellier
M. Smith	*Musa* Genetic Scientist	Australia	01-10-05	Montpellier
C. Staver	Senior Scientist, Coordinator Sustainable *Musa* Production and Utilization	USA	01-01-04	Montpellier
R. Swennen	Honorary Research Fellow	Belgium	01-12-95	KUL, Belgium
J. Tetang Tchinda	Regional Information Officer for Africa	Cameroon	15-08-02	Cameroon
I. Van den Bergh	Associate Scientist, *Musa* Technology Transfer	Belgium	01-10-97	Philippines
I. Van den Houwe	Officer in Charge ITC	Belgium	01-02-92	ITC, Belgium
L. Vega	Programme Assistant	Costa Rica	01-02-92	Costa Rica
A. Vézina	Science Writer and Public awareness specialist	Canada	15-07-02	Montpellier
T. Vidal	Computer Service Assistant	France	01-10-03	Montpellier
S. Voets	Administrative Assistant	Belgium	01-01-93	ITC, Belgium
C. Walugenbe	Driver/messenger	Uganda	17-01-2005	Uganda
N. Youdja	Consultant	Algeria	21-06-04	ITC, Belgium

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*left during the year.

List indicates members of the INIBAP programme of IPGRI.
In addition, staff within other programmes and departments of IPGRI contributed to the INIBAP programme during 2005.

Acronyms and abbreviations

ADRA	Adventist Development and Relief Agency, Tanzania
ARC	Austrian Research Centre, Austria
ARDI	Agriculture Research and Development Institute, Tanzania
BAC	bacterial artificial chromosome
BAPNET	Banana Asia and Pacific Network
BARNESA	Banana Research Network for Eastern and Southern Africa
BBTV	banana bunchy top virus
BPI	Bureau of Plant Industries, Philippines
BSV	banana streak virus
BXW	bacterial *Xanthomonas* wilt
CARBAP	Centre africain de recherches sur bananiers et plantains, Cameroon
CATIE	Centro Agronómico Tropical de Investigación y Enseñanza, Costa Rica
cDNA	complementary DNA
CEDAF	Centro para el Desarrollo Agropecuario y Forestal, Dominican Republic
CFC	Common Fund for Commodities, The Netherlands
CGIAR	Consultative Group on International Agricultural Research
CIAT-TSBF	Centro Internacional de Agricultura Tropical, Tropical Soil Biology and Fertility Institute, Kenya
CICY	Centro de Investigaciones Científicas de Yucatán, Mexico
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement, France
CMV	cucumber mosaic virus
CORBANA	Corporación Bananera Nacional, Costa Rica
CpDNA	chloroplast DNA
CSIR	Council for Scientific and Industrial Research, Ghana
CvSU	Cavite State University, Philippines
DA-BAR	Department of Agriculture – Bureau of Agricultural Research, Philippines
DAR	Department of Agricultural Research, Malawi
DArT	diversity array technology
DFID	Department for International Development, UK
DGDC	Directorate General for Development Cooperation, Belgium
DMMMSU	Don Mariano Marcos Memorial State University, Philippines
DNA	deoxyribonucleic acid
DR-Congo	Democratic Republic of Congo
EMBRAPA	Empresa Brasiliera de Pesquisa Agropecuaria, Brazil
ESPOL	Escuela Politécnica del Litoral, Ecuador
EST	expressed sequence tag
EU	European Union
FABI	Forestry and Agricultural Biotechnology Institute, South Africa
FADECO	Family Alliance for Development and Cooperation, Tanzania
FAIDA-MaLi	Faida Market Link, Tanzania
FAO	Food and Agriculture Organization of the United Nations, Italy
FHIA	Fundación Hondureña de Investigación Agrícola, Honduras
FONTAGRO	Fondo Regional de Tecnología Agropecuaria, USA
FUNDAGRO	Fundación para el Desarrollo Agropecuario, Ecuador
GCP	Generation Challenge Programme
IAEA	International Atomic Energy Agency, Austria
IDB	Inter-American Development Bank, USA
IDIAF	Instituto Dominicano de Investigaciones Agropecuarias y Forestales, Dominican Republic
IDIAP	Instituto de Investigaciones Agropecuarias de Panamá, Panama
IDRC	International Development Research Centre, Canada
IEB	Institute for Experimental Botany, Czech Republic
IFPRI	International Food Policy Research Institute, USA
IICA	Institut Interaméricain de Coopération pour l'Agriculture, Haïti
IITA	International Institute for Tropical Agriculture, Nigeria
IMTP	International *Musa* Testing Programme
INERA	Institut National pour l'Etude et la Recherche Agronomiques, Democratic Republic of Congo
INIA	Instituto Nacional de Investigacao Agronomica, Mozambique
INIA	Instituto Nacional de Investigaciones Agrícolas, Venezuela
INIEA	Instituto National de Investigación y Extensión Agraria, Peru
INIVIT	Instituto de Investigaciones en Viandas Tropicales, Cuba
IPGRI	International Plant Genetic Resources Institute, Italy
IRAG	Institut de Recherche Agronomique de Guinée, Guinea
IRAP	inter-retroelement amplified polymorphisms
IRAZ	Institut de recherches agronomique et zootechnique, Burundi
ISABU	Institut des Sciences Agronomiques du Burundi
ISAR	Institut des Sciences Agronomiques du Rwanda
ISPSC	Ilocos Sur Polytechnic State College, Philippines
ITC	INIBAP Transit Centre, Belgium
JIC	John Innes Centre, United Kingdom
KULeuven	Katholieke Universiteit Leuven, Belgium
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries, Uganda
MARDI	Malaysian Agricultural Research and Development Institute, Malaysia
MGIS	*Musa* Germplasm Information System
MMSU	Mariano Marcos State University, Philippines
mRNA	messenger RNA
*MUSA*CO	*Musa* Research Network for West and Central Africa
*MUSA*LAC	Plantain and Banana Research and Development Network for Latin America and the Caribbean
*MUSA*LIT	INIBAP bibliographic database
NARO	National Agricultural Research Organization, Uganda
NIAS	National Institute of Agrobiological Sciences, Japan
NIDA	Nkoola Institutional Development Associates Ltd, Uganda
NIHORT	National Horticultural Research Institute, Nigeria
NRCB	National Research Centre on Banana, India
NRMDC	National repository, multiplication and dissemination centre
PCARRD	Philippines Council for Agriculture Resources Research and Development, Philippines
PRO*MUSA*	Global Programme for *Musa* Improvement
RNA	ribonucleic acid
SARI	Southern Agricultural Research Institute, Ethiopia
SSR	simple sequence repeat
TARGET	Technology Applications for Rural Growth and Economic Transformation, USA
TBRI	Taiwan Banana Research Institute
TIGR	The Institute for Genomic Research, USA
UEM	University Eduardo Mondland, Mozambique
UK	United Kingdom
UNAN-LEON	Universidad Nacional Autónoma de Nicaragua-León, Nicaragua
USA	United States of America
USAID	United States Agency for International Development, USA
VVOB	Vlaamse Vereniging voor Ontwikkelingsamenwerking en Technische Bijstand, Belgium
WV Ghana	World Vision Ghana, Ghana

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