African Crop Science Journal, Vol.1, No. 1, pp. 1–8, 1993
Printed in Kenya.

GENETIC AND AGRONOMIC IMPROVEMENT FOR SUSTAINABLE PRODUCTION OF PLANTAIN AND BANANA IN SUB-SAHARAN AFRICA

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(*Received* 20 *March* 1993; *accepted* 25 *May* 1993)

ABSTRACT

Plantain and banana (*Musa* spp.) are integral components of the farming systems in the humid forest and mid-altitude ecologies of sub-Saharan Africa. They provide more than 25% of the carbohydrates for approximately 70 million people in the region. Major constraints to plantain and banana production are fungal diseases (black sigatoka, *Fusarium* wilt), pests (banana weevil, nematodes), and the phenomenon of yield decline. Soil degradation due to shortening fallow periods also accounts for decreased yields. Research on *Musa* at the International Institute of Tropical Agriculture (IITA) began in 1973. IITA included plantain and banana among its mandate crops in 1987 and the Plantain and Banana Improvement Program (PBIP) was created in 1991. Major achievements of IITA on the crop are the production of germplasm with black sigatoka resistance, and the development of improved systems for sustainable and perennial plantain production. Current research at PBIP focuses on gaining insight into the *Musa* genome, developing *Musa* breeding capability, breeding for durable black sigatoka resistance, developing biotechnology techniques for *Musa* breeding, investigating the post-harvest quality of plantains and analyzing genotype-by-cropping system interaction.

***Key Words*: *Musa* species, improvement, sustainable production.**

PLANTAIN AND BANANA IN AFRICA

Sub-Saharan Africa produces about 35% of the world *Musa* production of 70 million tons. This provides more than 25% of carbohydrate in the diets of approximately 70 million people in the region. In addition to being a staple food for rural and urban consumers, plantain and banana provide an important source of revenue for smallholders who mainly produce them in compound or home gardens. The gross value of annual production exceeds that of several other main food crops such as maize, rice, cassava and sweet potato (4).

Most cultivated *Musa* are triploids ($2n = 3x = 33$). Being almost completely sterile, they develop fruit by parthenocarpy. The genomes of cultivated varieties are derived from the diploid related species *Musa acuminata* (A genome) and *M. balbisian* a (B genome). The most important cultivars have characteristic genomic constitutions: dessert banana (AAA), East African highland banana (AAA), plantain (AAB), and cooking banana (ABB).

Although Southeast Asia is the center of origin of *Musa* species (7), considerable genetic diversity has evolved in sub-Saharan Africa (9). The humid lowlands of West and Central Africa are considered to be a secondary center of diversification for plantain, while the highlands of East Africa are a secondary center of diversity for cooking and beer bananas (5).

In the last two decades or so, plantain and banana productivity in sub-Saharan Africa has either stagnated or declined, due mainly to increased incidence of pests and diseases and to soil related problems.

Pest and disease pressure is believed to have been increasing over the past 15 years due to intensification of production. Rising population pressure on the land has also led to shortened fallow periods and, consequently, to soil degradation. These trends underlie the urgency of IITA's work.

Of the diseases, black sigatoka leaf spot, caused by the fungus *Mycosphaerella fijiensis* Morelet, is generally considered to constitute the most serious constraint to plantain and banana production in sub-Saharan Africa. The disease was accidentally introduced into Africa two decades ago, and spread rapidly first in Central and West Africa and later in East Africa. It causes severe defoliation, reducing plantain yields by up to 33% (1). All plantain cultivars, as well as some of the most widely grown banana cultivars, are susceptible to black sigatoka. Other major diseases, mainly in East Africa, are *Fusarium* wilt and the banana bunchy-top virus. Pests are also a well recognized constraint on *Musa* spp. The banana weevil *(Cosmopolites sordidus* Germar) is the most important insect pest of plantain and banana in Africa. Its larvae bore tunnels in the corm, causing the plant to weaken and lodge or break. Both plantains and the East African highland bananas are susceptible to the insect. Nematodes also cause serious root damage, particularly in plantain.

A formidable obstable to perennial plantain production in field plantations is the rapid yield decline that occurs after one or two years. In contrast, plantations of dessert banana remain in production for many years. The causes of this "plantain yield decline syndrome" are not fully understood, but major factors appear to include loss of soil organic matter, which results in poor soil structure and reduced soil fertility, and pest buildup. Also, stands lodge easily under field conditions due to factors characteristic of plantains. These include poor root development, slow ratooning and "high mat", a tendency of the plant base to elevate further out of the soil in successive growth cycles (ratoon crops). Interestingly, the yield decline syndrome is not usually observed in smallscale "backyard" plantain stands which benefit from generous applications of organic matter in the form of household refuse.

MUSA IMPROVEMENT RESEARCH: GLOBAL PERSPECTIVE

Musa improvement research world-wide was initiated in the early 1920s with the advent of the international trade in dessert banana. Despite more than 70 years of global research effort, however, no cultivar has been successfully developed through cross-breeding, and all commercial cultivars are clonal selections from natural land races of farmer's germplasm.

Banana breeding started in Trinidad in 1922 and Jamaica in 1924 (7) but these programs are no longer active. Currently, the most important breeding program in tropical America is that of the Fundacion Hondurena de Investigacion Agrocila (FHIA, Honduras). This program has continued the work started by the United Fruit Company in the late 1950s. *Musa* research is also currently underway in several institutions in Asia, especially in India, the Philippines, Taiwan and Australia.

In Africa, the Belgians initiated a breeding scheme in Zaire in the colonial time (1), but this work ceased on independence in 1960. Recently though, several institutions in Africa have embarked on plantain and banana research in the continent. The Institute de Recherche Agronomique et Zootechnique (IRAZ), located in Burundi, functions as a regional centre addressing the problems of banana production in the East African highlands. French researchers of the Institut de Recherches sur les Fruits et Agrumes (IRFA) also started a large program in several countries before 1970 (2).

Among the CGIAR centres, IITA has the mandate for research on the improvement of plantains and bananas, while the International

Network for the Improvement of Banana and Plantain (INIBAP) coordinates international germplasm exchange and testing, and training of developing-country scientists.

MUSA IMPROVEMENT AT IITA

Plantain research by IITA began in 1973, and originally focused on agronomic work and germplasm collection. In 1979, the center of plantain research was transfered from Ibadan to the humid forest zone at Onne Station. Agronomy, intercropping, mulching and propagation were investigated, resulting in the production of a manual on plantain cultivation intended for national agricultural programs and farmers (8). Recently, IITA also started work at Namulonge Research Station, near Kampala Uganda, aimed at developing improved germplasm and cultural practices for sustainable production of cooking/beer bananas in the mid- to high-attitude zones of East Africa.

IITA's field genebank contains 113 different cultivars of plantain (*Musa* spp., AAB group) collected from Nigeria, Ghana, Côte d'Ivoire, Cameroon, Gabon, Congo, Burundi and the Philippines. In addition to the plantain collection, another 3000 *Musa* accessions, ranging from wild species to the most common export banana varieties, are maintained at the Onne Station. The larger part of the field genebank is also duplicated *in vitro* using standard shoot-tip culture methodology (12). These are retained as a breeding resource and in trust for the world community. Many of the *Musa* accessions were introduced as *in vitro* cultures with the assistance of INIBAP and the Nigerian Plant Quarantine Service (13).

In response to the increasing pest and disease pressure on the crop, IITA decided in 1987 to include plantain and banana among the crops for which it conducts genetic improvement. In 1991 the Institute created a separate program for this purpose. Research emphasis was redirected from agronomy and taxanomy to the genetic improvement of *Musa*. Critical issues for crop improvement are being addressed by PBIP through interdisciplinary projects. These projects include breeding strategies to obtain resistance to black sigatoka disease and other pests, germplasm enhancement using biotechnology, improvement in postharvest quality and management, and the development of sustainable production systems.

Use of conventional breeding techniques. Crossing is generally considered the most simple strategy for the genetic improvement of most crops. For *Musa* species, this strategy was little used for a long period. Within the last decade, however, the breeding endeavor advanced more rapidly than anticipated due to two important factors. Firstly, while *Musa* triploids were considered to have too low a level of reproductive fertility to be useful in breeding, a number of female-fertility triploid plantain clones were identified in the IITA field genebank (15). Currently, 37 different cultivars are capable of producing true seed upon hand-pollination, the highest number of seed-fertile plantains reported (10). Secondly, seed production rates at the Onne station seems higher than in other locations for banana breeding (11). More than 200 seeds have been extracted from a single triploid plantain bunch when pollinated with a wild diploid banana (10).

Initially, the breeding approach involved the production of tetraploid progenies from $3x$ x $2x$ crosses in which the triploid female plantains produced $2n$ (=$3x$) eggs. This strategy is currently being extended to include the production of secondary triploids by crossing the tetraploid hybrids with diploids. A first wave of hundreds of secondary triploid hybrids were field established in 1992.

Diploid plantain-banana hybrids have also been recovered and later selected from the initial $3x$ x $2x$ crosses (Table 1). These diploids are important to plantain breeding because they provide opportunity for germplasm enhancement at the diploid level, and simplify genetic analyses due to disomic inheritance. The genetics of black sigatoka resistance, dwarfism, apical dominance, fruit parthenocarpy, bunch weight and other yield components in plantains were established using this diploid germplasm (5). The plantain-derived diploids are being evaluated for fruit quality traits prior to their utilization as regualr progenitors in the breeding program. Improved diploid banana germplasm has also been obtained through intraspecific hybridization (Table 2). The selection criteria for this diploid germplasm were fertility,

TABLE 1. Diploid plantain-derived hybrids selected for further use in breeding

Code/Hybrid no.		Female parent	Male parent
TMPx	597-2	Obino l'Ewai	Calcutta 4
TMPx	1199-6	Obino l'Ewai	Calcutta 4
TMPx	1297-3	French Reversion	Calcutta 4
TMPx	1448-1	Obino l'Ewai	Calcutta 4
TMPx	1489-3	Bobby Tannap	Calcutta 4
TMPx	1518-4	Bobby Tannap	Calcutta 4
TMPx	1549-7	Obino l'Ewai	Calcutta 4
TMPx	1586-2	Obino l'Ewai	Calcutta 4
TMPx	1605-1	Ntanga 2	Calcutta 4
TMPx	1657-4	Bobby Tannap	Calcutta 4
TMPx	1659-13	Bobby Tannap	Calcutta 4
TMPx	2348-6	Bungoisan	Calcutta 4
TMPx	2348-7	Bungoisan	Calcuta 4
TMPx	2625-5	Bobby Tannap	Calcutta 4
TMPx	2625-20	Bobby Tannap	Calcutta 4
TMPx	2829-62	Bobby Tannap	Calcutta 4
TMPx	4281-2	Bobby Tannap	Calcutta 4
TMPx	4400-8	Bobby Tannap	Calcutta 4
TMPx	4600-12	Bobby Tannap	Calcutta 4
TMPx	4600-15	Bobby Tannap	Calcutta 4
TMPx	5837-1	Bobby Tannap	Calcutta 4

TABLE 2 . Diploid banana hybrids selected for further use in breeding

Code/Hybrid no.		Female	Male
TMBx	5105-1	Pisang lilin	Calcutta 4
TMBx	1659-13	Tjau lagada	Calcutta 4
TMBx	6142-1	Nyamwihogora	Long Tavoy
TMBx	7197-2	SH - 3362	Long Tavoy
TMBx	8075-7	SH - 3362	Calcutta 4
TMBx	8532-1	Heva	Calcutta 4
TMBx	8848-1	Calcutta 4	Uwati
TMBx	9128-3	Tjau lagada	Pisang lilin
TMBx	9719-7	Manang	Calcutta 4
TMBx	9839-1	Calcutta 4	Padri
TMBx	9869-1	Long Tavoy	Unknown Dibit

both female and male fertility, black sigatoka resistance, and good bunch characteristics. Their breeding values are being assessed in crosses with tetraploid and triploid parents.

So far several hundred hybrid progenies have been planted in selection fields within 5 years of breeding work, and 25 tetraploid hybrids have been selected that combine moderate resistance to black sigatoka, high yield, large fruit and improved suckering (Table 3). Fourteen improved tropical *Musa* plantain hybrids (hereafter TMPx) have been registered (16) to place the improved germplasm in the public domain.

TMPx genotypes are now undergoing mulitlocational testing in order to implement an established flow of materials. This scheme includes the selection of promising hybrids in replicated early evaluation trials, and replicated preliminary yield trials for further testing in multilocational trials. In preliminary tests, bunch weight of the best performing hybrid was twice that of the plantain parent (33 and 16 MT ha^{-1},

TABLE 3. Selected tropical *Musa* plantain (TMPx) and banana (TMBx) hybrids and synthetics (TMPS) developed by IITA

Code/Hybrid no.		Female parent	Male parent	Testing stage
TMPx	548-4	Obino l'Ewai	Calcutta 4	MET, AMYT*
TMPx	548-9	Obino l'Ewai	Calcutta 4	MET, AMYT*
TMPx	582-4	Bobby Tannap	Calcutta 4	MET, AMYT*
TMBx	612-74	Bluggoe	Calcutta 4	MET, AMYT*
TMPx	1112-1	French Reversion	Calcutta 4	MET
TMPx	1621-1	Obino l'Ewai	Calcutta 4	MET*
TMPx	1658-4	Obino l'Ewai	Pisang lilin	MET*
TMPx	2482-2	Obino l'Ewai	TMBx 366-8	MET
TMPx	2637-49	Obino l'Ewai	Calcutta 4	MET*
TMPx	2776-20	Bobby Tannap	Calcutta 4	PYT
TMPx	2796-5	Bobby Tannap	Pisang lilin	MET, AMYT*
TMPx	4479-1	Bobby Tannap	Calcutta 4	PYT*
TMPx	4698-1	Obino l'Ewai	Calcutta 4	MET,AMYT*
TMPx	4744-1	Obino l'Ewai	Calcutta 4	PYT*
TMPx	5295-1	Laknau	Tjau Lagada	EET
TMPx	5511-2	Obino l'Ewai	Calcutta 4	MET*
TMPx	5706-1	Obino l'Ewai	Calcutta 4	PYT*
TMBx	5748-1	Dare	Long Tavoy	EET
TMPx	5860-1	Obino l'Ewai	Calcutta 4	PYT
TMPx	6930-1	Obino l'Ewai	Calcutta 4	MET*
TMPx	7002-1	Obino l'Ewai	Calcutta 4	AMYT*
TMPx	7152-2	Mbi Egome	Calcutta 4	EET
TMPx	7356-1	Obino l'Ewai	Calcutta 4	PYT
TMPx	10901-2	Akpakpak	Calcutta 4	EET
TMPS	548-9	TMPx 5489-9	OP	EET

EET — Selected in early evaluation trials.
PYT — Tested in plant crop and ratoon in preliminary yield trial.
MET — Evaluated in multilocational evaluation trial.
AMYT — Evaluated in advanced yield trial for potential cultivar release by NARS.
* — Registered in *HortScience*.

respectively) (3). In order to evaluate stability of resistance and yield, selected hybrids are being tested along with their susceptible and resistant parents against standard cultivars. This work is conducted in collaboration with national researchers of 15 public and private institutions in Nigeria, Cameroon, Ghana, Cuba, Dominican Republic and Australia. Selection is based on the combination of stable sigatoka resistance and adequate plant/bunch characteristics. Advanced yield trials of selected hybrids are currently being set up in collaboration with national agricultural research programs in Côte d'Ivoire, Ghana, Nigeria, Burundi, Uganda, Tanzania, and with ICIPE (Kenya).

Another important achievement of the IITA *Musa* improvement program was the elucidation of the inheritance of black sigatoka resistance in plantain. Analysis indicated that sigatoka resistance is controlled by a major recessive gene and two minor modifier genes with additive effects (6).

Experience gained from the black sigatoka resistance breeding effort has greatly expanded our repertoire of breeding skills. These skills will subsequently be incorporated in breeding for additional objectives such as banana weevil and nematode resistance, higher yield, shorter stature (including dwarfism), lodging resistance, reduced "high mat", more rapid suckering and improved post harvest quality.

***Musa* germplasm enhancement using biotechnology.** Conventional efforts to propagate, conserve, and breed cultivated *Musa* are fraught with obstacles such as low reproductive fertility, slow rate of vegetative propagation, and long growth cycle. Hence, tissue culture and molecular genetic methods are increasingly being used as enabling techniques for handling and improvement of *Musa* germplasm worldwide.

At IITA, shoot-tip culture is routinely used for rapid propagation, safe international exchange, and conservation of *Musa* germplasm (12). Micropropagation has been crucial for rapid supply of large numbers of female and male plants for crossing, and for the continual supply of promising new hybrids for field evaluation trials. Furthermore, over 300 new *Musa* accessions have been introduced as shoot-tip cultures during the past 7 years.

Embryo culture and rescue techniques are being applied to increase the germination rate of true seed from crosses; more than 10,000 seeds are cultured in the tissue culture laboratory at Onne each year. Use of somaclonal variation as a tool for genetic improvement of plantains derived from shoot-tip culture has also been extensively explored but with limited success. This work was described in detail by Vulysteke *et al.* (14).

The potential of other modern biotechniques are currently being evaluated in collaboration with several advanced laboratories. Work on genetic stability of plants regenerated from cell suspensions and from cryopreserved cultures is underway with the Catholic University of Leuven (KUL, Belgium). The production of transgenic *Musa* plants has been a major goal of the common research effort with KUL. Recently, plantlets were regenerated which showed stable transformation with GUS and kanamycin resistance genes introduced by the biolistics method (R. Swennen, pers comm.).

The use of molecular markers (RFLPs, VNTRs, RAPDs) for phylogenetic studies, construction of a linkage map, marker-assisted selection in breeding, and mapping sigatoka resistance loci are being investigated in collaboration with Dr. R.L. Jarret of the USDA/ARS at Griffin, Georgia, USA. Six segregating populations derived from $3x$ x $2x$ and $2x$ x $2x$ crosses were field established and have been characterized for different morphological and agronomic descriptors. DNA has been extracted from each clone and finger printed with RFLP markers for genetic analysis. We expect to have a saturated *Musa* map by the end of 1993.

POSTHARVEST RESEARCH

Quality attributes related to *Musa* fruit palatability and storage will strongly influence the adoption of improved varieties. Consumer preferences and postharvest properties of new varieties are being assessed at IITA. Flavour, texture, response to cooking procedures, shelf life, ripening, handling and marketing factors of the hybrids are being compared with those of the widely grown land-race cultivars. Data are being used by the breeders to select hybrids which are most likely to be accepted by consumers. Rapid scoring techniques are also being sought for key quality parameters.

IMPROVED SYSTEMS FOR SUSTAINABLE AND PERENNIAL PLANTAIN PRODUCTION

Previous agronomy research has demonstrated that high input of organic matter is essential to maintaining long term plantain productivity. Proper management of soil organic matter is particularly important to avoid rapid yield decline under field conditions in contrast to backyard gardens. Plaintains perform well in village compound gardens, where they benefit from the regular input of household organic matter and refuse, but exhibit only short term productivity in open fields. Yield decline is excerbated in fields having highly weathered soils, and even liberal application of chemical fertilizers fails to halt the rapid decline in vigor. This has compelled farmers to regularly move to new fields in cleared forest or bush fallow for plantain cultivation. The practiced is, however, not sustainable in view of the increasing population pressure on land and enhanced environmental awareness.

At IITA, agroforestry systems are being assessed for their ability to maintain long term productivity without degradation of the resource base. In alley cropping studies, in which hedgerow trees and shrubs serve as a source of mulch, it was found that plantains grown with *Acacia barterii* alleys, an indigenous tree species, performed better than with other hedgerow species (B. Ruhigwa and M. Gichuru, pers. comm.). It also performed well in an alley cropping system with spontaneous multi-species hedgerows. This system seems most appropriate and promising in terms of sustained productivity over extended cultivation periods, and for maintenance of plant species diversity in agro-ecosystems.

OUTLOOK FOR THE FUTURE

The most tangible achievement of the plantain and banana research at IITA so far has been the development of black sigatoka-resistant hybrids within a 5 year time frame. This has been achieved through a combination of conventional breeding techniques and the adoption of new approaches, including interspecific hybridization, ploidy manipulation, *in vitro* culture, host plant/pathogen interaction studies, and field testing and selection. The ultimate impact of this work will depend on how useful these new breeding materials are to national research programs and farmers, and their ability to use this material as an integral part of plantain and banana production systems.

ACKNOWLEDGEMENTS

We thank Dr. Mark D. Winslow (formerly at IITA) for critical reading of the manuscript. We also wish to acknowledge Drs. R. Swennen and G. F. Wilson, former IITA plantain scientists, other colleagues at IITA and Dr. E. De Langhe (formerly with INIBAP) for their close involvement.

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