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Banana and plantain breeding in IITA

IITA's banana and plantain program is 42 years old and its banana and plantain breeding program is 31 years old. Over these years IITA hybrids were developed at three IITA Musa research stations in Nigeria, Uganda, and Tanzania. Hybrids have been distributed to NARS and CGIAR partners in 11 African countries, and 7 countries in Latin America and Asia. The IITA Musa breeding program has become an international breeding platform with strategic alliances developed with 14 research partners all over the world to conduct research on all aspects of Musa breeding. IITA leads the global collaborative effort in banana breeding. IITA's Musa breeding program is located in three countries and consists of fields of collections, early screening and preliminary yield trials, nurseries, in vitro labs, molecular labs, pathology labs, etc.

A drone image taken to determine the canopy cover of banana plantations. The canopy cover of a banana plantation is one of the first parameters expected to be influenced by drought stress. Photo by Stanley Bayo of IITA-KUL.

IITA was the first CGIAR center to start research on plantain in 1976. IITA devoted a decade (1976-1986) to collecting missions of banana and plantain and their characterization. This germplasm was the basis for the set-up of the International Network for Bananas and Plantains that later became part of the International Plant Genetic Resources Institute (IPGRI) and Bioversity International. During the same period, IITA developed substantial experience working with farmers and end user values as the plantain program was part of the Farming Systems Program (1976-1987). In addition, the sustainable cultivation of plantain was optimized, a technology that is nowadays not only important for high fruit yield but also for high seed production in breeding.

What's going on in the IITA banana and plantain breeding program? The following are a series of articles that give an update on IITA/s banana improvement work.

Researchers use DNA prediction models to speed up banana breeding

An international team of scientists have for the first time demonstrated that it is possible to speed up banana breeding using genomic prediction models that accurately select banana hybrids with desired traits. The models use the plant's genetic data (DNA landmarks) to estimate its usefulness in breeding and predict the physical traits such as height, yield, and disease resistance before the plant is taken to the field.

This study, published in a paper, Genomic prediction in a multiploid crop: genotype by environment interaction and allele dosage effects on predictive ability in banana, in The Plant Genome journal provides the first empirical evidence on the use of genomic prediction in a banana population.

Why speed up banana breeding?

Banana, an important staple and source of income for millions of people in many tropical countries, are by nature sterile crops. They reproduce vegetatively through suckers and this limits the mingling and recombination (shuffling) of genes from the parents to children. Therefore, there is limited diversity in banana growing in a particular region, which makes them prone to the same pests, diseases, and environmental stress.

Efforts to develop improved high-yielding and disease-resistant varieties are frustrated by the sterile nature of the plant. This complicates the breeding process making it lengthy and costly—taking up to 20 years to deliver improved varieties to farmers.

Moses Nyine from IITA and a PhD student at Palacký University is the lead researcher. He says the findings of the study present a significant breakthrough for banana breeding in the face of the myriad pests and diseases affecting banana in Africa. These include banana weevil, nematodes, Black Sigatoka, Banana Xanthomonas wilt, Banana Bunchy top virus and more recently Fusarium Wilt (Panama disease/Tropical Race 4 [TR4]) detected in Africa for the first time in Mozambique in 2013.

Biotechnology and statistics to the rescue

The researchers collected data from the East Africa Highland Banana and their hybrids planted in two fields in Uganda for two crop cycles between 2013 and 2016. In total, 307 types of banana were observed under low and high input field management conditions. They collected data on 15 key traits and grouped them into five categories: plant stature, suckering behavior, black leaf streak resistance, fruit bunch, and fruit filling.

The DNA differences between the banana were mapped out using a technology called genotyping by sequencing (GBS). These data sets were then used to test the ability of six genomic prediction models to determine the banana with the best traits through cross validation. The BayesB model was found superior to other models, particularly in predicting fruit filling and fruit bunch traits.

The results demonstrate that genomic prediction is possible in banana breeding and the prediction accuracy can be improved by using models based on data from many different environments. The prediction accuracy within the training population based on genomic estimated breeding values (GEBV) was above 75% even with models that had low predictive abilities.

The study was conducted as part of a collaboration of researchers from IITA, the Institute of Experimental Botany; the Centre of Plant Structural and Functional Genomics; Palacký University, Olomouc, Czech Republic; and the Laboratory of Tropical Crop Improvement, Division of Crop Biotechnics, Katholieke Universiteit, Belgium.

Moses Nyine explaining his research in a banana field in Uganda.

Breeding better bananas

A team of international banana experts have developed 48 hybrids of Matooke, a popular cooking banana in the highlands of Eastern Africa, that are now under field assessment in Uganda to select those with the highest yields and confirm resistance to four major pests and diseases.

The hybrids are one of the key achievements of a five-year, multi-partnership initiative to deliver improved varieties of cooking banana to smallholder farmers in Uganda and Tanzania.

The project brings together experts from banana breeding programs across the world including Australia, Belgium, Brazil, Czech Republic, India, Kenya, Malaysia, South Africa, Sweden, and the USA to work with the teams in Tanzania and Uganda. It is led by IITA and funded by the Bill & Melinda Gates Foundation.

The aim of the project is to develop hybrid banana varieties with an increase of 30% in yields and 50% in resistance to at least three of the major pests and diseases compared with the varieties currently grown by the farmers under the same on-farm conditions.

According to Rony Swennen, Banana Breeder at IITA and the project's Team Leader, IITA is supporting the national breeding systems to make them more efficient and vibrant. The project aims to deliver hybrid banana of Matooke and Mchare that are not only high yielding and disease resistant but also meet the needs and preferences of the end-user at the end of five years.

The project is focusing on the two most popular types of East African Highland cooking banana, Matooke in Uganda and Mchare in Tanzania, and on the two major diseases attacking the crop—Fusarium Wilt and Black

Rony Swennen explaining the hybrid breeding process that led to NARITA.

Leaf Streak (Sigatoka disease), and two major pests—parasitic nematodes (microscopic worms) and weevils.

"In addition to the 48 hybrids, we have six other trials from which we expect to select over 600 hybrids for Preliminary Field Trials. We have also developed seeds for crossing to support the breeding work, says Jerome Kubiriba from the National Agricultural Research Organisation (NARO), who is also the team leader for the project's breeding efforts.

Bananas are sterile with very low seed sets making breeding very difficult. Researchers have to force them to develop seeds for crossing and developing varieties.

The project has also brought on board different experts to support and work alongside the breeding team to speed up and ease the lengthy and complicated banana breeding process.

The project has also developed rapid screening methods that can help reduce to a half or a quarter the time it takes for breeders to screen their varieties for resistance. The tools will also contribute to speeding up banana breeding efforts globally. The University of Stellenbosch leads these efforts.

The project's molecular biologists are developing biotech tools to support breeders in early screening. These include molecular markers that help breeders detect early in the breeding process the presence of the genes associated with the desired traits, such as resistance to pests and diseases, and only plantlets with those genes proceed for field trials.

Brigitte Uwimana, a molecular breeder with IITA-Uganda, said that the project is mapping genetic markers to help identify genes that control pest and disease resistance in the plants; and has developed models for predicting yield and other traits based on genotypic markers.

To facilitate data collection and analysis the project has supported the development of digital tools including a database and a mobile data collection app. The Musabase is a database specifically for banana breeders. Bioinformatics efforts are led by Boyce Thompson Institute.

A mobile app adapted to breeders' needs in the field has also been developed to allow real time collection of data. The app is being tested with the team in Arusha before being rolled out to the rest of the team.

Past collaboration between IITA and NARO saw the development of 27 early Matooke hybrids named NARITA. Two of these were formally released by NARO in 2010 in Uganda and are now being grown in at least 15% of the banana farms in Uganda.

The project is supporting the evaluation of 20 of these NARITA hybrids in Uganda and Tanzania for local suitability and acceptance by farmers.

The NARITAs were evaluated in five field locations in the two countries A baseline survey to understand the traits farmers look for in banana had also been conducted, with over 1,000 household interviews and over 100 focus group discussions. These will assist breeders in breeding banana that meet farmers' and other end-users' needs.

IITA and partners conduct first proteomic investigation in plantain and banana

Scientists from IITA and partner institutions have carried out the first known proteomic investigation into plantain. The results of the study are featured in a paper titled "The plantain proteome, a focus on allele specific proteins obtained from plantain fruits" by N.A. Campos, R. Swennen, and S.C. Carpentier. Proteomics entails the study of the expression of proteins in a cell or organism. This is important because proteins are responsible for both the structure and the functions of all living things.

Plantain fruit. Photo by Nádia Campos, KU Leuven.

IITA banana breeder Rony Swennen said the identification and public release of the plantain fruit proteome is an important step for plantain varietal selection and breeding. He said the research is important because little attention has been given to postharvest research in plantain, a staple especially in Central and West Africa and Latin America, which grows most of the world's plantains.

Fruit development and maturation in plantain is hardly studied unlike in the more popular dessert banana. As a result, he said plantain suffers from many pests and diseases, although it is currently bred for higher yield. The acceptance of new plantain hybrids by farmers needs to be accelerated, hence the importance of better understanding the fruit physiology of plantain to develop hybrids that are more acceptable to consumers and have a better shelf life.

The proteomic research into plantain used an easy and reproducible procedure for protein extraction and identification, resulting in the first proteome (set of proteins) of plantain fruits. The results were compared with the proteome from the dessert banana Cavendish.

The scientists found that both the plantain and Cavendish cultivars were relatively close genetically but showed contrasting phenotypic or physical differences such as size, texture, color of fruit, and flavor. These characteristics, the scientists said, comes from a different physiology and maturation process.

The plantain fruit preserves more starch for longer periods than sweet banana. The type of starch also differs. According to the scientists, there are two types of starch in banana: resistant starch (RS) and non-resistant starch. This classification is linked to the capacity to be digested by the human body. Plantain degrades RS faster, but at maturation, is richer in resistant starch.

The paper concluded that an improved understanding of the fruit maturation process may yield benefits for public health, farming, and agricultural business.

The study was conducted as part of a collaboration of researchers from IITA, the Laboratory of Tropical Crop Improvement, Division of Crop Biotechnics, Katholieke Universiteit, Belgium, and SYBIOMA: Facility for SYstems BIOlogy based MAss spectrometry, KU Leuven.

Taking stock of efforts to address pathogens of three deadly banana diseases

Black leaf streak disease or black Sigatoka, yellow Sigatoka, and eumusae leaf spot are three closely related and complex diseases that constrain banana and plantain production globally. They are caused by three fungi belonging to the genus Pseudocercospora. These are P. fijiensis, P. musae, and P. eumusae, that cause black Sigatoka, yellow Sigatoka, and eumusae leaf spot, respectively.

Much effort has gone into controlling these pathogens and their related diseases since the first pathogen, P. musae, was identified as a banana pest in Java Islands in 1902. The other two, P. fijiensis and P. eumusae, were reported in the Sigatoka district of the Fiji Islands in 1963 (thus the name sigatoka) and in Southeast Asia in the 1990s. Black Sigatoka has since spread and is considered the most problematic disease of banana globally.

A team of researchers from IITA have compiled these efforts in a paper “Progress in understanding Pseudocercospora banana pathogens and the development of resistant Musa germplasm”, published recently in the Plant Pathology Journal. They also identified areas that need further attention to save banana from these deadly diseases.

Control efforts

According to the paper, these fungi cause streaks on banana leaves that turn necrotic, significantly reducing their ability to photosynthesize. This can lead to 35–100% yield loss, due to poorly filled fruits and smaller and lighter bunches. They also cause premature ripening of the fruit.

Management of the pathogens includes the use of fungicide, but this increases the cost of production by 25–30%. In total, over $550 million is spent annually worldwide on these chemicals, which also pose environmental risks to those working and living near banana plantations.

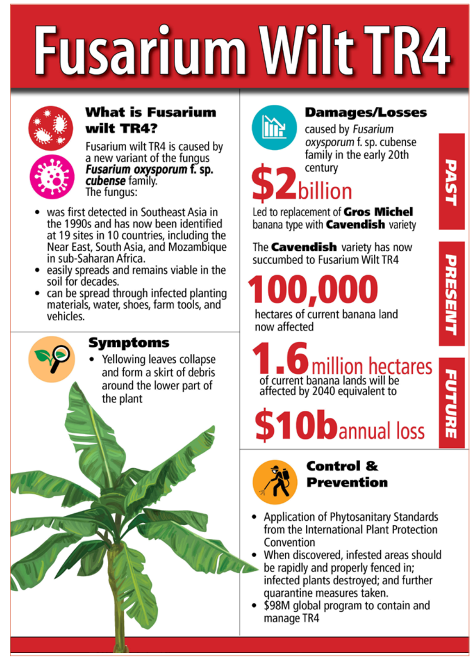
While non-chemical disease management approaches, such as the use of biological control agents, organic farming, cultural practices, and phytosanitary legislation, exist, they have not been widely adopted as they are often laborious and require specialized equipment that tends to be prohibitive in developing countries.

Climate change threat to banana

Traditionally, Pseudocercospora banana pathogens were separated by altitudinal and climatic gradients. P. musae was restricted to higher altitudes with cooler temperatures while P. fijiensis was more prevalent in lower, warmer areas with higher rainfall. However, it appears P. fijiensis has been shifting upwards to higher altitudes and in some cases, has replaced P. musae to become the dominant Pseudocercospora banana pathogen.

This gradual displacement suggests an evolutionary adaptation to either a changing climate or host fitness.

While researchers have suggested that the higher temperatures will increase the areas suitable for banana production by 50% by the year 2070, this may also affect Pseudocercospora banana pathogens and result in increased disease severity as well as the potential for emergence of new pathotypes. Therefore, calling for elaborate surveillance and management programs of these banana pathogens as the most cost-effective option to reduce future impacts.



Left: A Sigatoka susceptible highland cooking banana. Right: A Sigatoka resistant highland cooking banana developed by IITA. Photos by A. Alakonya, IITA.

Host resistance

The paper also looked at efforts to develop banana and plantain varieties with resistance to Pseudocercospora banana pathogens using both conventional and biotechnology methods by several breeding programs which started in 1922.

Most of the efforts have focused on P. fijiensis and some level of resistance or tolerance has been clearly demonstrated. Examples of successful breeding programs include IITA's improved P. fijiensis-resistant plantain hybrids, known as PITAs, and cooking banana hybrids called BITAs now available in several countries including Nigeria, Uganda, Cameroon, the Ivory Coast, and Ghana.

IITA, in collaboration with NARO-Uganda, has also developed several East-African Highland cooking banana hybrids (referred to as NARITAs). Some of these NARITA hybrids have been tested in Uganda by IITA and NARO and the most promising ones have already been released to farmers.

One of the factors that has led to these successes was the establishment of the International Musa Transit Center (ITC) in Belgium to support sanitization, multiplication, and distribution of genetic stocks from around the globe for breeding programs and to farmers.

These gains have also been made possible by integrating banana breeding with molecular tools due to the complexities of breeding banana, including its sterility, polyploid nature, low seed germination, and narrow genetic base.

To overcome these banana breeding challenges, a number of studies have been exploring transformation and have generated transgenic plants and evaluated them for resistance to Pseudocercospora in vitro in the screenhouse and under limited field conditions.

This has also led to the development of more efficient banana transformation protocols. However, the acceptability of genetically transformed banana still faces resistance from anti-GMO groups and banana-importing countries. Therefore, other options in biotechnology include the use of marker-assisted selection (MAS) to accelerate the germplasm selection process and genome editing.

Researchers develop a new way to describe plantain diversity in DRC

Researchers studying the morphological (structure and form) diversity of plantain in the Democratic Republic of Congo (DRC) have developed an innovative way to describe plantain diversity using descriptors based on performance, grouping them into main, secondary, and rare descriptors.

The morphological identification of plantain cultivars is important since molecular tools appear to have little value in supporting research in plantain taxonomy to differentiate plantain cultivars.

Three new descriptors

In the new system, three sets of descriptors are used: the first are the main descriptors such as bunch size and orientation, plant size and height, which allow a quick and easy separation of plantain cultivars.

Horn plantain variety 'Ikpolo Noir' found in DR Congo.

Bunch type was a major striking difference and quickly separated plantain cultivars into three main types. Other striking differences were the size of the pseudostem or trunk (giant, medium-sized, and small-sized) and the bunch orientation (which was generally pendulous or subhorizontal, and rarely horizontal and erect).

The secondary descriptors allow the differentiation of one cultivar from another within the same main group of bunch type, pseudostem size, or bunch orientation. Multiple secondary descriptors include pseudostem color, immature fruit peel color, fruit shape, fruit apex, fruit position, number of hands, fruit size, number of fingers per hand, and flower relicts at the fruit apex.

The third set are the rare descriptors, which allow the differentiation of one cultivar from all the others in the subgroup.

According to the researchers, this approach proved useful in differentiating the nearly 100 plantain accessions in the collection of the University of Kisangani (UNIKIS) in DRC. This approach makes cultivar description logical and faster because it moves from general to particular characteristics.

The study, titled The morphological diversity of plantain in the Democratic Republic of Congo by J.G. Adheka, D.B. Dhed'a, D. Karamura, G. Blomme, R. Swennen, and E. De Langhe, focused on the morphological characterization of plantain cultivars collected in the period 2005–2014 in 280 villages across nine provinces of DRC. These cultivars were established in two field collections at UNIKIS.

Most of the collected cultivars were French plantains (64 out of 98), followed by False Horn (23) and Horn (10) plantains.

Banana cultivars are usually described using Descriptors for bananas (Musa spp.) developed by IPGRI-INIBAP/CIRAD in 1996. The researchers had adapted these existing descriptors to better differentiate the variation and improve future research on plantains. This new work, published in Scientia Horticulturae, however, showed that this descriptor list is not appropriate for describing variation within the plantain subgroup, with 77 out of a total of 117 descriptors not considered useful.

The researchers believe that this existing descriptor list for banana will also not be appropriate in describing variation within other subgroups of banana, like the East African Highland banana, Pacific plantain, etc.

The observed variation was reproduced in the collection during succeeding cycles and confirmed the stability of the cultivars, as well as the value of the new descriptors. The classification of the plantain cultivars at the UNIKIS collection can be used as a standard for investigating plantain diversity for the entire African continent.

Large plantain diversity in DRC

The study results showed that the humid zone of DRC contains an exceptionally large diversity of plantains among the edible Musa subgroups. This means that DRC also has the largest diversity of plantains in Africa. The 100 different cultivars covered in the study represent just a part of the entire plantain variability zone in DRC. More cultivars are expected to be found in regions of the country that still need to be explored. The researchers believe that the diversity of plantain in DRC could be substantially larger than 120 cultivars.

Plantain characterization data from DRC offer a platform for reflections on the pan-African scale of plantain diversity. Assessing and characterizing the complete plantain diversity in Africa is possible by compiling characterization results of all Central and West African countries whereby UNIKIS in DRC will play a key role given its expertise and access to the largest plantain variability.

Since the planting of all accessions

False Horn plantain variety called 'Tala Lola' from Central DR Congo. Photo by R Swennen, IITA.

in one location is not feasible due to financial constraints, the researchers encouraged plantain curators to continue intensive contact, with regular exchange visits and discussions, to progressively reach an agreement on classification, synonymy, and uniqueness of all plantain cultivars.

In sub-Saharan Africa, an estimated 30 million people depend on banana as the principal source of dietary carbohydrate, with small-scale farmers making up the vast majority of banana and plantain producers. They grow the crop mainly for home consumption or for local markets. In West and Central Africa, about two-thirds of the banana cultivated and produced are plantain, which need to be processed and/or cooked for consumption.

The other third consists of dessert and other cooking bananas. In Africa, the major producing countries are Cameroon, Ghana, Nigeria, and Côte d'Ivoire. According to the FAO, production of plantain in these countries ranks high (12.3 million tons in 2014) among the starchy staples.

The study was conducted as part of a collaboration of researchers from University of Kisangani (UNIKIS), IITA, Bioversity International, and the Laboratory of Tropical Crop Improvement, Division of Crop Biotechnics, Katholieke Universiteit, Belgium.

Banana breeders challenged to breed for weevils and nematodes

Banana researchers from across the globe met in Kampala, Uganda, 27-29 March, to discuss options for safe and effective methods to control banana pests and diseases and to reduce the use of harmful chemical pesticides.

While banana is a major staple food and a source of income for millions of people in East Africa, its production is greatly hampered by a plethora of pests and diseases. One of the control methods has been the use of chemical pesticides, but this is no longer a sustainable option due to their harmful effects on the environment and toxic residues.

In the European Union, many pesticides have been progressively withdrawn from use or highly restricted. However, in sub-Saharan Africa, where phytosanitary policies and regulations are often less effective, such pesticides are still being (mis)used, posing a significant threat to vulnerable farmers and consumers of banana.

The workshop was organized by IITA in collaboration with National Agricultural Research Organisation (NARO), Real IPM, and the International Centre of Insect Physiology and Ecology (icipe) with support from the European Union.

The workshop, opened by the head of National Banana Research Program of NARO, Dr Jerome Kubiriba, was attended by researchers from Uganda, Kenya, Ethiopia, Nigeria, Tanzania, Costa Rica, Italy, Spain, the United Kingdom, Belgium, and Cuba. They shared lessons and experiences and approaches to tackle this problem. This will be followed by field visits to breeding laboratories and trial gardens of NARO, IITA, and Real IPM at Sendusu and Kawanda.

Danny Coyne and a team of researchers visiting a banana trial garden of IITA and NARO. Photo by IITA.

"With climate change, we predict that the pest and disease situation will become even worse as the higher temperatures and rainfall patterns will increase the multiplication rates and prevalence of disease pathogens and pests," says Danny Coyne, IITA Soil Health Specialist.

"Therefore, the researchers will discuss sustainable measures to address these threats while adapting to climate change through breeding varieties that are resistant to the major pests and diseases and combining this with biological control options."

The workshop is organized under the Microbial Uptakes for Sustainable management of major banana pests and diseases (MUSA) project funded by the European Union Horizon 2020. The project seeks to achieve sustainable intensification of banana and enset crops (false banana grown in Ethiopia) through identification, development, and implementation of integrated pest management (IPM) based on naturally occurring beneficial microorganisms. The project is led by Dr Aurelio Ciancio, who is based in Italy.

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