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Banana in Latin American and the Caribbean: Current State, Challenges and Perspectives

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Abstract

Latin America and the Caribbean (LAC), although not the center of origin of banana, grow 28% of the global production. Approximately 20 million tons (64% of production) are locally consumed, and seven countries of the region are in the top 10 banana exporting nations. In addition, 72% of exported plantains are produced in LAC. In spite of considerable technological change in recent decades in LAC, the crop continues to face important challenges. Of overarching priority is strengthening quarantine procedures against tropical race 4 of *Fusarium oxysporum* f. sp. *cubense, Banana bunchy top virus*, Xanthomonas wilt and other pests and diseases not yet present in LAC. Climate change and rising costs for fertilizers, fossil fuels and pesticides are also important challenges. Opportunities for increased grower income and greater contribution from banana to national economies are also constrained by an underinvested research and development system. Other threats and opportunities are specific to each of the seven common production systems: (1) conventional tropical Cavendish (AAA) production for export - black leaf streak (BLS) and increasing strict environmental and worker safety regulations; (2) organic tropical Cavendish production for export – crop nutrition, pests and diseases of fruits in postharvest, BLS; (3) subtropical Cavendish production - abiotic stresses; (4) plantain monoculture - BLS and water deficit; (5) monoculture of banana cultivars specific to certain countries, such as 'Prata' (AAB) in Brazil and 'Isla' and 'Palillo' (AAB, Pacific plantain) in Peru – Fusarium wilt; (6) banana associated in coffee and cocoa fields – Fusarium wilt and deficient marketing; and (7) mixed and monocrop banana produced at small scale for home consumption or local markets – BLS and poor management. Collaborative regional knowledge platforms may offer increasing benefits, especially with more sophisticated electronic tools for knowledge sharing. These can support key themes, such as identification of homologue and analogue zones; crop, climate and pest modeling; tools for the study of soil and root health; and relevant information to guide breeding strategies through genetic and genomics.

OVERVIEW OF BANANA PRODUCTION AND COMMERCIALIZATION IN LATIN AMERICA AND THE CARIBBEAN

Latin America and the Caribbean (LAC), although not the center of origin of bananas[1], grow 28% of the global production, which was estimated at 117 million tons in 2009 (Lescot, 2011). The region has three of the top 10 banana-producing countries, Brazil, Ecuador and Colombia ranked as 5, 7 and 8, respectively. In addition, six countries from LAC are in the top 10 Cavendish-exporting countries (Table 1). The bulk of production in LAC is of the Cavendish type (20 million tons), followed by plantains (6.8 million), other dessert types (4.2 million tons) and other cooking types (1.2 million tons) (Lescot, 2011).

The LAC region is a major exporter of banana, accounting for 66% of global Cavendish exports. Ecuador continues to be the world largest exporter of Cavendish banana with 4.9 million tons in 2009, followed by the Philippines and Costa Rica with 2.2 and 1.9 million tons, respectively (Table 1). Plantains also play a very important role in LAC, with 72% of plantains traded on international markets produced in this region. Nevertheless, 62% of banana and plantain production in LAC (20 million tons) is consumed locally, which indicates the high importance of these crops in local diets and food security throughout the region.

Banana production in LAC has more or less doubled since the 1960s, when production was estimated to be around 15 million tons (FAOstat, 2011; Fig. 2). The increase in production is mainly due to an increase in cultivated area, which almost doubled from an estimated 1.1 million hectares in 1961 to over 2 million hectares in 2009 (FAOstat, 2011; Fig. 2). However, total area is likely to be significantly higher, if the production in backyards, mixed cropping and forestry systems is included. Data thus show that average yields in the region have remained largely stable over the last 50 years, at roughly 15 t/ha, with plantain yields on average about 1/3 lower than banana yields. However, yields are highly variable throughout the region and depend on the production system.

Based on FAO data, some country-specific trends in yields can be observed. In Costa Rica, initial high yields fell in the beginning of the 1990s and have since recovered to about 55 t/ha currently. Ecuador, with a much lower starting point 20 years ago and some variation over time, seems to follow an increasing trend towards its current level of >30 t/ha. With yields between 30-40 t/ha, Colombia is at an intermediate level of banana productivity, with slightly increasing trend over the last years. Major producing countries, displaying lower yield levels include Brazil and Venezuela, where the latter shows a decline in yields over the last 20 years (Fig. 3A). Trends in plantain yields are similar, but with a lower average level (Fig. 3 B). A relatively high average yield (about 12 t/ha) is reported for Peru, while in Colombia, where plantains are intercropped with coffee, despite the increasing trend, the yield of about 8 t/ha is still below the regional average. In the Dominican Republic, plantain yield statistics show drastic variations due to major hurricanes, but have increased significantly over the last 8 years and are now above average with 12 t/ha (FAOStat, 2011).

The average farm gate prices for both banana and plantain have increased over the last 20 years, with accelerated increases since 2005 (FAOstat, 2011), indicating that the

[1] The term banana includes both dessert and cooking types of the genus *Musa*, unless otherwise mentioned.

demand on national and international markets has risen faster than production. Among countries, differences in average farm gate price are very high. Peru shows relatively low prices, where plantain prices only recently have recovered to the 1992 level of about US$100 per ton. In Panama, both banana and plantain prices are far below the regional average, without significant increases in the last years. High, but highly volatile, plantain prices can be observed in Colombia, Dominican Republic and Mexico. In the Caribbean, prices have increased sharply over the past decade and are far above the regional average, reaching more than US$1,000 per ton in Jamaica (FAOstat, 2011). Prices in the major exporting countries are very different. In Costa Rica higher than average prices are paid, in Ecuador farmers receive about 30% of the region's average, and in Honduras, only 60% of the regional average is paid.

PRINCIPAL BANANA PRODUCTION SYSTEMS IN LAC

Banana production in LAC can be subdivided into seven production systems, based on the cultivar group used, size of farms, use of inputs and whether the system is monocropped banana or banana with associated crops (Staver et al., 2010). Five of the systems are primarily monocropped, although temporary crops may be grown during the establishment period. For the remaining two systems, banana is grown with perennial crops and may only be a secondary crop in the system. Three systems are based on Cavendish, one on plantain and three may use a mix of cultivars or a minor cultivar. For each system, we will describe the genetic base, the use of external inputs and the primary pests and diseases which contribute to costs of production and reduce yields if not controlled. In all systems, there are opportunities for agroecological intensification (Côte et al., 2010).

Cavendish cultivars are produced in large plantations for the export market in the tropical regions of over 10 countries of Central and South America and the Caribbean and for national markets in three countries (Brazil, Mexico and Venezuela) covering over 1.2 million hectares. The increasing use of monoclonal selections propagated through tissue culture contributes to highly uniform plant types which can be planted at densities above 1,500 mats/hectare. Fertilizer use often exceeds 400 kg of N and 700 kg of K per year, and pesticides are used to control nematodes, with up to 4 applications per year, and black leaf streak (BLS), with 15-60 applications per year depending on total rainfall and the number of dry months. Insect pests and diseases of the bunch are increasingly controlled through biological means or indirectly with protective bags or cultural practices. Growers face increasing regulatory pressure on input use from legislation on environment, worker safety, and pesticide residue limits on fruits and from increasing pest and disease resistance to biocides. These issues define the most pressing short-term research issues. In the medium term, the research agenda focuses on biological control, soil and root health through crop rotation and vegetative ground covers, and the threat of new pests and diseases, such as tropical race 4 of *Fusarium oxysporum* f. sp. *cubense* (Foc).

There is also a growing sector of organic production of Cavendish for export, found in dry zones (150-600 mm precipitation/year) of the Dominican Republic, Peru, Ecuador and Colombia covering over 15,000 hectares with an expansion rate of more than 10%/year. These plantations are often in the hands of smaller growers using local planting material from a number of different cultivars of Cavendish. As planting areas expand and restrictions arising from certification increase, growers face increasing competition for organic nutrient sources. BLS infections increase as rainfall increases and particularly during years with above average rainfall under the influence of hurricanes or El Niño. The growers use concoctions of different locally produced and commercial products for control of this disease. In addition to issues of appropriate cultivars for organic production, nutrient management, more efficient irrigation and BLS control, organic growers also seek practical biological and cultural control practices for pests and diseases. These latter result in blemishes on the fruits or/and complicate long-distance shipping for countries such as Peru or Ecuador. The recent emergence of export organic banana production was mainly based on technologies developed or adapted by growers from methods used in conventional banana production and organic approaches from other crops.

The third sector based on Cavendish monocultures for national markets is found in subtropical regions of Brazil and in Argentina and Paraguay. Production areas reach 70,400 hectares (Van den Bergh et al., 2012). Although Sigatoka leaf spot and nematodes reduce yields, abiotic stress is a major determinant in management strategies, and growers report facing up to eight or more frosts or short periods of extreme cold per year which damage plant tissue and distort bunch emergence and finger formation. Fruit production slows or stops during the cooler temperatures and short days of winter. Temperatures during heat waves of summer may also exceed 35°C which is detrimental to productivity. Research issues include cultivar selection for temperature extremes, cold temperature protection measures, and pest and disease management, including dealing with future threats such as Fusarium strains adapted to the subtropics.

Plantains are also grown in monoculture both for national markets and, to a minor extent, for export. Grower plantation size varies from a hectare or less to over 100 hectares, and major production zones are found with yearly rainfall varying from 1200-2500 mm/year from Mexico to Bolivia. Each production zone has preferred cultivars, either Horn, False Horn or French. Increasingly, growers are using dwarf plantain and the ‘plantain-like’ hybrid FHIA-21 in higher densities, with annual or biennial replanting. This is combined with targeting high price periods or staggered harvests from successive blocks of different ages within the same plantation. Fertilizer and pesticide use is intensifying, particularly for export production or production contracted through supermarkets. However, even in intensive production, nutrient use does not exceed 50% of nutrients used in export Cavendish. Smallholders may use only 50-100 kg of N and K per hectare. Fungicides are increasingly used to control BLS varying from no applications to 12-15 sprays/year for intensive production. With increasing frequency of replanting and using clean planting material, problems with nematodes and weevils have declined. Research issues for plantain growers include BLS control, soil and root health through increased ground cover use, residue management and organic amendments, and improved water management. Improvement in the uniformity and productivity of plantain cultivars through the selection of elite plants is also being tested. Conventional export production technology has also been applied to plantain, but major research efforts to intensify production techniques for national markets were also made by CORPOICA in Colombia in the 1980s and 1990s and promoted through training courses and research grants led by the International Network for the Improvement of Banana and Plantain (INIBAP - now Bioversity International) in other plantain-growing countries of LAC in recent decades.

A special category among the monocropped bananas is useful to capture the diversity of cultivars in Latin America specific to certain countries. In Peru, for example, ‘Isla’, a Pacific plantain (AAB), is the most popular cultivar, and another cultivar from the same group, known locally as ‘Palillo’, is also a consumer favorite. In Brazil, ‘Prata’, an AAB dessert banana, is widely grown for national markets. The major production challenge for all three of these cultivars is Fusarium wilt. Apple banana (AAB) also has widespread consumer acceptance in Latin America, but monocrop production which has been attempted in numerous countries, including Venezuela and Mexico, is quickly disrupted by Fusarium wilt. Breeding for resistant and tolerant cultivars and strategies to generate Fusarium-suppressive soils are high research priorities.

In the last two production systems, banana and plantain are grown in association with other vegetation. Staver et al. (2010) estimated that in Mesoamerica (Mexico to Panama), banana is grown in over 255,000 hectares of smallholder coffee plantations and 43,000 hectares of cocoa, both as shade and in association with trees. This production system is also found throughout the Caribbean and the mid-altitude coffee of the Andes and low altitude cocoa growing areas of the Andes. ‘Gros Michel’ is the primary cultivar grown for national markets, although in Colombia, plantains are also a major secondary crop with coffee. A diversity of other cultivars is grown for home consumption and market, including Red and Red/Green, Sucrier, Bluggoe and Cavendish types (Staver et al., 2011). In this system, primarily found among smallholders, growers seldom fertilize bananas and use only cultural practices such as deleafing and replanting for pest and disease management. Fusarium wilt is the primary disease threat in this production system due to the importance of ‘Gros Michel’, which is highly susceptible. Research issues for increasing banana productivity and sustainability include Fusarium-resistant cultivars, optimizing light distribution among trees, bananas and the perennial crop, increasing the nitrogen contribution from trees, managing the microenvironment to minimize disease expression and improving soil health through increased leaf litter. For bananas grown in coffee plantations, there has been virtually no public sector production or post-harvest research investment. Small-scale growers, traders and market vendors have built up the production and value chain with their own investment.

Finally, the other mixed production system produces bananas primarily for home consumption, mainly found in the Amazon and Orinoco basins of South America and the Caribbean coast of Central America in bush and forest fallow agriculture. Up to a dozen cultivars may be grown in association with other food crops before the field returns to fallow. The system is also found in backyard gardens with a diversity of other crops including fruit, ornamental and shade trees and shrubs in rural and peri-urban households throughout the region. This production system seldom appears in agricultural statistics since diverse crops are present from only a couple up to 100 banana mats. The major problems facing this system include bacterial and fungal wilts which affect otherwise quite hardy cultivars of Bluggoe and dessert bananas, including ‘Apple’ and ‘Gros Michel’.

PLANT HEALTH – OVERVIEW OF KEY PEST AND DISEASES

The LAC region has experienced one of the most devastating plant disease epidemics in history. In the 1950s, export banana companies shifted to the Cavendish cultivar, due to increasingly unmanageable problems with Fusarium wilt, which devastated large production areas of the cultivar ‘Gros Michel’ (Stover, 1962). Financial losses of around US$400 million (Ploetz, 2005) equate to a 2012 value of at least US$2.3 billions. The introduction of Fusarium wilt-resistant Cavendish bananas saved the international banana export trade, as there were (and still are) no efficient practices to control the disease. While Cavendish plantations in LAC today remain unaffected by Foc race 1 (the race that destroyed 'Gros Michel' in the 1950s), a highly virulent race of Foc, known as tropical race 4 (TR4), is devastating Cavendish bananas in South Asia (Ploetz, 2005; Molina et al., 2011). The threat of Foc TR4 to countries and continents where it has not been reported yet is immense, as TR4 not only attacks Cavendish bananas, but also many banana cultivars important for food security and income generation, such as 'Gros Michel', 'Bluggoe' (ABB), 'Prata' (AAB), 'Silk' (AAB), 'FHIA-21' (AABB) and many others (Ploetz, 2005, Molina et al., 2011, Dita et al., 2011). It has been estimated that around 80% of global banana and plantain production comes from cultivars susceptible to Foc TR4 (Ploetz, 2005).

Preclusion, containment and host resistance are the most important disease management strategies. The development of resistant and commercially well-accepted genotypes is a long-term option. Thus, controlling further dissemination in South-East Asia and prevention of new incursions in TR4-free areas is highly desired to maintain local and commercial banana production (Dita et al., 2010; Molina et al., 2011; Ploetz et al., 2011;). Dita et al. (2010) published a DNA-based and TR4-specific diagnostic tool, applicable for both fungal and plant DNA. Recently, this method was also validated for infected, but symptomless plant and soil samples (Dita et al., this volume), which are the two main pathways for Foc dissemination. Such a tool is important for quarantine programs and should be adopted and further validated for rapid and reliable Foc TR4 diagnostic. A program to raise awareness of the threat of TR4 was discussed by Pocasangre et al. (2011) during the ISHS-ProMusa symposium held in China in 2009. Bioversity International has led the implementation of this program through MUSALAC with training courses in Cuba and Costa Rica in 2010 and Nicaragua and Mexico in 2011. In Mexico, all quarantine inspectors of the country were trained together with OIRSA (*Organismo Regional Internacional de Sanidad Agropecuaria*) representatives from Dominican Republic, Honduras, Guatemala and Nicaragua. These training courses have proven to be an excellent way both for raising awareness and capacity building on diagnostic, epidemiology and disease management.

To help prevent the introduction of TR4 on the American continent, private companies (Dole Fresh Fruit International, Chiquita and Del Monte) and regional scientists in LAC set down a list of recommendations and rules for travelling between Asia and Latin America. Before going on a field trip, *Musa* stakeholders should consult these guidelines on the MUSALAC website.

The advice is not just for Foc TR4. It also holds for other pathogens that have not yet reached the LAC region, such as the *Banana bunchy top virus,* which already made the jump from Asia to Africa, and the bacterial Xanthomonas wilt that is spreading through eastern Africa. There are numerous examples of diseases that have been brought to new areas through infected planting materials (e.g. see Blomme et al., this volume) which highlights the importance of clean seed systems (see Dubois et al. this volume) and good virus diagnostics.

Though LAC is thus still free of some important banana pathogens, others continue to be major production constraints. BLS disease, caused by *Mycosphaerella fijiensis* is the major challenge, primarily in Cavendish production for export and plantain monocultures. Fungicides contribute to the management of BLS and other leaf spots, but are costly and harmful to human health and the environment. Castelan et al. (this volume) reported how removal of necrotic leaves can limit the reduction in green life caused by BLS. Sonego et al. (this volume) showed that leaf removal alone was not efficient in controlling Mycosphaerella leaf spots, but good results can be obtained when it is used in combination with citric-biomass extract and fungicides. Two alternative protectant fungicides based on *Bacillus subtilis* and *Bacillus pumilus* strains were shown to be effective in reducing BLS severity in the field (Serrano et al., this volume). Climatic conditions greatly affect disease build-up. Regular field observations, monitoring of weather data and the use of crop models to forecast disease evolution are important to better time fungicide applications and optimize integrated control methods (Bendini et al. and Sonego et al., this volume). Therefore, integrated management by using different fungicides based on monitoring, combined with cultural practices to reduce inoculum levels, such as removal of infected leaves or leaf necrotic parts form the basis of BLS management for susceptible cultivars.

The use of resistant genotypes is recognized as one of the most sustainable solutions to many pests and diseases. Hybrids with resistance to BLS have been deployed in areas of high disease pressure, but wide-scale adoption is not always guaranteed because of differences in taste and processing qualities (e.g. see Saraiva et al., this volume). Garming et al. (this volume) analyzed the political, legal and market context that contributed to the widespread adoption of FHIA-21, a BLS-resistant plantain-like hybrid, in the Dominican Republic, and highlight the importance of consumer preferences, agricultural policy, market conditions and the personal engagement of key actors in the research and private sector. Alternative processing techniques, such as chips in the FHIA-21 or jams (de Godoy et al., this volume), can help in overcoming constraints for adoption of new resistant cultivars.

Hybrids such as FHIA-21 have only partial resistance to BLS, which is relatively more durable but not perpetual. Effective crop management practices, such as adequate fertilization and leaf removal, should also be implemented to avoid or delay resistance breakdown. This is especially true for regions with optimal conditions for BLS. Indeed, high levels of BLS severity have been observed in the last years in FHIA-21 in the Dominican Republic and in FHIA-18 in Cuba (Fig. 4A). Finally, special attention should be given to registration of new chemicals and recommended dosages to prevent fungicide resistance, which has been commonly observed in the last years.

While occasional damage caused by banana streak viruses (BSVs) is common in LAC, mainly in genotypes with the 'B' genome under special conditions, the current losses caused by this disease in Cavendish plantations in Peru and Ecuador need not be a problem (Fig. 4B-C). As Cavendish is totally 'A' genome, BSVs appear to be transmitted either by vectors (especially mealybugs, e.g. *Planococcus citri*) and/or in already infected planting material. Quarantine policies coupled with use of virus-free certified tissue culture plants are urgently needed to address this situation which is provoking losses up to 20% (Ciro Barreras, Peru, pers. commun.).

Erwinia (*Dyckeya* spp.) soft rot is a constraint for plantain production in Nicaragua, Panama and the Dominican Republic, mainly associated to flood-irrigation. This disease could eventually be spread to banana plantations and cause substantial losses if not controlled.

In addition, insect pests, such as the banana weevil (*Cosmopolites sordidus*) and banana rust thrips (*Chaetanaphothrips signipennis*), may cause losses in certain production systems. Damages caused by rust thrips on organic bananas in dry areas are increasing and can present a potential constraint if sustainable control measures are not adopted.

Finally, nematodes still represent a major problem and should not be ignored. Nematicide use restrictions and soil health disequilibrium caused by abusive or poorlyorientated applications places nematodes as a sensitive issue, mainly for Cavendish-exporting production systems. Implementing integrated soil health practices that deploy increasing organic amendments, cover crops, coupled with science-based soil management strategies seem to be the best way forward. However, the decision-making process for nematicide application is still based on numbers of nematodes per root weight.

BREEDING AND GENOMICS: ADVANCES AND PERSPECTIVES IN MUSA

Two banana main breeding programs currently operate in LAC, one at FHIA (*Fundacion Hondureña de Investigación Agricola*) and one at EMBRAPA *(Empresa Brasileira de Pesquisa Agropecuaria*). These programs have been working for a long time with relative success (see Amorim et al. and Aguilar et al., this volume). FHIA hybrids (e.g. FHIA-01, FHIA-02, FHIA-17, FHIA-18, FHIA-20, FHIA-21, FHIA-22, FHIA-23 and FHIA-25) have been disseminated globally. Adoption has been highest in Cuba and the Dominican Republic. EMBRAPA hybrids have been also disseminated in Brazil with higher impact on specific areas in the Amazonian regions in Brazil. The main attractive trait of these hybrids has been their BLS and Fusarium wilt resistance, because quality aspects (taste) and postharvest issues (finger drop) are in general not fully meeting consumer expectations. The FHIA breeding program currently focuses on developing Cavendish-type cultivars resistant to BLS maintaining all the quality traits of Cavendish varieties. The EMBRAPA breeding program is focused on developing Prata-type cultivars resistant to both BLS and Fusarium wilt. After years of working on developing tetraploid Prata-type hybrids, the program is now attempting to obtain triploid hybrids and associating classical breeding with molecular biology tools. One additional breeding program operates in Guadeloupe. This program, led by CIRAD, is specially focused on new dessert banana hybrids, but also on cooking bananas.

In spite of the importance of plantain for LAC, breeding initiatives for plantain are scarce and should urgently be encouraged, as the region relies on just a few cultivars with a narrow genetic base that are BLS susceptible. The exception is FHIA-21 which has been widely adopted only in the Dominican Republic, although informal reports based on field observations suggest that resistance to BLS in FHIA-21 is breaking down.

While BLS, Fusarium wilt and quality issues remain main targets for breeding, other traits concerning local production/consumption, such as nematode resistance, abiotic stress tolerance (drought, extreme temperatures), water-use efficiency and adaptability to agroforestry and mixed crop system, should not be ignored, especially in the light of climate change.

One of the sources of genetic variability in banana is somaclonal variation. Plant tissue culture induces variation (Jain, 2000), which has been used in banana cultivars to obtain superior quality banana clones (Hwang and Ko, 2004). However, although this strategy has been largely explored at TBRI (Taiwan Banana Research Institute) in Taiwan, efforts in LAC have not resulted in any new superior genotype. There are some reports from IBP (*Instituto de Biotecnología de las Plantas*) and INIVIT (*Instituto de Investigaciones en Viandas Tropicales*) in Cuba (Bermudez et al., 2002; Ventura et al., 2003), inducing mutation with gamma/cobalt radiation, but so far no distinctive genotypes are in the pipeline or being promoted. Somaclonal variation offers a promising approach, but its success relies on large populations, high-throughput phenotyping and also a bit of luck. These constraints may have made LAC researchers somewhat reluctant to spend time and resources on somaclonal variation as a breeding strategy for banana.

So far, ‘omics’ approaches have not yielded any tangible results in *Musa*. However, recent advances have generated a huge amount of data and new options for looking differently at key pathogens and their interaction with *Musa*. The *M. fijiensis* genome has been sequenced and data will be available soon (G.H.T. Kema, Plant Research International, pers. commun.) and a first attempt to draft the Foc genome was presented (Dita et al., 2011). In addition, a significant amount of information on *Musa*-pathogen interactions is becoming available as deep-sequencing technologies become cheaper (Cruz et al. this volume). However, the key piece of this puzzle is the *Musa* genome, which fortunately, at least the ‘A’ genome, has been concluded (D’Hont et al., 2012). With all these information on hand, different avenues for cross-linking among genomics, classical and transgenic-based[1] breeding strategies are opening up (Fig. 5). Crop improvement through genetic modification is now a reality. It has been proven that it is possible to transform different banana cultivars on a regular basis. However, the public concerns still remain as a strong barrier.

Independently of what breeding techniques are in place, it should be stressed that genomics and molecular biology are not necessarily linked to creating transgenic plants. It is important to reinforce the potential of banana and pathogen genomic studies as key components also for classical or conventional breeding programs. Scientists need to be updated because exploring the *Musa* genome coupled with “omic” tools and high-throughput phenotyping will bring new opportunities that should change the way we see *Musa* genetics. However, “omic” knowledge should be delivered in a more user-friendly way for classical plant breeders and agronomists in order to facilitate its adoption and application. Overall, for biotechnology to achieve its potential impact on banana breeding, clear, regular and interdisciplinary communication across the whole banana sector is needed, firstly to make sure that proper tools are applied to the most pressing problems and secondly to ensure that pathways for efficient delivery/uptake are in place.

SOCIO-ECONOMIC ASPECTS OF PRODUCTION AND COMMERCIALIZATION AT FARM LEVEL

The contribution of banana and plantain to smallholder livelihoods ranges from being the main income source to a small but welcome complement of cash generation, or as a food security and subsistence crop, depending on the production system. Plantains in Central America are mainly produced in monocrop plantations and contribute significantly to farm income. Case studies show that in Rivas, Nicaragua, plantains account for as much as 87% of farm household income; for small-scale farmers in Chiriquí, Panama, the contribution is 75% and in the Dominican Republic about 55% of total household income (Schreiner, 2010, Argüello 2011, Espinosa 2011). In contrast, in Colombia, about 85% of plantains are planted in intercropping systems with coffee, cocoa, cassava or other fruit trees (Espinal et al., 2005). Income levels are however very variable. In Nicaragua, plantains are perceived as a highly profitable crop, particularly in those regions where irrigation systems are available to farmers and distances to markets are short. Profits are much lower for rain-fed production due to price decay in glut periods, which is the case on the Nicaraguan island Ometepe and for many smallholders in the Dominican Republic and Panama.

[1] Transgenic-based breeding is used instead of molecular breeding to discriminate molecular approaches used as a support for classical breeding, i.e. market assisted selection.

Banana production and its relative weight for farmers' livelihoods is even more diverse: In some countries, smallholders produce bananas for export as the main income generating activity, for example in the Dominican Republic, West Indies, Peru and Ecuador (El Oro y Sur Guayas). On the other hand, export production in Costa Rica, Colombia, Panama, some parts in Ecuador and Honduras is concentrated on large farms with high productivity, while local and domestic markets are supplied by small-scale farmers and surplus or second quality from export production. Throughout the region, small coffee and cocoa producers use banana as shade crop and secondary source of income for domestic consumption. In Honduras, an estimated 11% of domestic consumption of dessert bananas and 100% of production of Gros Michel is harvested in coffee agroforestry systems (based on Castellón, 2010). In Costa Rica, the share is even higher with 18% of domestic consumption (based on Escobeda Aguilar, 2010). The productivity in these systems typically ranges between 3-4.5 t/ha, according to management and planting density, and up to 8 t/ha were observed in a survey among farmers in Nicaragua, Honduras, Costa Rica and Peru.

The relative importance of banana to livelihoods of small-scale farmers in these mixed production systems varies widely. In the most remote and mountainous areas, they are hardly commercialized at all. Here they constitute an important food security crop or are important for specific purposes, such as cheap staple food supply for hired coffee pickers (Alto Piura/Peru, Matagalpa/Nicaragua). Often the contribution of bananas from coffee or cocoa plantations is highly appreciated during scarcity times between coffee harvesting seasons (Tutule/Honduras, Matalpa/Nicaragua). However, this probably constitutes less than 10% of households' total cash flow. Nevertheless, in several coffee-producing areas, bananas generate up to 20% of yearly income and play an important role in mitigating risks of coffee price variation (Talamanca and Turrialba/Costa Rica, Peña Blanca/Honduras, Selva Central/Peru, central and marginal coffee areas/Colombia).

For the commercialization of banana and plantain, a majority of smallholders in the LAC region still rely predominantly on traditional supply chains selling their produce in bunches (12 bunches as base unit trade in Haiti), or in fingers (1,000 fingers base unit trade for plantain in the Dominican Republic and Venezuela) at farm gate or the nearest road to intermediaries, who then transport the product and sell on wholesale markets. Typically, a rough quality selection is carried out to separate "full" bunches and inferior-sized bunches which are commonly paid as "two or three for one". For special quality markets, sometimes the bunches are de-handed and fruits graded and packed in plastic boxes. Prices at farm gate and conditions for payment vary widely according to seasonal supply, distance to markets, competition among intermediaries and target consumer markets. Recent studies in Honduras, Nicaragua and Peru show that on average, farmers receive about 10-15% of the consumer price for their bananas (Rajala, 2010; Castellón, 2011; Martinez Moreno, 2011). Higher shares of consumer price have been estimated for plantain producers, with about 28% in some regions in Peru or more than 50% on average in the Dominican Republic (data from SEA 2000-2009). As most smallholders produce with minimal input levels at low cost and do not invest in commercialization either, their profits are low in absolute terms, but returns to investment are similar or even higher to that of other chain actors (Castellón, 2011). Supply chains with higher investment by small-scale farmers include bananas for export and/or organic production, e.g. in the Dominican Republic, Ecuador and Peru, and other niche markets such as farmer markets or organic production for processing into baby foods in Costa Rica, or for institutional markets such as school breakfast supply in Bolivia (Escobeda Aguilar, 2010; Garming et al., 2011). Processing is a more important value chain in plantains than in banana. Typical products include chips, flour, starch and pre-cooked convenience foods. In all countries in the LAC region, both small and medium-scale processing of plantains by farmers or specialized companies can be found, even for exports. Large-scale processors usually rely on contracted production by larger growers in order to guarantee consistent raw material supply and quality according to industrial standards. Yet, industrial demand is a minor part of plantain markets, e.g. 0.5% of production in Colombia (Espinal et al., 2005) and about 5% of production in the Dominican Republic.

Despite the continued dominance of traditional markets for banana supply chains, over the past decade, throughout the region, supermarkets have gained importance. Characteristics of this market segment are usually higher prices and higher requirements in terms of fruit quality – size, uniform ripening, stainless, quantities, processing and packaging and consistency of supply. So far, two main supply strategies have been pursued by supermarkets: the use of surplus or second quality from export banana production, and/or buying on traditional wholesale markets. Increasingly, supermarkets or their specialized suppliers also seek to buy more directly from farmers. In Costa Rica, the main supermarket supplier maintains an own network of specialized intermediaries buying from farmers who process and pack the bananas according to requirements. However, in other Central American countries, e.g. Honduras, supermarket suppliers seem to be willing to buy from small-scale farmers only if fixed contracts with collective marketing farmer organizations are possible (Castellón, 2011). With ever-growing importance of supermarkets in food retailing, the opportunities for smallholders to access higher quality and higher priced value chains might increase. However, viable business models still need to be developed for effective participation of smallholders in these value chains and for supportive infrastructure to adjust production, post-harvest and marketing processes.

CONCLUSIONS AND PERSPECTIVES

Without any doubt, banana and plantain are key crops for LAC for both food security and income generation. The increase of production experienced in recent decades in response to export and regional demands is largely associated with an increase in cultivated area, suggesting that opportunities for research investments exist. Informal surveys indicate that in spite of the importance of the crop and the increase in pest and disease pressure, research investments in the region through universities and national agricultural research institutes have dramatically dropped. In some countries, underinvestment has characterized agricultural research, while in others active programs in research have held steady or been reactivated.

Sixteen banana-growing countries in LAC make up MUSALAC, the regional network for research and development of banana and plantain in Latin America and the Caribbean (http://banana-networks.org/musalac/). MUSALAC has operated as an information exchange platform and a forum to identify common interests and research priorities, which can be addressed through multi-country research grants.

However, the magnitude of the aforementioned constraints of banana production in LAC needs more efforts and investments at national, regional and international levels. Some research outputs coming from other countries or continents could be applicable or scalable to others, but this is not always guaranteed. Therefore, research needs for specific production systems or countries include: BSV in Cavendish (Ecuador and Peru); Erwinia soft rot in plantains (Dominican Republic, Nicaragua and Panama); Fusarium wilt ('Gros

Michel' in agroforestry systems in Central America; 'Prata' in Brazil, 'Isla' and 'Palillo' in Peru), and fertilization and pest and disease control in organic farms. These all require well coordinated and structured national banana research programs. The present underinvestment has constrained opportunities for increased grower income and a greater contribution from banana to national economies.

In this review, five major topics for priority research or actions were identified: 1) Pest and disease management - nematodes, BLS, Fusarium wilt and BSVs; 2) Breeding - development of new varieties resistant to biotic and abiotic stresses; 3) Seed systems - use of disease-free certified planting material, quarantine regulations for importing/exporting planting material; 4) Post-harvest and marketing issues – implement strategies to reduce post-harvest losses and create better marketing mechanisms in the region to avoid unfair competition between LAC countries; and 5) Establishment of collaborative regional knowledge platforms. Knowledge for sustainable production of banana in LAC needs to be rationalized, publicly available and disseminated on a collaborative platform, to allow concerted prevention strategies for pests and diseases, joint effort of the private sector and regional guidance for policies. MUSALAC will take advantage of new electronic tools both for easier communication and spatial display and analysis of databases covering climate and socio-economic variables. In this way MUSALAC proposes to evolve from a research to an innovation platform both to develop a more regional focus on technology development and to incorporate a wider array of partners. In this new approach, partners with fewer research resources will be able to access technology for validation from partners with greater research resources. More informal innovation networks comprising a greater diversity of stakeholders beyond research across country boundaries will be promoted to address bottlenecks and opportunities of high regional priority.

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Tables

Table 1. Cavendish exports and total banana production in the top 10 Cavendish-exporting countries. Latin American and Caribbean countries are highlighted. Source: FruiTrop, 2011.

Country	Cavendish export (tons)	% of production exported	% of world exports	Total banana production (tons)
Ecuador	4,944,968	84.3	27.6	5,869,388
Philippines	2,192,600	28.8	12.3	7,601,564
Costa Rica	1,869,218	89.8	10.5	2,082,000
Colombia	1,802,581	31.6	10.1	5,705,784
Guatemala	1,215,380	65.5	6.8	1,855,000
Honduras	562,340	65.4	3.1	860,000
Canary Islands	371,000	93.2	2.0	398,011
Panama	344,660	69.8	1.9	494,000
Cameroon	281,000	12.4	1.6	2,220,000
Côte d'Ivoire	264,344	13.8	1.5	1,921,454

Figures

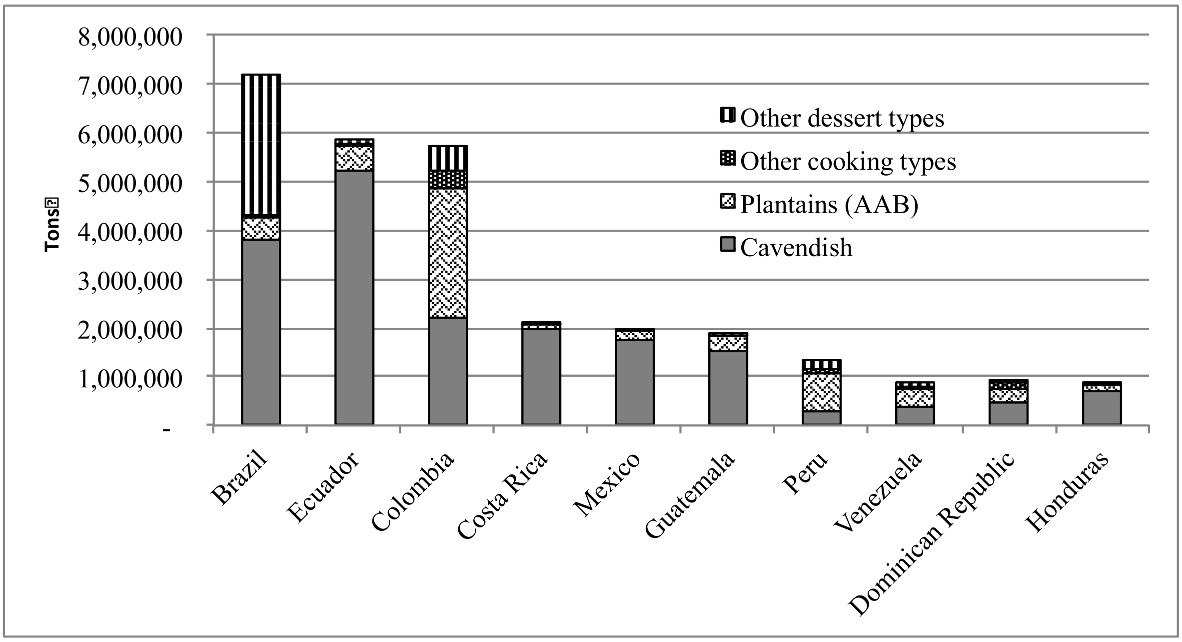

Fig. 1. Banana cultivars distribution in the top 10 producing countries from Latin American and the Caribbean. Source: FruiTrop, 2011.

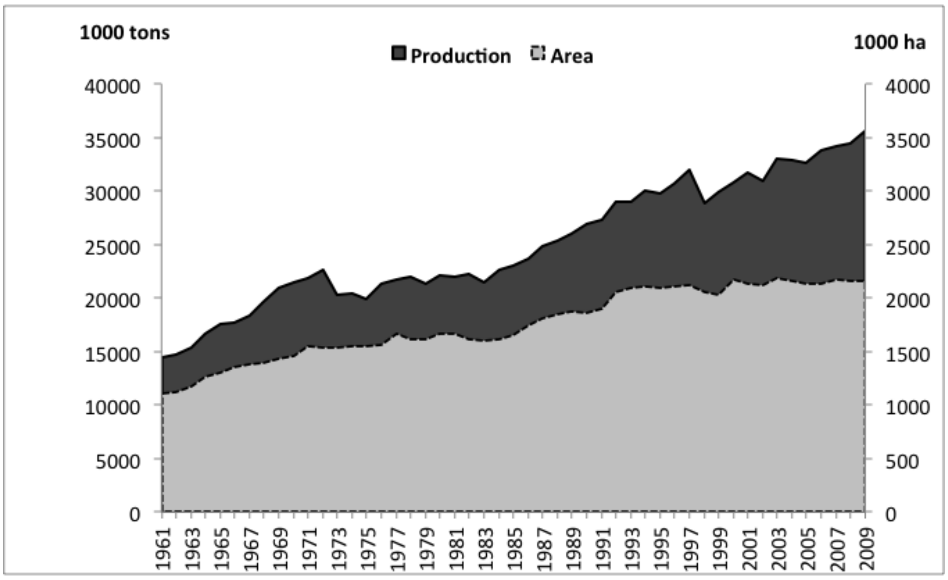

Fig. 2. Banana production (tons) and cultivated area (hectare) in Latin America and the Caribbean between 1961 and 2009. Source: FAOSTAT, 2009.

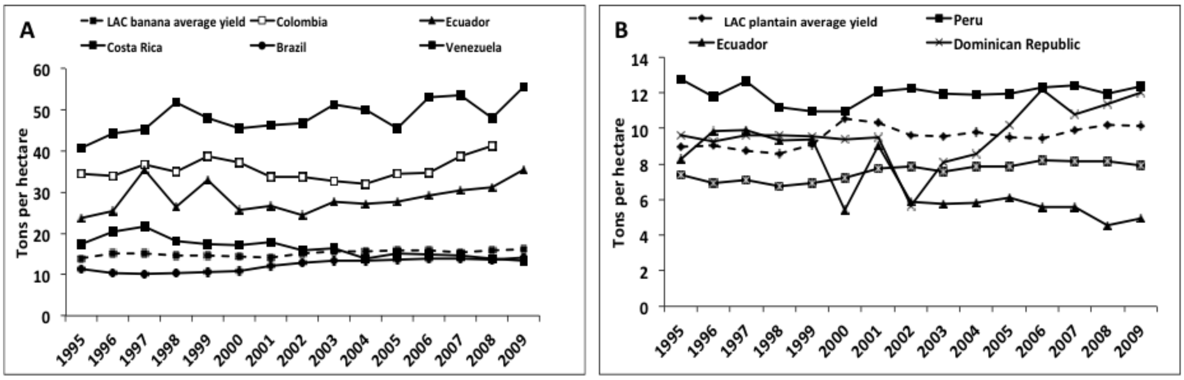

Fig. 3. Average of banana (A) and plantain (B) yields (t/ha) in Latin America and selected countries. Source: FAOSTAT, 2009.

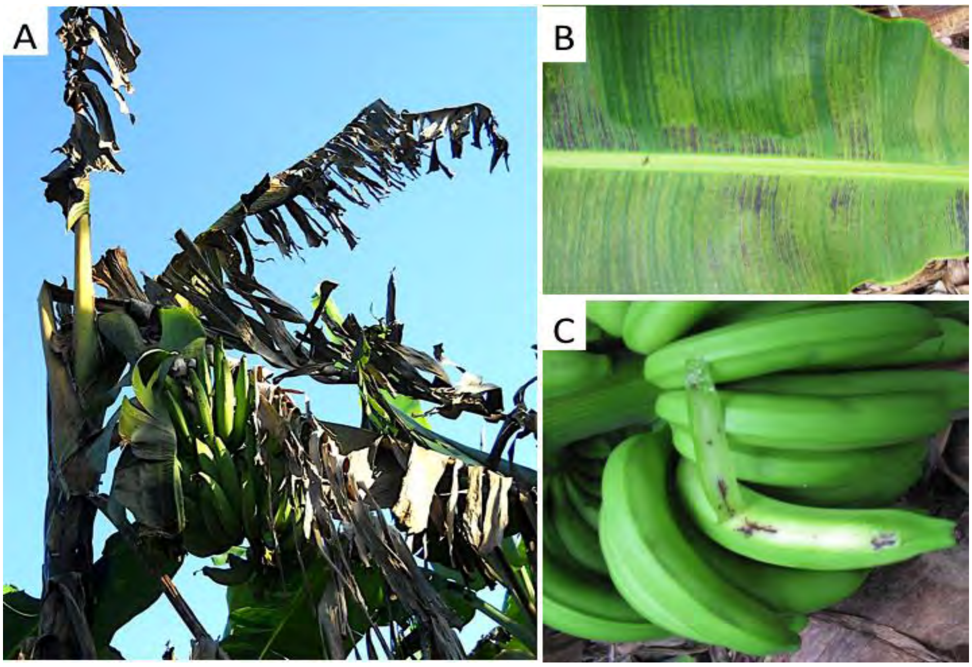

Fig. 4. A. Symptoms of black leaf streak on 'FHIA-21' in Dominican Republic (Photo: M. Dita, Bioversity International). B. Banana streak virus symptoms on a Cavendish leaf (M. Dita, Bioversity International). C. Banana streak virus symptoms on Cavendish fruits (Photo: Ciro Barreras, INIA, Perú).

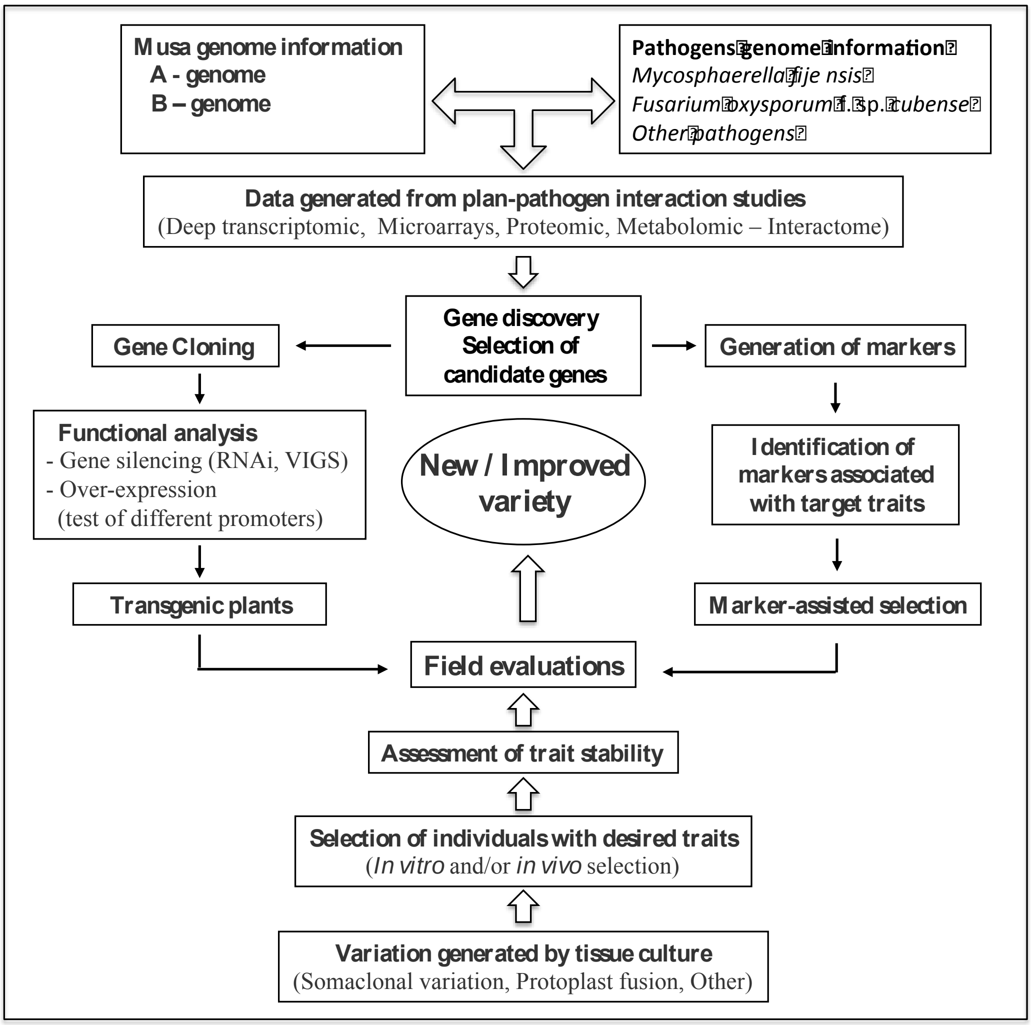

Fig. 5. Integrated scheme outlining key steps for banana breeding with focus on pathogen resistance. VIGS: Virus-induced gene silencing; RNAi: RNA interference; TF: Transcription factors. (Modified from Dita et al., 2006).