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Technical Note:

Tropical Race 4 of Panama Disease

in Banana Farming

Environmental, Social & Governance

Agribusiness

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Contents

Acronyms

CORBANA	Corporación Bananera Nacional (Costa Rica)
COVID-19	Coronavirus Disease 2019
ECA	East and Central Africa
ESMS	Environmental and Social Management System
FOC	Fusarium oxysporum f. sp. cubense
GCTCV	Giant Cavendish Tissue Culture Variants
IDB Invest	Private sector branch of the Inter-American Development Bank Group
LAC	Latin America and the Caribbean
SME	Small and medium-sized enterprises
TR4	Tropical race 4 of Fusarium oxysporum f. sp. cubense
VC	Vegetative compatibility

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Executive Summary

Various diseases and nematodes are the most significant biotic constraints for export dessert banana production. Notably, tropical race 4 (TR4) of Panama Disease (caused by *Fusarium oxysporum f. sp. cubense* – FOC, for short) affects the Cavendish subgroup, which is now responsible for 47% of all production worldwide (virtually all exported fruit and over 30% of all remaining production). The recent outbreak of TR4 in Colombia threatens future export production in Latin America and the Caribbean (LAC), where most of global export production occurs. Although there is substantial positive literature on biological, chemical or cultural measures, effective management of the disease is largely restricted to using resistant cultivars where the pathogen has established.

What Is TR4?

Tropical race 4 (TR4) is a strain of the banana pathogen *Fusarium oxysporum f. sp. cubense* (FOC). This fungus causes Panama Disease, otherwise known as fusarium wilt of banana. TR4 is unusual, as it affects cultivars that are not affected by other races of FOC, such as those in Cavendish subgroup, 'Berangan' and 'Pisang mas'. However, it also affects cultivars that are affected by other races of FOC, such as those in the subgroups 'Silk,' 'Pome,' 'Bluggoe' (Asian cooking banana), and 'Gros Michel' (formerly the dessert banana dominating export trade until mid-20th century). The wide host range of TR4 is one of many issues challenging those that manage the disease it causes (Ploetz 2015a,b).

The first evidence of a Cavendish-destroying strain of FOC (TR4), was documented in Taiwan in 1998. In less than a decade, TR4 spread throughout southeast Asia and several new countries such as: Australia, Mozambique, Vietnam, Lebanon, Myanmar, Jordan, Israel, and Oman. Some at great distances from the previous out-breaks.

Damage caused by TR4 became evident in the 1990s in newly planted Cavendish monocultures in southeast Asia. TR4 has spread throughout southern and western Asia, as well as to Mozambique, culminating in the 2019 outbreak in Colombia's Guajira Peninsula. For LAC, it is important that the pathogen does not spread further. Containment in Colombia is essential, as TR4 would devastate national, banana-based economies in the region (Ploetz 2015a).

Much of what is known about Panama Disease and its management has been known for several decades (Ploetz 1994, 2015a,b, Stover 1962). Significantly, Panama Disease cannot be controlled by fumigants or fungicides. Furthermore, FOC can survive in the soil for many years, and once it is present in a field it spreads rather quickly. The pathogen can survive for decades in the absence of a banana host. Gros Michel monocultures on which the early trades depended were devastated by race 1 of FOC, which led to a transition to Cavendish cultivars in the mid-1900s; the latter resist race 1 but are less than ideal replacements. For example, significant adjustments in harvesting, handling and shipping were required for Cavendish, as its fruit are much more fragile than those of Gros Michel.

This document serves as a technical note for the management of Panama Disease caused by TR4, including preventative measures, early detection, and management when it is present.

COVID-19 and Banana Supply

Food availability has become a priority during the COVID-19 pandemic (Reardon et al. 2020). The banana (both dessert and cooking) and plantain (solely for cooking) are a staple in around 80 countries and considered a nutritious food during times of catastrophes, a good indication of banana's importance to the global food chain. Government responses to the COVID-19 pandemic have significantly closed the global economy, causing cash flow problems for many local food producing companies. The banana producing countries in LAC are no exception. To secure banana production and business continuity, it becomes essential to provide healthy and safe working conditions to agricultural workers in line with Performance Standard 2[1] requirements. To help clients with this task, the IDB Invest has produced a Guidance for the Agriculture Sector on COVID-19[2] for field workers, contractors, suppliers, processing facilities, worker accommodations and transport of personnel to working sites.

In Latin America, COVID-19 impacted Ecuador, one of the largest banana exporters in the world, with around one third of the 20 million metric tons of bananas shipped globally. While there was continuity of banana field production, the pandemic meant a temporary logistic bottleneck in the port of Guayaquil, causing interruptions in shipping (Crawford et al. 2020). Timely implementation of safe working conditions to prevent COVID-19, introduced in the port, meant resuming shipments of banana. Cargo interruptions and implementation of safety procedures in field production and the value chain to comply with government health regulations, while also ensuring keeping operations successful, are however translating on higher transaction costs to local producers, slashing margins, and with a potential to trigger price increases to consumers.

As part of their Environmental and Social Management System (ESMS) companies involved in the banana business should consider developing policies and procedures to manage COVID-19 in a systematic fashion. The identification of risks and impacts will lead to appropriate strategies for prevention and a mitigation process that may include:

- Management system policies and procedures on how to determine and manage suspected and identified cases. Procedures communicated clearly to all those concerned.
- Prevention procedures covering basic hygiene, frequent handwashing, social distancing, cleaning, disinfection, use of personal protective equipment (contractors, supply chain, visitors, worker accommodation sites, migrant workers, and the surrounding communities).
- ESMS stakeholder engagement procedures and grievance mechanisms.
- Besides national and international health system guidelines, it is suggested to use the IDB Invest Guidance for the Agriculture Sector on COVID-19.

[1] For more information on the Performance Standards visit ifc.org/performancestandards
[2] To access the publication visit https://idbinvest.org/es/download/9868

Management of TR4

FOC can survive in soil for decades, and has multiple modes of transmission, including planting materials (e.g. infected bananas suckers and infected weeds), soil and water (Ploetz 2015b, Stover 1962). Thus, TR4 can be disseminated via vehicles and footwear that enter plantations. FOC also has a long latent period. Cryptic infection impedes interdiction, as widespread infestation can occur before symptoms develop; external symptoms of the disease typically develop only 2 to 9 months after plants are infected. All of these factors make management of Panama Disease especially challenging.

PREVENTIVE MEASURES

To ensure that plantations remain free of TR4 it is imperative that access be monitored and restricted, and that plantation boundaries be maintained with deep moats and vegetative barriers, preferably those that would discourage trespass. However, given the ease with which FOC spreads and the disease's long latent period, effective exclusion is difficult (Ploetz 2015b, Stover 1962). Importantly, there are no effective fungicides and economically viable biological control of Panama Disease in the field has not been demonstrated. Likewise, soil amendments and cultural and physical measures are, at best, partially or only temporarily effective. Although disease-suppressive soils are known, transferring this desirable trait to disease-conducive soils has not been demonstrated. In infested soil, it is usually possible to continue production only with resistant cultivars (Ploetz 2015b). In general, susceptible cultivars can only be grown in pathogen-free soil, which becomes increasingly scarce as FOC spreads. For example, Cavendish cultivars can no longer be grown on a commercially viable scale in wide areas in southeast Asia due to the spread of TR4.

EARLY IDENTIFICATION

When exclusion of TR4 has failed, early detection of the disease is crucial (Ploetz 2015a,b). Cavendish cultivars that are used for export production are resistant to race 1 of FOC, which is widely present in Latin America (where TR4 is not widely distributed); thus, Cavendish plants should not develop symptoms of Panama Disease in Latin America. The appearance of symptoms of Panama Disease on Cavendish is a first indication that prompt action is needed (see Box A for symptoms of Panama Disease).

Initially, affected plants are mixed with healthy plants, and frequent visual assessments of production fields for sick plants should be made by all who work in plantations (Dita et al. 2018, Stover 1962). This can be done via ground-based surveys or with aerial drones, which enable larger areas to be surveyed (if drones identify suspicious plants, ground verification of the symptoms should be conducted).

Field workers must be trained on how to identify external symptoms of Panama Disease. Although symptoms of Panama Disease also develop internally (e.g. discoloration or darkening of vascular elements inside the pseudostem), cutting a suspected infected plant to determine whether internal symptoms are present should not be done by field workers, since it increases the risk of pathogen spread. This should be done by technically trained personnel. Once external symptoms of Panama Disease are observed in Cavendish plantations, government-certified diagnostic labs (e.g. CORBANA in Costa Rica) should be engaged to ensure that accurate diagnoses occur without spreading the pathogen.

To confirm the presence of TR4, two general approaches can be used: 1) Vegetative Compatibility (VC) Tests (Ordoñez et al. 2015, Ploetz 2006, 2015a, Ploetz and Correll 1988), which take up to 2 weeks to complete; or 2) Molecular Tests, which can yield results sooner than VC Tests (Carvalhais et al. 2019, Dita et al. 2010, 2018, Ordoñez et al. 2019). Several different molecular methods have been reported, some of which are either not reliable or yield ambiguous results (Ploetz 2015a). Nonetheless, a few recently reported measures are highly specific and can be used to identify TR4 in environmental samples, such as soil or irrigation water (Ordoñez et al. 2019). Notably, the Dita Method (which is also known as the Clear Detection Method) is reliable if samples from symptomatic banana plants are assayed (Dita et al. 2010, 2018). Note that reports of the non-specificity of the Dita Method have occurred when it has not been used to evaluate symptomatic banana plants, e.g. environmental samples (Magdama et al. 2019). For rapid, reliable, and sensitive diagnoses of TR4 in symptomatic banana plants, the Dita Method should be used.

Recently, molecular markers specific to FOC strains of East and Central Africa (ECA) have been developed for the identification of FOC Lineage VI DNA, both in the absence and presence of banana DNA. The availability of molecular markers for diagnostic tests would support quarantine regulations in ECA and assist in the screening for banana resistance to FOC (Ndayihanzamaso et al. 2020).

DIFFICULTY IN MANAGEMENT

There are limited options for managing Panama Disease (Ploetz 2015a,b, Stover 1962). Its perennial nature has complicated the development of long-term measures, and poor resistance exists in important types of banana. In general, susceptible banana cultivars

can be grown only if pathogen-free propagation materials are used in pathogen-free soil. Tissue-culture-derived plantlets are the most reliable source of clean material, even though they are more susceptible to Panama Disease than traditional seed pieces of banana in infested soil (Smith et al. 1998). Tissue-cultured plantlets should be used to propagate this crop whenever possible, since they are free of fungi, bacteria and nematodes that affect banana. Ideally, source materials for plantlets (explants) should be indexed for viruses (e.g. Banana bunchy top virus) to ensure that plantlets are ultimately free of all banana pathogens.

Once fields are infested, or plants are infected with FOC, protective or therapeutic measures do not exist (Dita et al. 2018, Ploetz 2015b, Stover 1962). No fungicide effectively protects banana plants from infection or cures the disease after plants are infected. Unfortunately, FOC resides in a protected location, host xylem, and effective products that control systemic infections are not available. Soil fumigants (e.g. MeBr-chloropicrin) and other non-chemical measures (e.g. flooding) can eliminate FOC in infested soil but are expensive and only temporarily effective as treated soil is quickly re-colonized by the pathogen.

In general, only resistant cultivars can be grown in FOC-infested soil (Ploetz 2015b). There are no good TR4-resistant replacements for Cavendish cultivars up to date. Unfortunately, bananas that resist TR4 produce small bunches of fruit that do not meet the sensory or aesthetic standards required by the export trade, and TR4-resistant replacements for Grand Nain or other Cavendish cultivars that are used by the export trade do not exist. The best options for producing export type dessert bananas in TR4-infested soil are somaclonal selections of Giant Cavendish (GCTCV lines), Dwarf Cavendish (Guijiao No 9), and other Cavendish variants that tolerate TR4 (Hwang and Ko 2004, Wei et al. 2018); however, they are not fully resistant and are often not widely available. For example, a superior selection of GCTCV 218 that does well in TR4-infested soil is apparently produced only in Mindanao (Philippines). Notably, the somaclonal selections have longer production cycles, lower bunch weight and produce hands that are difficult to pack in standard 15 or 18 kilogram boxes.

Until better replacements for commercial Cavendish cultivars are widely available, there will be a critical need to impede the spread of TR4 in the Western Hemisphere and restrict outbreaks once they occur in a region or plantation. Key measures in its management are regional coordination of efforts and an awareness of the potential impact of TR4 once it spreads to a given area (Montiflor et al. 2019). At the farm level, as soon as TR4 is confirmed access to affected plants should be restricted, ideally by fencing and surrounding the affected mat(s) and adjacent non-symptomatic mats with a moat (Dita et al. 2018). Likewise, access to affected plantations should be restricted by fences and footbaths filled with disinfectant.

PHYTOSANITATION

Rigorous phytosanitary measures should be observed whenever the pathogen has been confirmed. Well (borehole) water should be used for irrigation whenever possible, since surface water, such as that from rivers or lakes, is easily contaminated by the pathogen (Stover 1962).

When contamination of surface water is a concern, decontamination can be achieved in the following ways:

1. Physical processes, such as slow sand filters, sedimentation and distillation
2. Biological processes, such as biologically active carbon
3. Chemical processes, such as flocculation and chlorination
4. Reverse osmosis

Clean footwear should be available for each worker on a given farm, and foot traffic in and out of plantations should be strictly monitored. Strategies for ensuring that clean footwear is used can be observed at the following YouTube video: On-farming Biosecurity – Managing Footwear https://www.youtube.com/watch?v=FlxbM4Zb6es.

Vehicles, footwear, and all other machinery and tools that enter and leave plantains should be thoroughly cleaned and disinfected. Disinfectants vary widely in effectiveness (Meldrum et al. 2013). Quaternary ammonia compounds are often effective, but even the best products are not immediately effective.

Where do we go from here?

Difficult times are ahead for banana farmers as TR4 profoundly changes Cavendish-based banana production. If not implementing any preventive measures, TR4 presents significant challenges for banana producing countries in LAC to maintain essential operations in their own enterprises to keep the banana chain supply worldwide. The calls for action involve government policy implementation to prevent disease dissemination into countries, private sector involvement, long-term investments to help implement phytosanitary practices, and science-based approaches to ensure business continuity at the plantation level. Actions on phytosanitary measures should involve smallholders and SMEs in the supply chain, and the society at large. Management scenarios suggested are:

Private Sector

1. Ideally, all plantations should be secure (discourage unwanted access) and have a single-entry point. Rigorous disinfestation protocols should be established for vehicles, footwear, tools, etc. that enter and leave plantations.

2. Where TR4 is established, continued production becomes exceedingly difficult. Excellent phytosanitation is needed (e.g. restricted plantation access, clean irrigation water, pathogen-free planting material, isolation of affected mats, sanitation and clean inputs, especially irrigation).

3. Frequent surveillance of plantations for suspicious or symptomatic plants (fusarium wilt should not develop on Cavendish cultivars).

4. Clear protocols must be in place for samples that are taken for diagnosis, as well as a chain of command for such samples (to whom and how to ship or mail).

5. Pathogen-free planting material are an absolute necessity. When TR4 is not found in an area, exclusion is essential. Safe movement of banana germplasm should be a practice, using tissue-culture-derived plantlets of virus-indexed material. To ensure disease-free status of planting material, access to plantations should be monitored and restricted.

6. Identify research or work priorities for the next 5 and 10 years.

National Phytosanitary Agencies

1. Ideally, international ports of entry should have scent dogs to exclude foreign plant material. Trained personnel, X-ray machines are additional useful assets.

2. In the best scenario, each country should have a dedicated molecular detection lab in which suspect plant samples could be processed to detect TR4.

3. Frequent surveillance of production areas for suspect plants.

4. Clear chain of command for samples and sampling protocols should be in place.

5. Training to enable plantation personnel to identify symptoms of fusarium wilt and enable proper sampling for diagnosis. Training may also be necessary for personnel in diagnostic lab(s).

6. Where it is not possible to continue multicycle production (where widespread infestation occurs), TR4-tolerant somaclones should be accessed and tested in close collaboration with the private sector for performance and market acceptability.

BOX A: **SYMPTOMS OF PANAMA DISEASE**

Leaf yellowing
Likely to appear first at the lower and older leaves, initiating from the leaf's edges and growing further towards the midrib. The plant can also lack a healthy green color.

Wilting of leaves
Affected leaves wilt and collapse, and eventually form a skirt of dead leaves around affected plants. Some leaves may become yellow or remain green and upright.

Stem splitting
Usually initiates on the base of the plant and extends a couple of layers into the stem. In the later stages of the disease, the split can extend much further up and into the stem.

Early stage of TR4 infection – yellowing leaf margins
© Department of Agriculture and Fisheries

Advanced stage of infection - skirt of dead leaves around stem
© Department of Agriculture and Fisheries

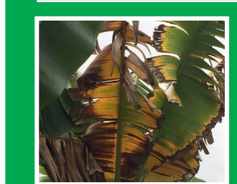
Early stage of TR4 infection - entire leaf yellowing with leaf margins browning
© Department of Agriculture and Fisheries

Sometimes splitting of the stem may occur
© Department of Agriculture and Fisheries

Intermediate stage of infection - more browning and leaves starting to die
© Department of Agriculture and Fisheries

Internal symptom of Panama TR4: reddish brown discolouration of the pseudostem. Note: If you think the plant is infected with Panama TR4, do not cut it to inspect for internal discolouration
© Department of Agriculture and Fisheries

Advanced stage of infection - leaves wilt and collapse around pseudostem
© Department of Agriculture and Fisheries



Advanced stage of infection - brown leaf margins and advanced yellowing
© Department of Agriculture and Fisheries

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Glossary

Cryptic Infection
Or asymptomatic fungal infections, are compatible host-pathogen interactions which do not always result in overt negative effects. They are increasingly recognized as a common feature of many symbiotic associations between fungi and their hosts. The epidemics only become apparent once symptoms develop, by which time the outbreak will have grown, and new, sometimes distant outbreaks may have been established through long-distance dispersal.

Cultivar
Or cultivated variety is an assemblage of plants selected for desirable characteristics that are maintained during propagation.

Germplasm
[1] A set of genes that is transmitted by reproduction to offspring through gametes or reproductive cells.

[2] Living genetic resources such as seeds or tissues that are maintained for the purpose of animal and plant breeding, preservation, and other research uses.

Interdiction
The action of intercepting and preventing the movement of a prohibited commodity.

Monoculture
Agricultural practice consisting of growing a single crop in an entire farm or area (FAO).

Pseudostem
A false stem made of the rolled bases of leaves, which may be 2 or 3 m tall as in banana.

Somaclonal
Variation seen in plants that have been produced by plant tissue culture. Chromosomal rearrangements are an important source of this variation.

Xylem
One of the two types of transport tissue in vascular plants, phloem being the other. The basic function of xylem is to transport water from roots to stems and leaves, but it also transports nutrients.

FOR FURTHER INFORMATION PLEASE VISIT THE FOLLOWING:

General Background
https://www.youtube.com/watch?v=onPpPeTGESE

Regional Information (OIRSA)
http://www.musalit.org/seeMore.php?id=14819

Technical Manual – FAO
https://urldefense.proofpoint.com/v2/url?u=http-3A__www.fao.org_fileadmin_templates_banana_documents_Docs-5FResources-5F2015_TR4_13Manual Fusarium.pdf&d=DwMFaQ&c=sJ6xIWYx-zLMB3EPkvcnVg&r=xjGlAo9lVrlXl-rHg7j9Bw&m=1QdAbAV9qCLT4I8meJ6E-SmGWLoMlJP1SW69wOn4R-Q&s=IrjBk0fBPO9_DfsUdCr6ogiQNCcR6rbzNLFx0QfBo4o&e= rHg7j9Bw&m=1QdAbAV9qCLT4I8meJ6E-SmGWLoMlJP1SW69wOn4R-Q&s=IrjBk0fBPO9_DfsUdCr6ogiQNCcR6rbzNLFx0QfBo4o&e=

Australian – Philippine Cooperation
https://www.youtube.com/watch?v=GAZGa1v7u8A

National Contingency Plans
http://www.fao.org/3/a0450e/a0450e.pdf

Banana Facts and Figures – FAO
http://www.fao.org/economic/est/est-commodities/bananas/bananafacts/en/#.XqNe28hKhPY

APSnet
https://www.apsnet.org/edcenter/apsnetfeatures/Documents/2005/PanamaDisease1.pdf

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