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TR4-Resistant Bananas: Securing the future of the banana industry

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ABSTRACT

The imminent threat *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (FOC-TR4), along with the persistence of Black Sigatoka, requires a comprehensive response to safeguard global banana production. In this context, the Musa Breeding Company (MBC) consortium has formed a strategic alliance that has yielded significant results after 9 years of research. By utilizing advanced techniques such as pollination, embryo rescue, and a robust bioassay program under controlled (Stellenbosch) and field conditions (Australia), 4 immune hybrids and 28 highly resistant hybrids to FOC-TR4 have been identified from a total of 117 evaluated hybrids. These new hybrids not only exhibit high resistance but also preserve the agronomic and performance qualities characteristic of Cavendish bananas. They are projected to be commercially available between 2027 and 2028, representing a crucial advance for resilience, economic sustainability, and food security in the global banana industry.

Keywords: FOC-TR4, Mejoramiento genético, Híbridos de banano, Cultivo convencional

RESUMEN

La amenaza inminente del *Fusarium oxysporum* f. sp. *cubense* Raza 4 Tropical 4 (FOC-R4T) y la persistencia de la Sigatoka Negra exigen una respuesta integral para salvaguardar la producción de bananos a nivel mundial. En este sentido, el consorcio Musa Breeding Company (MBC) ha formado una alianza estratégica que ha mostrado resultados significativos después de 9 años de investigación. Mediante el uso de técnicas avanzadas de polinización, rescate de embriones y un programa robusto de bioensayos en condiciones controladas (Stellenbosch) y de campo (Australia), se ha logrado identificar 4 híbridos inmunes y 28 altamente resistentes al FOC-R4T de un total de 117 híbridos evaluados. Estos nuevos híbridos no solo presentan una alta resistencia, sino que también mantienen las cualidades agronómicas y de rendimiento propias del banano Cavendish. Se proyecta que estarán disponibles comercialmente entre 2027 y 2028, lo que representa un avance crucial para la resiliencia, sostenibilidad económica y seguridad alimentaria de la industria bananera global.

Keywords: FOC-TR4, Genetic Improvement, Banana hybrids, Conventional Breeding

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INTRODUCTION

Bananas are a key food product worldwide, being Cavendish varieties the most important in the export market, representing approximately 50% of the 95% of global trade (Garcia-Bastidas *et al*., 2022). The Cavendish varieties emerged after of the decline of Gros Michel, which was affected by the Fusarium race 1 fungus. Although Cavendish is resistant to this strain, a new variant called Tropical Race 4 (TR4) has begun to impact its production since its emergence between 1960 and 1970. FOC-TR4 has been reported in 21 countries (Nguyen *et al*., 2025), including Colombia, Peru, and Venezuela, with rigorous analyses currently underway in Ecuador to identify its presence. Given the ineradicable presence of this fungus, the situation is critical, gradually affecting banana plantations. To combat this threat, the Musa Breeding Company (MBC) has been established as a consortium focused on genetic improvement by means conventional breeding. This effort involves leading companies in banana production and export (Dole Food Company, NQBR, AgroAmerica), and FHIA. Its goal is to develop Cavendish-type banana hybrids that are resistant to FOC-TR4 and Black Sigatoka, thereby ensuring sustainable banana production worldwide.

MATERIAL AND METHODS

Parental material and breeding strategy

Cavendish tetraploid mother's and improved diploids created by FHIA were used for the consortium's Banana Breeding Program. The parental material used underwent a pre-breeding process to obtain 4n and 2n materials. The main objective was to create Cavendish hybrids that are resistant to FOC-TR4 and Black Sigatoka, with good taste and yield.

Hand pollination

Our banana and plantain breeding program is entirely conventional. Between 2016 and 2025, approximately 15 million banana fingers were hand pollinated. Each morning from 6:00 to 10:00 a.m. fresh banana male structures were collected to pollinate individual female flowers. Each pollinator had a set number of pollinations to perform daily based on breeding strategies.

Embryo rescue

After pollination, banana bunches were harvested carefully and ripened separately per crossing strategy. Every banana bunch was peeled, and water was added to a container to soften the pulp. The next day, the pulp was separated from the seeds using a centrifuge machine. Then, banana seeds were dried and stored for the embryo rescue process. All seeds were disinfected and opened under aseptic conditions. Each

embryo was placed in culture medium for germination, and three weeks later, changed to new medium for embryo development and rooting. The rescue procedure is kept at a controlled temperature (23 °C) in the growth room and lasts for about 8 weeks. Approximately 220,000 seeds have been processed, and we have obtained 105,000 embryos and 53,000 hybrids, of which 163 have been selected for evaluation.

Evaluation and selection of new hybrids

After each embryo had rooted in the growth room, plants were transferred to the greenhouse and placed in pots with soil mixed with organic matter and nutrients following a soil lab recommendation. After 8-10 weeks, plants were transferred to the shade house for hardening before field planting for evaluation. After 8-10 weeks of hardening, the plants are taken to the field for phenotypic characterization. For the selection of candidate hybrids, the plants were evaluated at shooting and harvest. Finally, the taste, one of the most important parameters at this stage, was assessed. Hybrids that meet the commercial parameters for plant height, bunch weight, Black Sigatoka tolerance, and taste were selected for further evaluation. For each hybrid, Specific and Detailed evaluation was conducted using a Randomized Complete Block Design (RBD).

TR4 pot trial evaluations

All selected hybrids underwent an evaluation process against FOC-TR4. Since the pathogen is not present in Honduras, the evaluations were conducted at Stellenbosch University in South Africa, following the methodology of Dr. Altus Viljoen (Ndayihanzamaso *et al*., 2022).

TR4 field trial evaluations

All selected hybrids were propagated for further FOC-TR4 screening in the Northern Territory in Australia, where they used FOC-TR4-contaminated soils for disease evaluation. In this test, plants were processed through the Australian Government's phytosanitary quarantine facilities. After release, plants went to a greenhouse for hardening before being planted in the field. In the field, plants were handled according to the methodology used by Mintoff *et al*., 2021.

Pre-commercial and Plant Breeder Rights process

Banana hybrids that meet the characteristics of resistance to FOC-TR4, resistance to Black Sigatoka, good bunch weight, and excellent taste were moved on to the pre-commercial stage, where conditions of yield, boxes/bunch, packaging, agronomic performance, green and yellow life, and acceptance by the final consumer were evaluated. At the same time, data was collected to apply for plant breeders' rights

(PBR), in accordance with the requirements of the International Union for the Protection of New Varieties of Plants (UPOV).

RESULTS AND DISCUSSION

Pot Trial results

Conducting pot trials has allowed us to assess the success of our breeding program in creating new banana hybrids resistant to FOC-TR4. We have evaluated 117 hybrids (all types), of which four are immune, 28 are highly resistant, 22 are partially resistant, 18 are susceptible, 17 are highly susceptible, and 28 have pending resistance scores (Figure 1).

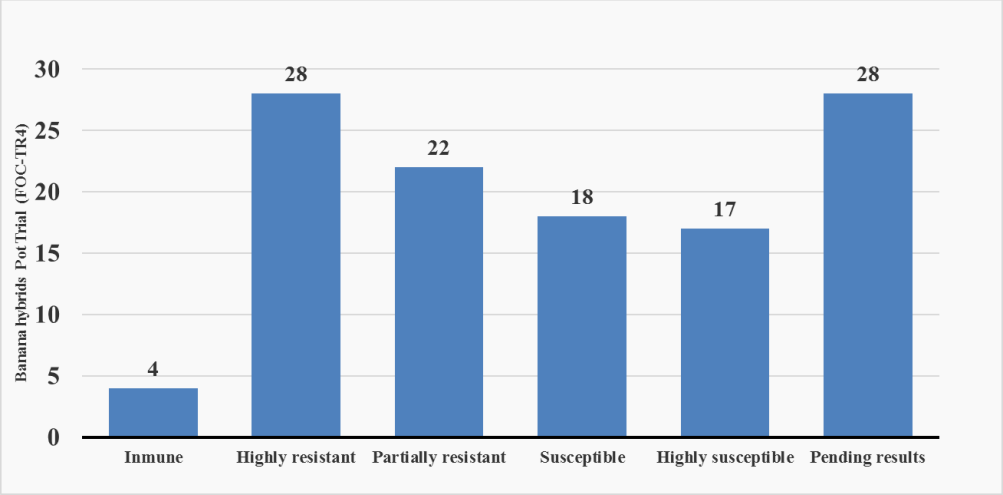


Figure 1. Response of banana hybrids to artificial inoculations of FOC-TR4 in pot trials.

Pot and Field Trials

The purpose of comparing the pot trial and field trial results is to see if the initial pot trial data can help identify FOC-TR4-resistant hybrids for further evaluations in the field. The comparison in table 1 shows that hybrids with high and moderate resistance in the pot trial also behaved similarly in the field (A sample of the total evaluated hybrids). However, some hybrids that seemed susceptible in the pot trial turned out to be more tolerant to the disease when tested in the field.

Table 1. Results of banana hybrids against FOC-TR4 in pot and field trials.

Hybrid ID	Rhizome Discoloration Index (RDI) Stellenbosch University South Africa (Pot Trials)	Percentage of Plants with Internal Symptoms (R1) (Death or Harvest) (Northern Territory Australia) (Field Trial)
Positive control	4.8	51.1
Negative control	1	?
H1	1,5	0
H2	1,6	0
H3	3,6	0
H4	2	26.6
H5	3,2	42.3
H6	3,5	0
H7	2,5	57.3
H8	2,7	0
H9	2,6	0
H10	1,1	0
H11	3,8	33.9
H12	2,8	23.4

Cavendish promising results

The results on Cavendish-type hybrids resistant to FOC-R4T are impressive; some are already in the pre-commercial stage, and data is being collected for patent and PBR filing. Their yield, bunch conformation, finger shape, plant height, and flavor are like those of commercially available Cavendish varieties. Another important characteristic is the genetic resistance to Black Sigatoka; in this regard, some hybrids exhibit high tolerance to this disease, in addition to their resistance to FOC-TR4. The photos below show a comparison of the CAV-H1 hybrid TR4- resistant, which has similar characteristics to the commercial Cavendish (CAV) variety (Figure 2A). The following photo shows four Cavendish-type hybrids under evaluation process (CAV-H2 to CAV-H5) (Figure 2B).



Figure 2. Cavendish-type banana hybrids under evaluation for commercial release.

Gros Michel promising results

Among the breeding strategies used, tetraploid Gros Michel-type parents (GM) were included to obtain improved hybrids with genetic resistance to FOC-TR4 and Black Sigatoka. The photos below show (Figure 3) promising hybrids currently being field evaluated. The flavor, bunch size, and finger size of new GM-derived hybrids have commercial potential.



Figure 3. Gros Michel-type banana hybrids under evaluation for commercial release.

Exotic bananas promising results

As part of genetic recombination in the genetic improvement process, we have selected some banana hybrids that are not Cavendish-like but have excellent characteristics for niche markets, such as Manzano-type (MT) (Figure 4A). Orange pulp high beta-carotene content (BET) (Figure 4B) TR4 resistant.

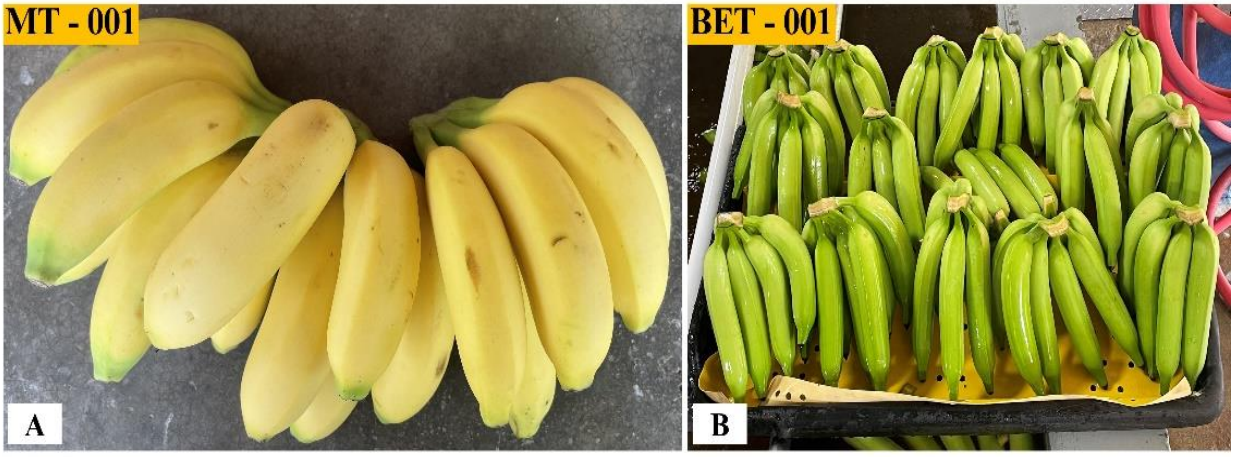


Figure 4. Exotic bananas under evaluation for commercial release.

CONCLUSIONES

After nine years of dedicated work, the MBC's banana breeding program can showcase promising results as alternatives to Cavendish in response to the FOC-TR4 threat.

The first hybrids with genetic resistance to FOC-TR4 and Black Sigatoka are expected to be available between 2027 and 2028.

In addition to Cavendish-type banana hybrids, MBC will offer Gros Michel and exotic bananas resistant to FOC-TR4 and Black Sigatoka.

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