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Innovative banana improvement at rahan meristem: addressing TR4, Black Sigatoka and climate change

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ABSTRACT

The global banana industry faces major threats from *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (TR4), Black Sigatoka disease (BLSD), and increasing abiotic stresses driven by climate change. Most commercial triploid banana cultivars are sterile and parthenocarpic, limiting conventional breeding approaches. Rahan Meristem has developed an integrated biotechnological strategy combining mutation breeding and genome editing to introduce genetic variability and improve elite Cavendish clones. Mutant lines resistant to TR4 were generated and evaluated in multi-location field trials in the Philippines, Colombia, and Israel. Selected resistant lines showed over 90% survival in heavily infected fields while maintaining agronomic performance comparable to commercial controls. In parallel, CRISPR-based genome editing was applied to modify banana genes associated with susceptibility to BLSD and tolerance to abiotic stresses such as heat, drought, and salinity. Edited plants demonstrated enhanced tolerance traits and were officially classified as non-GMO by Philippine regulatory authorities, enabling field validation. These results demonstrate that modern biotechnological approaches can rapidly deliver disease-resistant and climate-resilient banana varieties suitable for tropical production systems.

Keywords: Banana, Fusarium TR4, Black Sigatoka, Genome editing, Climate change

RESUMEN

La industria bananera mundial se enfrenta a amenazas importantes derivadas de *Fusarium oxysporum* f. sp. *cubense* Raza 4 Tropical (R4T), la enfermedad de la Sigatoka Negra (SN) y el aumento de los estreses abióticos provocados por el cambio climático. La mayoría de los cultivares comerciales de banano triploide son estériles y partenocárpicos, lo que limita los enfoques de mejoramiento convencional. Rahan Meristem ha desarrollado una estrategia biotecnológica integrada que combina el mejoramiento por mutación y la edición del genoma para introducir variabilidad genética y mejorar clones élite de Cavendish. Se generaron líneas mutantes resistentes a R4T y se evaluaron en ensayos de campo en múltiples localidades de Filipinas, Colombia e Israel. Las líneas resistentes seleccionadas mostraron una supervivencia superior al 90 % en campos altamente infectados, manteniendo un rendimiento agronómico comparable al de los controles comerciales. Paralelamente, se aplicó la edición del genoma basada en CRISPR para modificar genes del banano asociados con la susceptibilidad a la SN y la tolerancia a estreses abióticos como el calor, la sequía y la salinidad. Las plantas editadas demostraron rasgos de tolerancia mejorados y fueron clasificadas oficialmente como no transgénicas por las autoridades reguladoras Filipinas, lo que permitió su validación en campo. Estos resultados demuestran que los enfoques biotecnológicos modernos pueden generar

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rápidamente variedades de banano resistentes a enfermedades y adaptadas al clima, aptas para los sistemas de producción en los trópicos.

Palabras clave: Banano, Fusarium R4T, Sigatoka negra, Edición genómica, Cambio climático

INTRODUCTION

Banana (*Musa* spp.) production is increasingly threatened by Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (TR4), Black Sigatoka disease (BLSD), and climate-change-driven abiotic stresses. Commercial banana production relies on genetically uniform, sterile triploid Cavendish cultivars, severely limiting conventional breeding options. TR4 is a soil-borne pathogen that causes long-term field contamination and plant death, with no effective chemical control, making host resistance essential. BLSD significantly reduces photosynthetic leaf area and yield, requiring intensive fungicide use with increasing resistance risks. In parallel, rising temperatures, increased drought frequency, and soil salinization are reducing yield stability in major banana-producing regions of Latin America (WMO-No. 1330).

Modern biotechnological approaches, including mutation breeding and genome editing, provide effective tools to overcome genetic bottlenecks in banana. This study presents Rahan Meristem's integrated strategy to develop Cavendish-based banana lines with durable TR4 resistance, high tolerance to BLSD, and enhanced resilience to climate-related stresses.

MATERIALS AND METHODS

Mutation breeding for TR4 resistance was conducted according to US patent US12082544B2 using elite Cavendish (GAL) and Valery clones. Mutant plants were screened under controlled TR4 pressure and subsequently evaluated in multi-location field trials in the Philippines and Colombia.

Genome editing was performed using CRISPR/Cas systems on embryogenic cell suspensions derived from the GAL cultivar, following published banana genome-editing protocols (Guy et al; 2024). Independent single-gene edits were generated targeting genes associated with BLSD susceptibility and abiotic stress tolerance. Edited plants were validated by PCR and sequencing prior to phenotypic evaluation and field trials, conducted under regulatory approval in the Philippines.

RESULTS AND DISCUSSION

TR4 Resistance

Initial screening at Wageningen University identified asymptomatic mutant plants grown in TR4-infested substrate (Figure 1). Selected plants were propagated via tissue culture and evaluated in three successive field trials under high TR4 pressure in the Philippines (2018–2023), followed by validation in Colombia. Across trials, resistant clones consistently showed minimal disease incidence and maintained yield and developmental parameters comparable to the commercial GAL cultivar (Figure 2). Progressive selection increased resistance stability, with the best clones exhibiting less than 1% infection after the first harvest. Colombian trials confirmed resistance robustness across environments, with >90% plant survival under natural TR4 infection.

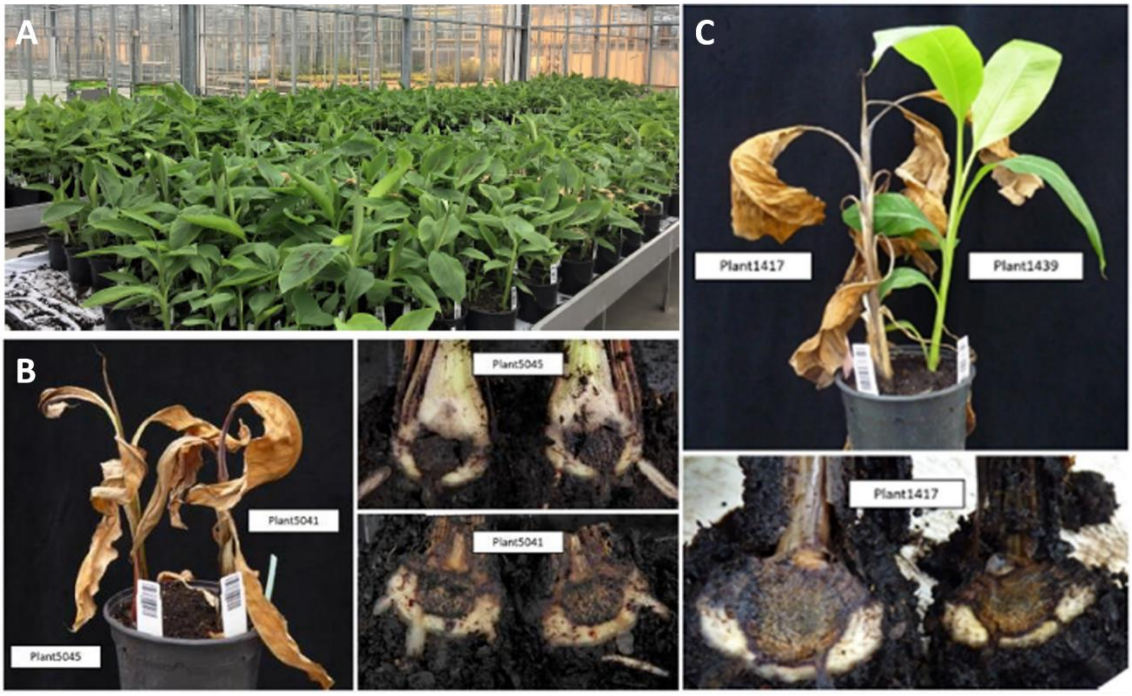


Figure 1. Co-cultivation assay for the identification of asymptomatic banana plants under Fusarium (TR4) pressure. (A) Banana plants grown under greenhouse conditions at Wageningen University, with two plants per pot to ensure uniform exposure to TR4-infested substrate during the initial selection phase.(B) Representative symptoms observed in susceptible plants following TR4 infection. (C) Representative examples of pots containing two banana plants grown in TR4-infested substrate, where one plant remains asymptomatic while the companion plant displays typical TR4 symptoms.

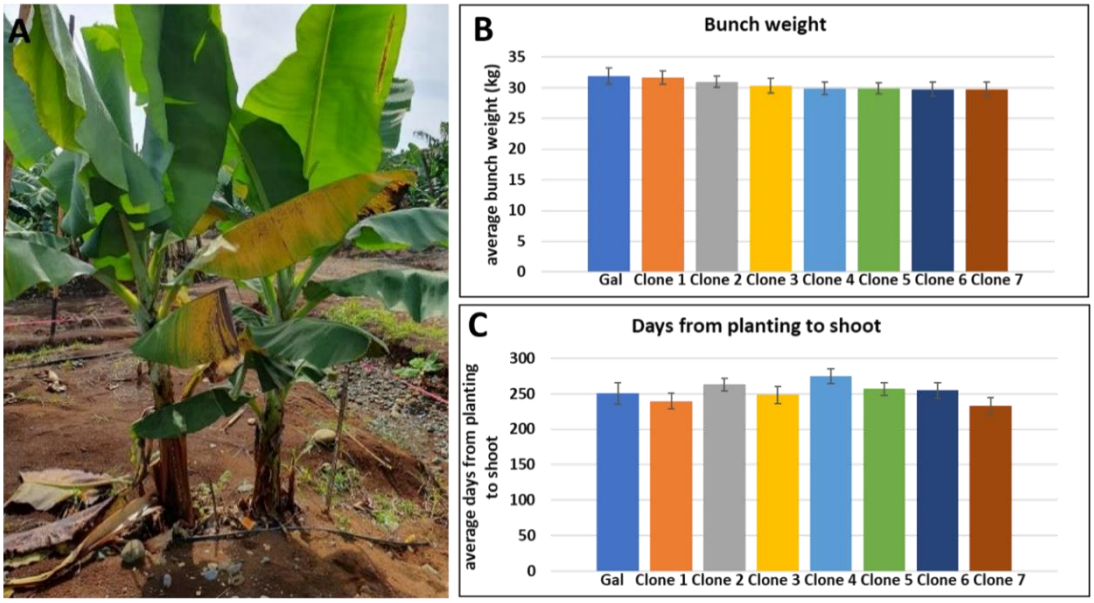


Figure 2. Performance of TR4-resistant banana clones under severe field infection pressure in the Philippine field trial. (A) Showing paired plantings, where the commercial control plant (left in the image) exhibits clear symptoms of *Fusarium* (TR4), including leaf yellowing and wilting, while an adjacent resistant clone planted at a distance of approximately 20–30 cm (right in the image) remains asymptomatic. (B) Bunch weight of seven selected mutant clones relative to the original GAL cultivar, showing no significant differences among genotypes. (C) Time from planting to shooting (days) for the same clones, demonstrating developmental timing comparable to GAL.

Genome Editing for BLSD High Tolerance

Eighteen candidate genes associated with BLSD susceptibility were independently edited using CRISPR/Cas. Edited plants were regenerated from all targets, and molecular analysis confirmed targeted mutations in approximately 70% of regenerated plants, each carrying a mutation in a single gene. The successful production of genome edited banana plants from embryogenic cell suspensions highlights the establishment of a robust and reproducible genome-editing pipeline (Figure 3 up), enabling the generation of large, genetically defined plant populations for future phenotypic screening and field evaluation. The first batch of genome-edited plants was planted in the Philippines in late 2025 under high BLSD pressure, following regulatory approval. Field evaluation is ongoing (Figure 3 down).



Figure 3. Genome-editing pipeline and field evaluation of banana plants for Black Sigatoka disease tolerance. The upper panel illustrates the genome-editing workflow in banana, starting from embryogenic cell suspensions, CRISPR/Cas-mediated targeted genome modification, and subsequent regeneration through somatic embryogenesis to produce rooted plantlets. The lower panel shows the field trial established in the Philippines, where genome-edited banana plants were planted under natural Black Sigatoka disease pressure for phenotypic evaluation and validation.

Climate Change Resilience

Banana production in Latin America is increasingly exposed to climatic stressors, including rising temperatures (Figure 4A), more frequent heat extremes, and shifts in water availability. Genome editing was also applied to genes associated with heat, drought, and salinity tolerance using the same cell-suspension-based pipeline. Edited plants are currently being evaluated under controlled stress conditions in collaboration with the Hebrew University of Jerusalem (Figure 4). Preliminary screening aims to identify lines with improved adaptation to elevated temperature, reduced water availability, and saline soils.



Figure 4. Climate trends and evaluation of genome-edited banana plants for abiotic stress resilience. (A) Increase in annual average temperature over the last five decades in selected Latin American banana-producing countries (Ecuador, Colombia, and Costa Rica), based on regional climate assessments reported by the World Meteorological Organization and the IPCC Sixth Assessment Report. (B) Field evaluation of genome-edited banana plants under elevated temperature conditions at the Hebrew University experimental plantation, used to assess heat tolerance. (C) Controlled lysimeter-based experiments at the Hebrew University Faculty of Agriculture for the evaluation of genome-edited banana plants with improved water-use efficiency under reduced water availability.

CONCLUSIONS

This study demonstrates Rahan Meristem's integrated and forward-looking approach to addressing the most critical challenges currently facing global banana production: Fusarium wilt caused by *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (TR4), Black Sigatoka disease, and the increasing impact of climate change. By combining mutation breeding, genome editing, and extensive multi-location field validation, Rahan Meristem have the ability to develop Cavendish-based banana lines that maintain commercial agronomic performance while exhibiting enhanced resistance or tolerance to major biotic and abiotic stresses. Through a rigorous, multi-year selection process conducted under extreme disease pressure in the Philippines and Colombia, TR4-resistant Cavendish clones were identified with stable resistance and yield performance comparable to the commercial GAL cultivar. In parallel, genome-editing technologies enabled the precise modification of banana genes, resulting in independent edited lines that are now being selected for high tolerance to Black Sigatoka disease. In addition, genome editing was applied to develop banana lines with improved resilience to climate-related stresses. Ongoing evaluations under controlled stress conditions identifying promising candidates with enhanced adaptive capacity, addressing the growing vulnerability of banana production systems under future climate scenarios.

Collectively, these results highlight Rahan Meristem's commitment to deploying the most advanced biotechnological tools to support banana growers worldwide. The long-term objective is the development of next-generation Cavendish-based varieties that combine durable TR4 resistance, high tolerance to Black Sigatoka disease, and improved resilience to climate change. Such varieties will be essential for ensuring the sustainability, productivity, and economic viability of banana cultivation in the coming decades.

REFERENCES

Assa G, Kalter N, Rosenberg M, Beck A, Markovich O, Gontmakher T, Hendel A, Yakhini Z. 2024. Quantifying allele-specific CRISPR editing activity with CRISPECTOR2.0, Nucleic Acids Research, Volume 52, Issue 16, 9 September 2024, Page e78.

IPCC. 2021. Climate Change 2021: The physical science basis. Contribution of working group i to the sixth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

United States Patent. 2024. Method for producing banana plants with tolerance to *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4. US12082544B2.

World Meteorological Organization (WMO). 2023. State of the Climate in Latin America and the Caribbean. WMO-No. 1330. Geneva, Switzerland.