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Selection-based breeding for the development of low-stature, fast, heavy-bunch banana cultivars

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ABSTRACT

The development of improved cultivars is a key driver of progress in agriculture. Classical breeding through hybridization is rare in banana, as most commercial cultivars are sterile. Instead, selection-based breeding—identifying and propagating superior individuals within existing cultivars—offers a practical and efficient alternative for crop improvement. Our work focuses on developing improved selections of the industry-standard cultivar Grand Nain, targeting three key traits: reduced plant height, a shorter life cycle, and heavier bunches—traits that reduce labor costs and enhance productivity. Three representative selections are highlighted: Tiny-IL, combining reduced stature (42 cm, -)13.3%(less than Grand Nain) with high bunch weight; Barak, characterized by a shorter growth cycle, flowering 15 days earlier than Grand Nain and exhibiting a PC-to-R1 ratio of 0.75 compared with 0.21 in Grand Nain; and Goliath, producing exceptionally heavy bunches, with an increase of 11.5 kg (+20.8%) in bunch weight. In parallel, we developed two superior selections from TR4-tolerant Taiwanese clones, featuring a significantly shorter life cycle and heavy bunches. However, field trials revealed reduced tolerance compared with the parental lines, suggesting a trade-off between accelerated growth and pathogen resistance. Currently, 22 promising Grand Nain selections are undergoing large-scale, multi-year clonal trials across diverse environments. These efforts aim to deliver improved, high-yielding cultivars adapted to the evolving challenges of global banana production.

Key words: Selection-based breeding, Grand Nain, Low stature, Short life cycle, Heavy bunch

RESUMEN

El desarrollo de cultivares mejorados es un factor clave del progreso agrícola. En banano, el mejoramiento clásico mediante cruzamientos es poco común, ya que la mayoría de los cultivares comerciales son estériles. En su lugar, el mejoramiento basado en selección —la identificación y propagación de plantas individuos superiores dentro de cultivares existentes— ofrece una alternativa práctica y eficiente para mejorar el cultivo. Nuestro trabajo se centra en desarrollar selecciones mejoradas del cultivar estándar de la industria, Grand Nain, enfocadas en tres rasgos principales: menor altura de planta, ciclo de vida más corto y racimos más pesados, características que reducen los costos de mano de obra y aumentan la productividad. Se destacan tres selecciones representativas: Tiny-IL, que combina una reducción de 42 cm (-13,3 %) en altura respecto a Grand Nain con alto peso de racimo; Barak, caracterizada por un ciclo más corto, con floración 15 días antes que Grand Nain y una relación PC-R1 de 0,75 frente a 0,21 en Grand Nain; y Goliath, que produce racimos excepcionalmente pesados, con un incremento de 11,5 kg (+20,8 %). En paralelo, se desarrollaron dos selecciones superiores a partir de clones taiwaneses tolerantes a TR4, con ciclos más cortos y racimos pesados. Sin embargo, los ensayos de campo mostraron menor tolerancia que las líneas parentales, lo que sugiere una compensación entre crecimiento acelerado y resistencia a patógenos. Actualmente, 22 selecciones prometedoras de Grand Nain se evalúan en ensayos clonales multianuales y en diversos ambientes, con el objetivo de generar cultivares mejorados y productivos adaptados a los desafíos cambiantes de la producción mundial de banana.

Keywords: Crianza basada en la selección, Grand Nain, Baja estatura, Ciclo de vida corto, Racimo pesado

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INTRODUCTION

Banana (*Musa* spp.) is one of the most important fruit crops globally, providing a major source of calories and income for millions of people across tropical and subtropical regions (FAO, 2025). Despite its economic and nutritional significance, genetic improvement in banana remains challenging due to the sterility, triploidy, and narrow genetic base of most commercial cultivars. Conventional breeding through hybridization—an essential driver of crop improvement in other species—is therefore rarely feasible in banana (Cheng *et al.,* 2024). As a result, selection-based breeding has emerged as a practical and powerful approach for banana improvement. This strategy focuses on identifying naturally occurring variants or somaclonal selections that express superior agronomic performance, such as improved tolerance to diseases, reduced plant height, shortened growth cycle, enhanced bunch weight, and better fruit quality (Ferreira *et al*., 2023). Unlike conventional breeding, selection-based improvement capitalizes on genetic variation within vegetatively propagated populations, allowing progress even in the absence of sexual recombination. Although bananas (*Musa* spp.) display broad genetic diversity across wild and cultivated accessions (Christelová *et al*., 2017), the commercial banana industry is largely based on a narrow genetic basis, dominated by the Cavendish subgroup, particularly the cultivars Williams and Grand Nain. This genetic uniformity has created a global monoculture that is highly vulnerable to biotic and abiotic stresses, including emerging diseases such as Fusarium wilt Tropical Race 4 (TR4) and the increasing impacts of climate change. The heavy reliance on a few closely related genotypes underscores the urgent need to develop new banana cultivars with improved agronomic performance, enhanced resilience, and broader genetic diversity to ensure sustainable production and market stability. The present study describes the implementation of a selection-based breeding program for banana, focusing on the enhancement of Grand Nain. Through multi-year evaluations and comparative trials, we aim to demonstrate the potential of this approach to deliver shorter, faster, and heavier-bunches banana lines suitable for diverse growing environments.

MATERIALS AND METHODS

Plant material and experimental sites

The selection-based breeding activity was conducted using Musa acuminata cultivars of the AAA genomic group. Two independent breeding tracks were established: (i) selections from the commercial cultivar Grand Nain, and (ii) selections from Taiwanese TR4-tolerant clones 218 and 247. Experiments were conducted in Northern Israel. Grand Nain selections in the Western Galilee (Kibbutz Mezuba,

33°03'50.2"N, 35°08'45.2"E) and Taiwanese TR4-tolerant selections in the Jordan Valley (Kibbutz Ein Gev, 32°46'43.0"N, 35°38'22.7"E). The climate in both regions is subtropical, characterized by warm, dry summers and cold winters, with annual maximum and minimum temperatures of 35–40°C and 2–4°C, and 400–500 mm of rainfall concentrated between November and March.

Selection Process and Propagation

In each selection plot, all plants were visually screened for at least three crop cycles to identify superior agronomic performance. Plants exhibiting desirable traits—reduced height (<290 cm), a shorter growth cycle (flowering ≥10 days earlier than Grand Nain), increased bunch weight (>35 kg), and improved plant architecture (open, well-spaced hands)—were tagged. From each tagged plant, 5–10 follower plants were collected and propagated via tissue culture (Ginosar Agro, Kibbutz Ginosar, Israel). Each selected line was multiplied to produce uniform clonal replicates for subsequent clonal evaluation. The initial screening encompassed ~20,000 Grand Nain plants and 200 TR4-tolerant Taiwanese clone plants (218 and 247).

Field Evaluation and Experimental Design

Clonal evaluations were conducted in two phases. Phase I was an observational trial with a single bordered replication, comprising 18 measured plants per line. Phase II employed a randomized complete block design with four replicates, each consisting of 24 measured plants (96 plants per genotype). Phase II trials were established in August 2022 (TR4-tolerant clone selections) and August 2024 (Grand Nain selections). All studies were conducted in 6-m-high screenhouse plots. Tissue-cultured plants (40–50 cm, grown in 1.2-L pots) were used for planting. Spacing was 3 m between mats within rows and 4 m between rows, with three plants per mat, giving a density of 2,500 plants/ha.

Plots were fertigated via a drip system with 300 kg N/ha/year (as NH_4NO_3), 450 kg K_2O/ha/year, and 50 kg P_2O_5/ha/year. Irrigation was applied daily during the dry season (April–November), totaling approximately 1700 mm annually.

Data Collection and Statistical Analysis

The following parameters were recorded to assess horticultural performance: pseudostem height and circumference measured 1 m above ground after bunch emergence; bunch emergence and harvest dates; number of hands per bunch; bunch weight; and finger traits, including weight and length of the middle finger from the outer whorl of the third basal hand. For TR4 resistance (Taiwanese TR4-tolerant clone selections only), external Fusarium wilt symptoms were visually evaluated monthly using a 1–5 scale (1 = symptom-free, 5 = dead).

Statistical analyses were performed using JMP 13 software (SAS Institute Inc., Cary, NC, USA). Phase I data were analysed using two-sample t-tests, and Phase II using analysis of variance (ANOVA) under an RCBD model with block treated as a random effect.

RESULTS AND DISCUSSION

Grand Nain Selections: Twenty-two individual plants exhibiting desirable agronomic traits were identified through multi-year visual field screening of approximately 20,000 plants. The main selection criteria included reduced plant height (two selections), a shorter life cycle (six selections), and increased bunch weight (fourteen selections). Plants showing potential superiority for one or more of these traits were propagated through tissue culture and established in a small-scale clonal validation (Phase I) plot designed as an observational trial to verify the initial field observations and genetic stability. The following section presents results from the first production cycle (parent crop) for three representative selections, each expressing one of the key target traits. Tiny-IL represents the low-stature selection group. This line combines a 42 cm (13.5%) reduction in plant height relative to Grand Nain, with a 6.9 cm (10.4%) increase in pseudostem diameter (Table 1, Figure 1a). The reduced plant height facilitates field management, lowers labor costs, and decreases the risk of wind damage or pseudostem breakage. The smaller plant size and reduced canopy area allow for higher planting density. Combined with a slightly heavier bunch weight (Table 1, Figure 2b), these traits indicate strong potential for improved yield efficiency per unit area. Finger length and weight in Tiny-IL were comparable to those of Grand Nain (Table 1).

Table 1. Comparative performance of the selection Tiny-IL relative to the commercial control Grand Nain in the parent crop (Phase I; observational trial; n = 18 plants per line). Different letters within the column indicate statistically significant differences according to a t-test ($p < 0.05$).

Genotype	Pseudostem height (cm)	Pseudostem circumference (cm)	Shooting date (dd/mm/yyyy)	Harvest date (dd/mm/yyyy)	Hand number in bunch	Bunch weight (kg)	Finger length (cm)	Finger weight (g)
Grand Nain	313a	66.4b	27/07/2023	12/10/2023	12.7	43.8	21.8	186
Tiny-IL	271b	73.3a	23/07/2023	25/10/2023	12.8	45.2	22.1	179



Figure 1. Comparison of plant height and bunch development between Grand Nain (left) and Tiny-IL (right): (a) seven months and (b) fourteen months after planting.

Barak represents the "short life cycle" selection group. It flowered 15 days earlier and was harvested 39 days before Grand Nain (Table 2). Moreover, its PC-to-R1 ratio—representing the number of daughter-plant bunches harvested within the same year as the mother plant—was three times higher than the industry standard (Table 2), indicating a potentially high harvest index and annual yield capacity. Despite its smaller stature and reduced pseudostem circumference, Barak produced bunches and fingers comparable in weight and size to those of Grand Nain (Table 2). Goliath represents the "big-bunch" selection group. The plants are large, with tall and robust pseudostems (408 cm in height and 81.6 cm in circumference), corresponding to 63 cm and 10.1 cm more than Grand Nain, respectively (Table 2), indicating vigorous vegetative growth. Goliath produced the heaviest bunches (55.0 kg), which is 9.5 kg—or 20.8%—greater than Grand Nain, and the highest number of hands per bunch (14.5), surpassing the standard cultivar by 2 hands. Although it produced more hands, finger length and weight were comparable to Grand Nain (Table 2), confirming that the yield advantage resulted primarily from an increased number of fruits rather than enlargement of individual fruits.

Table 2. Comparative performance of the selections Barak and Goliath relative to the commercial control Grand Nain in the parent crop (Phase I; observational trial; n = 18 plants per line). Different letters within a column indicate statistically significant differences according to a t-test ($p < 0.05$).

Genotype	Pseudostem height (cm)	Pseudostem circumference (cm)	Shooting date (dd/mm/yyyy)	Harvest date (dd/mm/yyyy)	Hand number in bunch	Bunch weight (kg)	Finger length (cm)	Finger weight (g)	PC to R1 ratio
Grand Nain	345ab	71.5b	14/07/2024b	16/11/2024c	12.5ab	45.5b	23.8	235	0.21
Barak	316b	68.7c	29/06/2024a	08/10/2024a	11.5b	46.8b	22.3	210	0.75
Goliath	408a	81.6a	24/07/2024b	30/10/2024b	14.5a	55.0a	23.6	212.0	0

Taiwanese TR4-tolerant clones .Through selection within the TR4-tolerant Taiwanese clones 218 and 247, two superior lines—218-12 and 247-1—were developed, exhibiting markedly shorter production cycles and heavier bunches than their parental genotypes. Flowering occurred 27 and 32 days earlier, and harvest 33 and 49 days earlier, respectively, compared with the parental lines. Bunch weight increased by 11.6 kg (+50%) in 218-12 and 13.7 kg (+72%) in 247-1, leading to yield gains of over 60%. These results highlight the efficiency of selection-based breeding for improving productivity and shortening the growth cycle within existing banana cultivars.

Table 3. Agronomic performance of the TR4 tolearnt clones 218 and 247 and their improved.

Genotype	Pseudostem height (cm)	Pseudostem circumference (cm)	Shooting date (dd/mm/yyyy)	Harvest date (dd/mm/yyyy)	Hand number in bunch	Bunch weight (kg)	Finger length (cm)	Finger weight (g)	Bunches per ha.	Yield (ton/ha.)
Grand Nain	287b	62.9b	28/07/2023a	23/11/2023a	11.1ab	31.8a	20.7ab	175ab	2083a	65.7a
218	277b	62.2b	31/08/2023b	07/01/2024b	10.3ab	22.9b	19.6ab	165ab	1583b	35.3b
218-12	298b	70.2a	30/07/2023a	19/11/2023a	10.8ab	34.5a	21.9a	194a	1666b	56.7ab
247	330a	62.8b	29/08/2023b	11/01/2024b	9.5b	19.0b	18.5b	142b	1875ab	37.2b
247-1	354a	67.9a	02/08/2023a	09/12/2023ab	11.9a	32.7a	20.9ab	196a	1875ab	61.2a

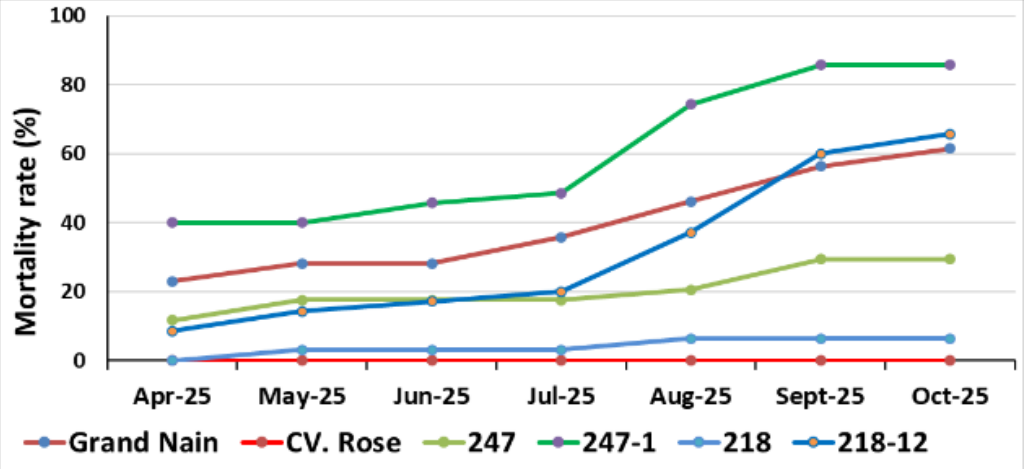


Figure 2. Monthly progression of plant mortality (%) among banana genotypes under TR4-infested field conditions between April and October 2025. Each point represents the mean of 32 plants per genotype.

Selections 218-12 and 247-1 under TR4-free field conditions. N=96 plants. Different letters within a column indicate statistically significant differences according to one-way ANOVA ($p < 0.05$).

The new clones and their parental lines were planted in August 2024 in a TR4-infested plot to assess Panama disease tolerance, alongside Grand Nain (susceptible) and Cv. Rose (resistant) controls. By October 2025, mortality reached 62% in Grand Nain and 0% in Cv. Rose. The parental clones 218 and 247 showed partial tolerance (6% and 29% mortality), whereas the selected lines 218-12 and 247-1 were more susceptible, with 66% and 86% mortality, respectively (Figure 2). The unexpected susceptibility of the selected lines 218-12 and 247-1 compared with their parental clones may reflect a trade-off between rapid growth and disease tolerance (Huot et al., 2014, Zaret *et al*., 2024). Moreover, the prevailing subtropical environmental conditions during the trial— characterized by high air and soil temperatures—likely created an optimal environment for rapid pathogen proliferation and symptom expression.

CONCLUSIONS

Collectively, these findings demonstrate the capacity of selection-based breeding to rapidly generate distinct and genetically stable phenotypes—Tiny-IL for reduced stature, Barak for rapid cycling, and Goliath for heavy bunch production—highlighting

the effectiveness of this approach in diversifying the banana industry with improved cultivars.

Data collection will continue for at least five successive production cycles in Phase II to validate the observed trends. Given the strong environmental influence on banana performance, further evaluation across diverse tropical and subtropical regions is essential to confirm the stability and adaptability of the selected lines. The TR4-tolerant Taiwanese selections project illustrates a trade-off between accelerated growth and pathogen resistance. Nevertheless, evaluating these improved selections in environments with slower disease progression remains worthwhile.

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