Yield and Fruit Quality Traits of Two Banana Cultivars Grown at Two Locations in Puerto Rico under Black Leaf Streak Disease Pressure

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SUMMARY. Banana (*Musa acuminata* AAA) is the most exported fruit worldwide and represents a major source of revenue for Central American and South American countries as well as the Caribbean region, among others. Black leaf streak disease (BLSD) or black sigatoka, caused by *Pseudocercospora fijiensis* (formerly *Mycosphaerella fijiensis*), is responsible for significant losses to this crop due to the high susceptibility of the most economically important cultivars. BLSD does not immediately kill banana plants, but it causes severe leaf necrosis that results in reduced photosynthetic area, thereby adversely impacting bunch weight and fruit production. Without cultural and chemical control, yields can be reduced by 20% to 80%, depending on severity. This study evaluated ‘FHIA-17’, a BLSD-resistant synthetic hybrid (AAAA), against ‘Grand Nain’, a standard commercial cultivar with no BLSD tolerance, at two locations in Puerto Rico on Ultisol (Corozal site) and Oxisol (Isabela site) soils where BLSD was not managed. Significantly lower bunch yield (45,990 kg·ha⁻¹) and significantly fewer fruit (220,671 fruit/ha) were obtained at Corozal than at Isabela (53,755 kg·ha⁻¹; 380,241 fruit/ha). Lower production at Corozal was the result of higher severity of BLSD at this location than at Isabela and to soil factors interfering with optimum nutrient uptake. Average fruit production of ‘FHIA-17’ was significantly higher than that of ‘Grand Nain’ at both locations, with bunch yields of 68,105 and 72,634 kg·ha⁻¹ at Corozal and Isabela, respectively. Fruit of the third-upper hand was significantly longer for ‘FHIA-17’ at Corozal but not different at Isabela; however, ‘FHIA-17’ fruit in this hand were of significantly greater diameter. Fruit in the last hand of ‘FHIA-17’ were significantly longer than in ‘Grand Nain’ at Corozal, but of significantly greater diameter at both locations. At both locations, the mean fruit weight was significantly higher in ‘FHIA-17’ than in ‘Grand Nain’. The number of functional leaves present at flowering and at harvest was significantly higher in ‘FHIA-17’ than in ‘Grand Nain’ at both locations, indicating more availability of photosynthetic area in ‘FHIA-17’ during the fruit-filling period. The harvest cycle of ‘FHIA-17’ was significantly longer than for ‘Grand Nain’. It took 315 and 204 more days in Corozal and Isabela, respectively, to harvest three cycles (mother crop and two ratoon crops) of ‘FHIA-17’ than for ‘Grand Nain’. No significant differences were found for starch and soluble sugars in green unripe or fully mature fruit among cultivars. In this long-term study, ‘FHIA-17’ showed to have good production and resistance against BLSD and is a viable alternative to current commercial cultivars. Its relative advantage of reduced production costs by not needing fungicide applications should be weighed against its longer harvest cycle to produce a fruit bunch.

Banana is a tropical rhizomatous perennial plant whose center of origin lies in the humid tropical belt that extends from India to the Solomon Islands (Bioversity International, 2020a; Perrier et al., 2011). India is the largest banana-producing country followed by China, Indonesia, Ecuador, and the Philippines, accounting for 53% of total world production [Food and Agriculture Organization of the United Nations (FAO), 2020]. Ecuador is the largest banana exporter, totaling 27% of world exports (FAO, 2020); however, banana production also represents a major source of revenue in Central America and the Caribbean region

(Bioversity International, 2020b). In the United States, smaller scale commercial production occurs in Puerto

Rico (5051 acres), Hawaii (1159 acres), and southern Florida (952 acres), where producers supply local and regional markets [Bioversity International, 2020b; Crane and Balerdi, 2019; U.S. Department of Agriculture (USDA), 2017]. Bananas are commercially packed as individual fruit (i.e., “fingers”), clusters, hands, or in a combination of clusters and hands. A cluster is at least two but not more than seven fingers attached to the crown (cut portion of stalk). A hand is eight or more fingers attached to the crown (USDA, 2004).

Banana classification is based on the nomenclature developed by Simmonds and Shepherd (1955). Most edible bananas originally came from two wild, seeded species, *M. acuminata* (A genome) and *Musa balbisiana* (B genome). The genomic contributions from these two species determines the ploidy and genetic makeup or subgroups. For example, the “AAA” genomic group forms the most commercially valuable group and is composed of several subgroups of which the “Cavendish” subgroup is the most important for export and local markets. Important cultivars in this subgroup include Grand Nain, Williams, and Mons Mari, among others (Bioversity International, 2020c; Robinson and Galán-Saúco, 2010; Subbaraya et al., 2011). Other genomic groups include “AAAA” (tetraploid banana), produced by breeding “AA” pollen parents with “AAA” female parents, “AAB” (plantains), “ABB” (cooking banana), “AAB” (dessert bananas), and even manmade or synthetic tetraploid hybrids (AABB) (Bioversity International, 2020c; Irizarry et al., 2001).

Since its description in 1963 (Rhodes, 1964), BLSD has spread to most banana and plantain growing regions. The first record of BLSD in Latin America is from Honduras in 1972 and since then the disease has spread to Belize (1975); Guatemala

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
100	bar	kPa	0.01
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
28.3495	oz	g	0.0353
0.001	ppm	mg·g ⁻¹	1000
1	ppm	mg·kg ⁻¹	1
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

(1977); Nicaragua, El Salvador, and Costa Rica (1979); Mexico (1980); Panama and Colombia (1981); Ecuador (1986); Venezuela (1991); Peru (1994); Bolivia (1996); Brazil (1998); Bahamas (2004); and French Guiana (2008). In the Caribbean region, the disease was first reported in Cuba (1992), Jamaica (1994), Dominican Republic (1996), Haiti (2000), Trinidad and Tobago (2003), Grenada (2005), Saint Vincent (2009), Saint Lucia and Martinique (2010), and Dominica and Guadeloupe (2012) (Robinson and Galán-Saúco, 2010). In the continental United States, BLSD was first found in Florida in 1998 (Ploetz and Mourichon, 1999) and confirmed in the U.S. territory of Puerto Rico in 2004 (Irish et al., 2006).

Although banana production in the Western Hemisphere is seriously threatened by the emergence of a strain of the soilborne fungus *Fusarium oxysporum* f. sp. *cubense* tropical race 4 [Foc TR4 (Maymon et al., 2020; Yonow et al., 2019)], BLSD continues to be one of the most limiting factors in banana production worldwide. BLSD does not immediately kill its host plants but causes severe leaf necrosis that results in reduced photosynthetic area affecting bunch weight and fruit quality. Without chemical and cultural control, yields can be reduced by 20% to 80%, depending on disease severity (Churchill, 2011; Etebu and Young-Harry, 2011). Fruit harvested from heavily infected plants ripen prematurely and unevenly and result in unmarketable fruit. The need to manage the disease to a level that does not affect fruit

production and quality makes BLSD the most economically important foliar disease of banana. In Puerto Rico, BLSD has steadily led to higher production costs associated with added labor for cultural practices and increased use of fungicides (Alamo et al., 2007). Approximately 30% of the total cost of production is associated with pruning of heavily infected, nonfunctional leaves and the use of chemical control measures for BLSD (Etebu and Young-Harry, 2011).

Managing BLSD with fungicidal applications can be expensive and can be hazardous to human health and the environment; therefore, breeding for disease resistance offers the most sustainable and effective means of disease management. Several international breeding programs have released BLSD-tolerant plantain and banana hybrids, most of which are parthenocarpic synthetic tetraploids generated by crossing triploid banana and fertile, true plantain cultivars with wild or improved diploid (*Musa* AA) parents (Ortiz et al., 1998; Robinson and Galán-Saúco, 2010; Rowe and Rosales, 1993; Swennen and Vuylsteke, 1993).

The USDA, Agricultural Research Service (ARS), Tropical Agriculture Research Station (TARS) in Mayaguez, PR, is the official repository for *Musa* species germplasm for the National Plant Germplasm System. The authors have introduced to the repository disease-resistant banana genotypes for field evaluation from international breeding programs (Irish et al., 2013). In this study, the authors compared performance by measuring yield and fruit quality traits in two banana cultivars grown under BLSD pressure at two locations in Puerto Rico.

Materials and methods

This study was conducted in 2010–13 in Puerto Rico at the USDA-ARS-TARS Research Farm in Isabela (Coto clay: clayey, kaolinitic isohyperthermic Typic Hapludox) and at the Corozal Agricultural Experiment Station of the University of Puerto Rico (Corozal clay: clayey, mixed, isohyperthermic Aquic Haplohumults). Soil and climatic characteristics are described in Tables 1 and 2, respectively. Soil samples from each site were collected 2 months before planting by taking 15 borings at a depth of 0 to 25 cm from each of the projected cultivar rows. Samples were air-dried and passed through a 16-mesh screen. Soil pH in water and 0.01 M calcium chloride (1 soil: 2 water) were measured with a glass electrode. Phosphorous (P) and exchangeable cations [potassium (K), magnesium (Mg), and calcium (Ca)] were extracted with Mehlich III solution [extract was composed of 0.2 M acetic acid, 0.25 M ammonium nitrate, 0.015 M ammonium fluoride, 0.013 M nitric acid, and 0.001 M EDTA (Amacher, 2007)], Exchangeable aluminum (Al) was extracted with 1 N potassium chloride. All elements were determined by inductively coupled plasma spectrometry (Sumner and Miller, 2007). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers, 2007). Soil ammonium (NH₄) and nitrate (NO₃) were determined by steam distillation (Mulvaney, 2007).

The banana cultivars evaluated in the experiment were the BLSD-tolerant FHIA-17 (*Musa* AAAA) and the disease-susceptible Grand Nain (*Musa* AAA) “Cavendish” subgroup. ‘FHIA-17’ was developed at the Fundación

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Table 1. Average preplant soil characteristics at two banana test sites in Puerto Rico (Corozal and Isabela) measured to a depth of 25 cm (9.8 inches).

Soil characteristics ^z	Corozal (Ultisol)	Isabela (Oxisol)
pH in water	4.87	6.36
pH in calcium chloride	4.21	5.77
Ammonium nitrogen (mg·kg ⁻¹)	155	41
Nitrate nitrogen (mg·kg ⁻¹)	14	22
Organic carbon (%)	1.57	1.52
Phosphorous (mg·kg ⁻¹)	8	30
Potassium (mg·kg ⁻¹)	125	143
Calcium (mg·kg ⁻¹)	1352	1625
Magnesium (mg·kg ⁻¹)	102	95
Aluminum (mg·kg ⁻¹)	238	ND ^y

^z1 mg·kg⁻¹ = 1 ppm.

^yNot detectable.

Table 2. Weather data at two banana test sites in Puerto Rico (Corozal and Isabela) in 2010–13.

Site characteristics ^z	Corozal	Isabela
Total rainfall (cm)	159	164
Maximum temperature (°C)	29.6	28.4
Minimum temperature (°C)	20.4	21.4
Elevation (m)	195	126

^z1 cm = 0.3937 inch, (1.8 × °C) + 32 = °F, 1 m = 3.2808 ft.

Hondureña de Investigación Agrícola (FHIA), Honduras, Central America (Fundación Hondureña de Investigaciones Agrícolas, 2021). ‘Grand Nain’ is the most extensively grown cultivar under commercial production worldwide. The ‘FHIA-17’ source planting material was obtained as virus-free (indexed), in vitro cultured plantlets from the Bioversity International’s *Musa* International Transit Center at the Catholic University in Leuven, Belgium. Before field transplanting, ‘FHIA-17’ plant material was increased via in vitro micropropagation following conventional protocols (Vuylsteke, 1989) and acclimatized in a greenhouse for 3 months. Plants were regularly watered and fertilized with 20N–8.7P–16.6K + micronutrients water soluble fertilizer (Evergreen; Plant Foods, Vero Beach, FL) and 19N–2.6P–10K slow-release fertilizer (Osmocote; The Scotts Co., Marysville, OH). Six-month-old tissue cultured plantlets of ‘FHIA-17’ and medium-size corms obtained from sword suckers of ‘Grand Nain’ were planted at 6 × 6-ft spacing in a randomized complete block design with six replications. Within a replication, there were two plots of two rows to accommodate each treatment (cultivars). Each treatment plot had 14 plants of which the inner 10 were harvested. Alleys of 12 ft separated the replications (equivalent to 806 plants/acre). Two guard plants of each cultivar separated the 10 experimental treatment plants between treatment plots and there were two guard rows at the end of each plot. The experiment was surrounded by three rows of BLSD-susceptible ‘Grand Nain’ banana plants that served as a source of natural inoculum for *P. fijiensis*.

Fertilization was provided using a 10N–2.2P–24.9K–1.8Mg granular commercial mixture by applying 0.25 and 0.5 lb at 1 and 2 months after transplanting, respectively, and 1 lb of fertilizer per plant thereafter every 3 months until the experiment was completed.

Nematodes, soilborne insects, and weeds were controlled by following recommended cultural practices (University of Puerto Rico, Agricultural Experiment Station, 1995). Plots were drip-irrigated when the soil water tension, measured with tensiometers (Irrometer Co., Riverside, CA) at a depth of 1 ft, exceeded 20 kPa. No leaf pruning, or foliar spraying was carried out to control BLSD. A selective desuckering program was implemented ≈4 months after planting to allow the development of a single ratoon sucker per stump for the subsequent crop.

At flowering (bunch-shooting) and harvest, the number of functional leaves per plant was recorded. Approximately 2 weeks after flowering, the male flower bud and the false hands were removed from the immature bunches. For the mother crop, the number of days to flower was determined as the time interval between field planting and flowering. For the ratoon crops, this was determined by counting the number of days elapsed between the mother crop harvest date and flowering. At flowering, plant height and pseudostem diameter were measured from mother and ratoon plants. These measurements were taken from the base of the plants to the point of bunch emergence for plant height and to 1 m aboveground level for pseudostem diameter.

Bunches were harvested when fruit reached the mature green stage, ≈110 d after flowering. At harvest, bunches were weighed, and the number of hands and fruit counted and then cut from the rachis. The length of the fruit on its outside edge and diameter at widest point were measured from three fruit of the middle section of the third-upper and last hands in the bunch. These fruit measurements were pooled to obtain an average for each hand. The weight for both third and last hands was also recorded. Values for bunch weight and yield per unit area were obtained

after subtracting the rachis weight from the total bunch weight.

BLSD severity was assessed at flowering time for the mother and ratoon crops. Using Gauhl’s modification of Stover’s severity scale adapted from Orjeda (1998), all leaves for every plant evaluated were scored on a 0 to 6 scale where 0 = no symptoms; 1 = 1%, 2 = 2% to 5%, 3 = 6% to 15%, 4 = 16% to 33%, 5 = 34% to 50%, and 6 = >51% of the leaf area affected.

To determine the presence of *P. fijiensis* causing infection on evaluated banana cultivars from other possible related fungal species, 20 isolates were recovered for testing. Pure cultures (i.e., single ascospores) were isolated from randomly selected senescent leaf tissue from five ‘Grand Nain’ and five ‘FHIA-17’ plants from both the Corozal and Isabela locations using an ascospore discharge technique (Johanson and Jeger, 1993). Fungal mycelium was grown in potato dextrose broth on an orbital shaker, and harvested, lyophilized, and ground in a mortar and pestle in liquid nitrogen before DNA extraction. DNA was extracted using a DNeasy Plant Mini Kit (Qiagen, Valencia, CA) following the manufacturer’s protocols for lyophilized fungal mycelium. DNA for each isolate was amplified using a *P. fijiensis* species-specific primer set (ACTR/MfactF) in combination with a positive internal control primer set (TMG3/TMG4) for the β-tubulin gene developed by Arzanlou et al. (2007). Polymerase chain reactions (PCRs) also included genomic DNA from pure cultures of *P. fijiensis*, and *Pseudocercospora musicola* (yellow sigatoka), and *Pseudocercospora eumusae* (eumusae leaf spot) (provided by G. Kema, Wageningen University) as well as a negative water control to serve as references. All PCR reactions were performed as described by Arzanlou et al. (2007) on a thermocycler (T-100; Bio-Rad, Hercules, CA) and were electrophoresed in 1.5% agarose gels and stained with ethidium bromide. Agarose gels were visualized and photographed using a transilluminator (Epi Chemi II Darkroom; UVP, Upland, CA).

Analysis of variance was carried using the GLM procedure of SAS (version 9.4 for Windows; SAS Institute, Cary, NC). After a significant F test at $P \leq 0.05$, mean separation was

Table 3. Yield and bunch traits of ‘FHIA-17’ and ‘Grand Nain’ banana planted at two locations in Puerto Rico under black leaf streak disease pressure. Values are means of six replications and 3 years (2010–13).

Location	Cultivar	Bunch yield (kg·ha ⁻¹) ^z	Fruit (no./ha) ^z	Hands per bunch (no.) ^y	Third hand wt (kg) ^{z,y}	Third hand fruit length (cm) ^{z,y}	Third hand fruit width (mm) ^{z,y}	Last hand wt (kg) ^{z,y}	Last hand fruit length (cm) ^{z,y}	Last hand fruit width (mm) ^{z,y}	Mean fruit wt (g) ^z
Corozal	FHIA-17	68,105	358,376	11.1	3.83	22.0	39.0	1.79	16.9	33.6	190.4
	Grand Nain	23,875	220,671	7.7	1.83	19.3	29.7	0.94	14.9	26.4	104.7
	Average	45,990	289,523	9.4	2.83	20.6	34.3	1.36	15.9	30.0	147.5
	HSD (0.05) ^x	3,047	12,236	0.29	0.28	0.41	0.87	0.09	0.50	0.89	10.9
Isabela	FHIA-17	72,634	444,133	12.5	3.82	22.0	36.6	1.74	16.7	31.2	164.7
	Grand Nain	36,378	316,350	9.2	2.36	22.0	29.9	1.14	16.6	25.6	114.8
	Average	53,755	380,241	10.8	3.24	22.0	33.2	1.44	16.6	28.4	139.7
	HSD (0.05)	2,781	15,027	0.36	0.16	NS	0.60	0.08	NS	0.58	5.7
	HSD (0.05) ^w	1,976	9,284	0.22	0.15	0.28	0.51	0.06	0.28	0.51	5.9
	Year (Y)	***	***	***	***	***	***	***	***	*	***
	Location (L)	***	***	***	*	***	**	*	***	***	*
	Y × L	***	NS	NS	***	***	**	***	***	**	***
	Cultivar (C)	***	***	***	***	***	***	***	***	***	***
	L × C	***	NS	NS	***	***	***	***	***	**	***
	Y × C	***	***	*	***	***	***	***	***	***	***
	Y × L × C	***	NS	NS	***	***	***	***	***	***	***

^z1 kg·ha⁻¹ = 0.8922 lb/acre, 1 fruit/ha = 0.4047 fruit/acre, 1 kg = 2.2046 lb, 1 cm = 0.3937 inch, 1 mm = 0.0394 inch, 1 g = 0.0353 oz.

^yThe first three upper hands of plantain bunches contain ≈50% of the total fruit. Therefore, the weight of the third-upper hand is often used to represent an average weight of all the hands in the bunch. Similarly, higher fruit weight and size in the last hand is indicative of higher marketable weight in fruit of hands after the third hand (Goenaga and Irizarry, 2006).

^xTukey's honestly significant difference test at $P = 0.05$.

^wCompares means among locations.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively

performed with the Tukey's honestly significant difference range test. For comparison of BLSD resistance and yield performance and to prevent analyzing an incomplete data set, only three harvest cycles (mother crop and two ratoon crops) were statistically analyzed.

Results and discussion

Following PCR amplification, *P. fijiensis* infection was confirmed at both locations by electrophoretic separation and visualization of both the diagnostic [≈500 base pairs (bp)] and β-tubulin gene (≈300 bp) fragments from isolates recovered from both cultivars as well as in the positive control reference sample. All 10 isolates recovered from both cultivars from Isabela amplified the diagnostic ≈500 bp and internal control fragments. In contrast, only two isolates/DNA samples from ‘FHIA-17’ and one from ‘Grand Nain’ amplified the ≈500 bp and internal control fragment from Corozal. The remaining seven samples from Corozal amplified the internal β-tubulin gene fragment, but nothing else. In addition, only the internal β-tubulin gene fragment was

amplified for both *P. musicola*, and *P. eumusae* reference samples and no amplification was seen for negative water control. These findings evidence the presence of BLSD in both locations.

Year, location, and cultivars showed highly significant effects ($P \leq 0.01$) for most parameters measured in the study (Tables 3 and 4). Except for plant height, pseudostem diameter, bunch rachis weight, total number of fruit, and number of hands per bunch, the location × cultivar interaction was significant, indicating that cultivars responded differently for yield, fruit traits, plant attributes, and reaction to BLSD at both locations. The year × cultivar interaction was significant for all parameters studied except for plant height, indicating that plant height of cultivars was a stable trait across years (Tables 3 and 4).

Cultivars exhibited drastic yield differences between the mother (year 1) and ratoon (years 2, 3) crops (Tables 3 and 5). Contrary to the rapid yield decline that occurs in commercial plantain production after harvest of the mother crop (Goenaga et al., 1993, 2019), banana yields tend to increase in

successive ratoon crops after harvest of the mother crop (Goenaga and Irizarry, 1995; Irizarry et al., 1989). In this study, the bunch yield obtained by the ‘FHIA-17’ second ratoon crop was 37% and 8% higher in Corozal and Isabela, respectively, than the mother crop. In ‘Grand Nain’, bunch yield for the second ratoon was 168% and 60% higher, respectively, than the mother crop (Table 5).

Average bunch yield, total number of fruit, as well as many other bunch and hand traits were significantly different between locations (Table 3). Significantly lower bunch yield (45,990 kg·ha⁻¹) and significantly fewer fruit (289,523 fruit/ha) were obtained at Corozal than at Isabela (53,755 kg·ha⁻¹; 380,241 fruit/ha). Lower bunch yield at Corozal than at Isabela was the result of significantly lower number of fruit harvested particularly in ‘Grand Nain’, which produced 30% fewer fruit at Corozal than at Isabela (Table 3). Less fruit production at Corozal could have been the result of several factors. Severity of BLSD was higher at Corozal than at Isabela, particularly in leaves 4 to 7, which are photosynthetically active

Table 4. Plant traits of ‘FHIA-17’ and ‘Grand Nain’ banana planted at two locations in Puerto Rico under black leaf streak disease pressure. Values are means of six replications and 3 years (2010–13).

Location	Cultivar	Plant ht (m) ^z	Stem diam (cm) ^z	Leaves at flowering (no.)	Leaves at harvest (no.)	Time to flower (d)	Time to harvest (d)	Rachis wt (kg) ^z
Corozal	FHIA-17	3.60	27.2	10.8	6.2	918	1027	2.77
	Grand Nain	2.31	17.1	7.5	0.67	611	712	1.17
	Average	2.96	22.1	9.2	3.4	765	870	1.97
	HSD (0.05) ^y	0.07	0.35	0.36	0.43	35.0	34.0	0.11
Isabela	FHIA-17	3.97	30.1	10.7	4.9	629	732	3.47
	Grand Nain	2.64	19.7	8.7	0.9	432	528	1.84
	Average	3.30	24.9	9.7	2.9	530	630	2.65
	HSD (0.05)	0.09	0.44	0.19	0.29	21.3	20.8	0.16
	HSD (0.05) ^x	0.05	0.27	0.19	0.25	19.6	19.1	0.09
	Year (Y)	***	***	***	***	***	***	***
	Location (L)	***	***	***	***	***	***	***
	Y × L	***	NS	***	*	***	***	*
	Cultivar (C)	***	***	***	***	***	***	***
	L × C	NS	NS	***	***	***	***	NS
	Y × C	NS	***	***	***	***	***	***
	Y × L × C	NS	NS	***	***	NS	*	*

^z1 m = 3.2808 ft, 1 cm = 0.3937 inch, 1 kg = 2.2046 lb.

^yTukey's honestly significant difference test at $P = 0.05$.

^xCompares means among locations.

NS, *, ***Nonsignificant or significant at $P \leq 0.05$ or 0.001, respectively.

(Robinson et al., 1992), particularly in plants having up to 12 leaves like in this study (Table 6). Another reason for lower productivity at Corozal may be related to soil factors interfering with optimum nutrient uptake. The soil at Corozal is a highly weathered Ultisol, typical of the humid tropics and are characterized by intensive leaching, moderate cation exchange capacity, high soil acidity, and, consequently, a low supply of bases (USDA, 1999). The soil at the Corozal site is more acidic and has a much higher concentration of Al, than at Isabela (Table 1). High soil Al in the soil solution not only replaces divalent cations

such as Mg and Ca but also inhibits root growth (Eckhard et al., 2012). Leaf tissue sampling conducted during the experimental period showed an average leaf Mg concentration of 0.22% ($n = 65$) for cultivars grown at Corozal (data not shown), whereas at Isabela was 0.31% ($n = 44$). Studies conducted by Irizarry et al. (1988, 1990, 2000) showed that Mg concentration of 0.30% in leaves of banana and plantain grown in Ultisol soils is considered optimum for growth and productivity. These limiting growth factors may also help to explain shorter plants with smaller stem diameters, smaller rachis weights, and more days

required to flower in plants at the Corozal site (Table 4).

At both locations, ‘FHIA-17’ produced significantly more fruit and yield per area than ‘Grand Nain’ (Tables 3 and 5). The weights of the third-upper and last hand in the bunch were also significantly higher in cultivar FHIA-17 than in Grand Nain (Table 3). Fruit of the third-upper bunch hand of ‘FHIA-17’ were significantly longer at Corozal but not different at Isabela. However, ‘FHIA-17’ fruit in this hand were of significantly greater diameter at both locations (Table 3). Fruit in the bunch last hand of ‘FHIA-17’ were significantly longer at Corozal, but of

Table 5. Bunch and fruit yield of ‘FHIA-17’ and ‘Grand Nain’ banana grown at two locations in Puerto Rico (Corozal and Isabela) under black leaf streak disease pressure during a 3-year production cycle (2010–13). Values are means of six replications.

Cultivar	Corozal				Isabela			
	3-yr	Mother crop	First ratoon crop	Second ratoon crop	3-yr	Mother crop	First ratoon crop	Second ratoon crop
Bunch yield (kg·ha ⁻¹) ^z								
FHIA-17	68,105	59,833	62,391	82,091	72,634	73,886	64,384	79,633
Grand Nain	23,875	13,555	21,794	36,278	36,278	23,189	48,803	37,142
HSD ^y	3,047	9,068	5,035	3,736	2,781	2,954	8,303	4,853
Fruit yield (no./ha) ^z								
FHIA-17	358,376	304,080	358,963	412,085	444,133	392,616	447,366	492,415
Grand Nain	220,671	178,667	224,613	258,732	316,350	302,153	310,459	336,438
HSD	12,236	21,701	29,790	24,523	15,027	18,673	36,497	35,712

^z1 kg·ha⁻¹ = 0.8922 lb/acre, 1 fruit/ha = 0.4047 fruit/acre.

^yTukey's honestly significant difference test at $P = 0.05$.

Table 6. Black leaf streak disease severity on ‘FHIA-17’ and ‘Grand Nain’ banana planted at two locations in Puerto Rico. Values are means of six replications and 3 years (2010–13).

Location	Cultivar	Leaf no. ^z											
		1	2	3	4	5	6	7	8	9	10	11	12
Disease severity (0–6 scale) ^y													
Corozal	FHIA-17	0	0	0.43	1.04	1.49	1.91	2.45	2.85	3.44	3.81	4.22	4.77
	Grand Nain	0.33	0.48	1.28	2.56	3.55	3.88	3.98	4.02	4.60	4.85	5.00	5.00
	Average	0.16	0.24	0.85	1.80	2.52	2.89	3.21	3.43	4.02	4.33	4.61	4.88
Isabela	HSD (0.05) ^x	NS	0.48	0.28	0.20	0.27	0.35	0.43	0.79	0.60	0.42	0.01	NS
	FHIA-17	0.33	0.37	0.40	0.44	0.68	1.24	1.98	2.64	3.19	3.46	3.56	3.98
	Grand Nain	0.43	0.85	1.23	1.50	2.14	2.62	3.23	3.39	4.27	4.64	4.67	5.00
	Average	0.38	0.61	0.81	0.97	1.41	1.93	2.60	3.01	3.73	4.05	4.11	4.49
	HSD (0.05)	NS	0.20	0.19	0.17	0.28	0.30	0.38	0.49	0.50	0.37	NS	NS
	HSD (0.05) ^w	NS	0.25	NS	0.12	0.18	0.22	0.26	NS	NS	NS	0.45	NS
	Year (Y)	***	***	***	***	***	***	***	**	**	NS	NS	NS
	Location (L)	NS	*	NS	***	***	***	**	NS	NS	NS	**	**
	Y x L	*	**	**	***	***	***	**	*	NS	NS	NS	**
	Cultivar (C)	NS	***	***	***	***	***	***	***	***	***	NS	NS
L x C	NS	NS	NS	***	**	*	NS	NS	**	**	NS	NS	
Y x C	*	***	***	***	***	***	NS	*	***	***	NS	NS	
Y x L x C	NS	NS	NS	***	***	***	***	***	*	*	NS	NS	

^z1 = youngest/top-most leaf, 12 = oldest leaf.

^yDisease severity based on a 0–6 rating scale (0 = no symptoms; 1 = 1%; 2 = 2% to 5%; 3 = 6% to 15%; 4 = 16% to 33%; 5 = 34% to 50%; and 6 = >51% of the leaf area affected) found in Orjeda (1998).

^xTukey’s honestly significant difference test at $P = 0.05$.

^wCompares means among locations.

NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

significantly greater diameter at both locations (Table 3). Average mean fruit weight was significantly higher at Corozal than at Isabela (Table 3). This could have been the result of fewer fruit per bunch competing for assimilates. At both locations, the mean fruit weight was significantly higher in ‘FHIA-17’ than in ‘Grand Nain’ (Table 3).

It is noteworthy that the harvest cycle of ‘FHIA-17’ was significantly longer than for ‘Grand Nain’. It took 315 and 204 d more in Corozal and Isabela, respectively, to harvest three cycles (mother crop and two ratoon crops) of ‘FHIA-17’ than for ‘Grand Nain’ (Table 4). By the time the experiment was completed by harvesting the second ratoon crop (year 3) of ‘FHIA-17’ in Corozal, ‘Grand Nain’ plants had completed two additional cycles (third and fourth ratoons) that yielded 36,876 and 37,308 kg·ha^{−1}, respectively (data not shown). A third ratoon cycle for ‘FHIA-17’ was still not completed at Corozal. However, in Isabela, a third ratoon of ‘FHIA-17’ and ‘Grand Nain’ developed and yielded 73,088 and 43,919 kg·ha^{−1}, respectively (data not shown). No fourth ratoon crop was completed for either cultivar in Isabela.

It is generally accepted that eight functional leaves at flowering time are

sufficient for adequate bunch growth and development (Robinson et al., 1992; Vargas et al., 2009). Beyond the flowering stage, no new leaves are produced to contribute assimilates for fruit-filling. If the incidence of BLSD is high at flowering time or earlier, fruit-filling is compromised and bunch yield is reduced as a result of reduced leaf photosynthetic area. At both locations, the number of functional leaves at flowering was significantly higher in ‘FHIA-17’ than in ‘Grand Nain’ (Table 4). But more striking, at harvest time, ‘FHIA-17’ plants had significantly more functional leaves than ‘Grand Nain’. This indicates that during the ≈100-d period between flowering and harvest, ‘FHIA-17’ plants had more leaf photosynthetic area for adequate fruit-filling and possibly contributed to higher bunch yield in this cultivar at both locations. It also confirmed good BLSD resistance in ‘FHIA-17’. In a recent study, Guillemet et al. (2018) compared two leaf management systems in banana planted at two locations over three production cycles. In one system (“Reference”), systemic and protective fungicides were applied every 3 to 5 weeks and BLSD-damaged leaf parts were removed every 7 to 15 d. In the other system (“Prototype”), no fungicides were applied

4 months after planting, but sanitary leaf removal was made every 4 to 7 d to eliminate necrotic lesions caused by BLSD as soon as possible as they appeared. Their results showed that, except for cycle 3 (second ratoon) at one location, there were no significant differences in bunch yield between the reference and prototype systems. The authors concluded that relatively high yields in the prototype system with very small number of leaves present at harvest could be explained by manual defoliation occurring gradually rather than whole leaves cut at flowering as done in studies seeking to determine the effect of leaf pruning on bunch yield. The authors suggested that leaves present on flowering, for part of the filling-out phase, as well as remobilization of photosynthate from stems, bunch, and suckers, could have been responsible for adequate fruit-filling. In our study, no fungicides were applied at any time and leaves damaged by BLSD, or sections of these, were not cut from plants or removed from the experimental plots. In many banana-producing areas, the removal of BLSD-infected leaves every 4 to 7 d is not cost-effective due to significant increases in labor costs. This, as well as not having to apply fungicides, definitely is an advantage for using ‘FHIA-17’ as planting material.

Table 7. Concentration of starch and soluble sugars at harvest time (mature green) and fully mature (ripened yellow) fruit of ‘FHIA-17’ and ‘Grand Nain’ banana. Values are means of three replications of fruit grown at Isabela, PR.

Cultivar	Harvest time (mg·g ⁻¹) ^z				Fully mature fruit (mg·g ⁻¹)			
	Starch	glucose	fructose	sucrose	Starch	glucose	fructose	sucrose
FHIA-17	155	ND	2.26	7.56	96	30.2	49.0	224
Grand Nain	166	ND	1.46	3.47	95	24.6	47.9	232
HSD (0.05) ^y	NS	NS	NS	NS	NS	NS	NS	NS

^z1 mg·g⁻¹ = 1000 ppm.

^yTukey's honestly significant difference test at $P = 0.05$.

In industrialized nations, banana is mainly consumed ripe (sweet) but can also be consumed in many parts of the world as a staple starchy vegetable by boiling green fruit. When harvested (green and unripe), the concentration of starch is high and as the fruit matures, starch is converted to sugars and the peel color changes from green to yellow. Little is known about the organoleptic characteristics of ‘FHIA-17’ fruit. To be accepted by consumers, organoleptic traits of ‘FHIA-17’ should be similar to commercial cultivars such as Grand Nain, one of the principal cultivars used in the export market. In this study, no significant differences were found for starch and soluble sugars in green unripe or fully mature fruit among cultivars (Table 7).

Conclusions

This long-term study demonstrated that ‘FHIA-17’ has resistance against BLSD, is a good producer, and may represent a viable alternative to current disease-susceptible cultivars. At the current (2021) farm gate price of \$21.00 per 40-lb box of ripe banana fruit, the average fruit yield of ‘FHIA-17’ (Table 3) would have amounted to gross profits of \$78,826/ha and \$84,068/ha at Corozal and Isabela, respectively, without the need to incur in fungicide application costs. However, its use should be considered after determining its cost-saving effects of not using fungicides (labor and product) vs. a longer harvest cycle than ‘Grand Nain’ to produce a fruit bunch. Studies conducted at Isabela and Corozal with ‘Grand Nain’ sprayed against yellow sigatoka, showed plants yielding as high as 70,700 kg·ha⁻¹ (\$81,830/ha) and 47,900 kg·ha⁻¹ (\$55,441/ha), respectively, at each location. At the time these studies were conducted, BLSD was not present in Puerto Rico (Goenaga and Irizarry, 1998, 2000) but spraying against

yellow sigatoka control is not too different from for BLSD.

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