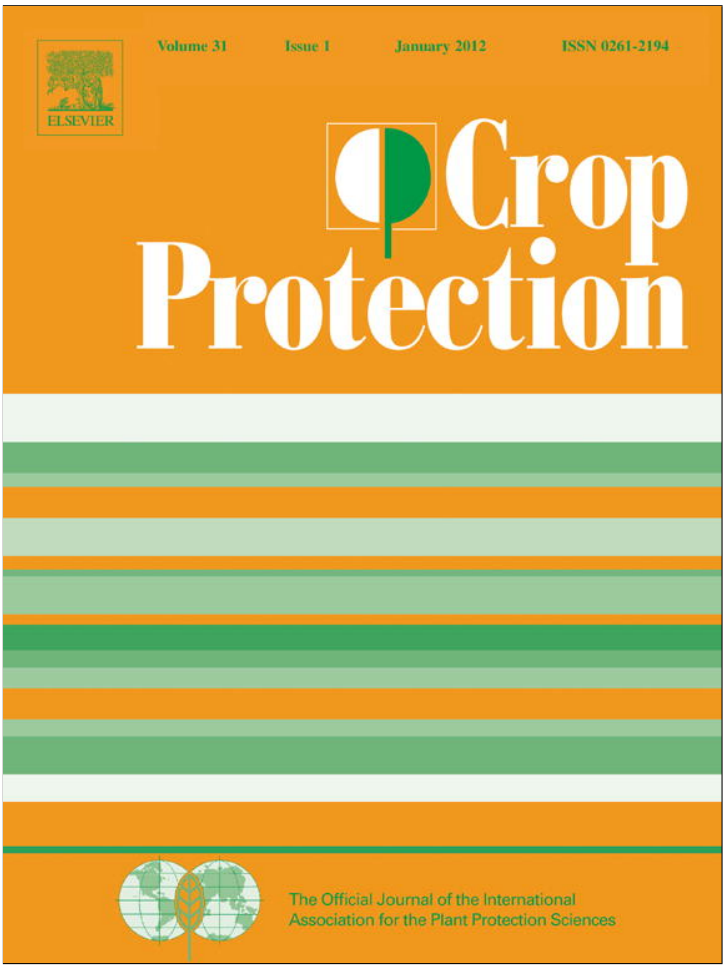

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Differential responses to plant-feeding nematodes among sibling cultivars of dessert bananas (Cavendish subgroup) and a synthetic hybrid

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ABSTRACT

All bananas cultivated for export are Cavendish cultivars and are considered to be very susceptible to both the burrowing nematode *Radopholus similis* and the lesion nematode *Pratylenchus coffeae*. Twelve cultivars of *Musa* spp. genome AAA cv. Grande Naine from mass field selections in Martinique and Guadeloupe were cloned and micro-propagated in tissue culture. Resistance of these sibling cultivars to nematodes was tested in two growth chamber trials and in one 2-year field trial in a former banana field heavily infested with nematodes and without control methods (no guying or nematicide applications). The field trial also included a new synthetic hybrid FB920 that has tolerance to yellow and black Sigatoka and partial resistance to nematodes. Trends were similar in growth chamber and field trials in that all Cavendish cultivars were susceptible to nematode species, although some differences in susceptibility were detected, and in particular roots of the selected cultivar MA13 contained fewer *R. similis* than the most susceptible cultivars of Cavendish (cvs. Petite naine, Poyo and L93). Cultivar MA13 was also less susceptible than most commercial cultivars to *P. coffeae* in the growth chamber trials, and a similar but insignificant trend was documented in the field trial. In the field trial, all cultivars experienced severe damage (lengthening of vegetative and reproductive stages, uprooting and reduced yield), which was attributed to the high level of nematode infestation. Although tolerance to nematodes in the field trial was greater for the synthetic new hybrid FB920 than for the Cavendish cultivars, FB920 produces small bunches and tall plants that will prevent its development as a banana for export (but will not prevent its production by small holders). In summary, this study shows that there is useful variation in tolerance to *R. similis* and *P. coffeae* among sibling Cavendish cultivars and that growth chamber trials with *in vitro*-cultivated plants are useful for screening for such susceptibility.

1. Introduction

Because all commercial, edible bananas are sterile, they are propagated vegetatively. Since the spread of Panama disease in the 1960s and the replacement of the susceptible cultivar Gros Michel, most of the cultivated cultivars of dessert bananas now belong to the Cavendish subgroup (*Musa* spp. genome AAA) (Lescot, 2004), and all of these are variants of one genotype (cv. Grande Naine). As mentioned by Gowen et al. (2005), banana is the only major fruit or vegetable crop in the world that mainly relies on one cultivar. It follows that this vegetative cultivation has narrowed the variability in resistance or tolerance to pests in commercial dessert banana production.

Plant-feeding nematodes are widespread and are among the most damaging pests of all banana cultivars, causing severe crop losses in commercial banana plantations for export. The overall structure of the plant-feeding nematode community is strongly affected by the host status of cultivated plants (Quénéhervé et al., 2011) and by the associated plants, e.g., weeds (Duyck et al., 2009). The host status of banana cultivars is thus a major issue to better understand the population dynamics and community structures of plant-feeding nematodes.

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The rapid development of meristem culture techniques has revolutionized banana propagation (Israeli et al., 1995), and commercial tissue culture laboratories that can produce millions of banana plantlets are now established throughout the world. Since Champion (1963), researchers and banana growers have widely accepted that cultivars from the Cavendish subgroup are highly and equally susceptible to pests and pathogens, apart from Panama disease, including nematodes. Although all dessert bananas have been vegetatively propagated from a very narrow genetic base, they do differ in pest susceptibility and other phenotypic characteristics depending on where they were propagated. In 1998, agronomists from the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) began a field program to select Cavendish individuals based on multiple, locally defined criteria, including dwarfism, hardiness, drought or cold tolerance, productivity, bunch conformation and finger size. In 2003, following preliminary observations that one of these cultivars (cv. MA13) had reduced field susceptibility to plant-feeding nematodes, the current authors decided to investigate the variability in responses among available Cavendish cultivars (selected and commercial) to two serious nematode pests of banana: the burrowing nematode *Radopholus similis* (Cobb) Thorne and the lesion nematode *Pratylenchus coffeae* Goodey. The results of two repeated laboratory experiments and a larger field trial are reported here.

2. Materials and methods

2.1. Growth chamber trials

Two screenings were conducted in a growth chamber under strictly controlled conditions following methods described previously (Quénéhervé et al., 2006). Those banana cultivars previously identified in Martinique and Guadeloupe during a mass field selection program were obtained as *in vitro* propagated plantlets (Vitropic, Montpellier, France). Some other cultivars were directly purchased from a banana nursery as *in vitro* propagated plantlets of different origin (i.e., Rahan Meristem, Israel); the cultivars are listed in Tables 1–4. Plantlets were then transferred in PVC culture tubes (4.5 cm-diameter; 17.5 cm-length; 237 cm^3-volume) filled with sterilized Andosol (pH 6.2, organic matter content 7.3%) and allowed to growth in a culture room. The growth chambers were kept at 24–28 ± 1 °C (thermoperiod night/day) with 14 h of light during 6–7 weeks. Irrigation was automatized as needed (Gardena, Ulm, Germany) and fertilization was supplied at planting by 1 g of Osmocote Plus (10-11-18 + 2MgO + Microelements; Scotts, UK, Howden, Great Britain). In the first screening, five of the selected cultivars (L93, L52, L852, L835 and MA13) and five commercial cultivars (Poyo, Williams, Americani, Zechalv and Petite Naine) all belonging to the Cavendish subgroup were challenged separately with *R. similis* and *P. coffeae*. In the second screening, 10 of the selected cultivars (Jobo, GB1, L33, L35, L52, L902, L93, MA13, NE1 and MB2) and four commercial cultivars (Poyo, Williams, Americani and Petite naine) of the Cavendish subgroup were challenged separately with *R. similis* and *P. coffeae*. Each combination of cultivar and nematode was represented by six replicate pots in the first screening and by five replicate pots in the second screening. For both screenings, each replicate pot contained one plant and was inoculated with 400 nematodes (adults and/or juveniles). Roots were removed from the soil 45 days after inoculation, weighed (fresh weight) and placed in a mist chamber for 2 weeks for nematode extraction (Seinhorst, 1950). The extracted nematodes were counted and used to determine the number per g of root and multiplication rate (final number of nematodes in roots divided by the initial inoculum).

Table 1
Nematode densities in roots and multiplication rates of *Radopholus similis* on selections or cultivars of *Musa* spp. (genome AAA) 45 days after inoculation with 400 nematodes per plant under controlled conditions.

Cavendish cultivar	Screening 1		Screening 2	
	R. similis/g fresh root	Multiplication rate	*R. similis*/g fresh root	Multiplication rate
MA13[a]	1008 ± 225	37.4	782 ± 88 a	21.5 a
L93[a]	1174 ± 292	48.0	997 ± 196 ab	30.4 ab
L33[a]	–	–	1306 ± 298 abcde	32.7 ab
MB2[a]	–	–	1127 ± 175 abc	34.3 abc
L35[a]	–	–	1197 ± 170 abcd	36.3 abcd
NE1[a]	–	–	1413 ± 189 abcdeef	41.3 bcd
L902[a]	–	–	1538 ± 199 bcdef	41.8 bcd
Poyo[a]	1063 ± 436	37.5	1447 ± 159 abcdef	42.0 bcd
Jobo[a]	–	–	1562 ± 233 bcdef	45.5 bcd
GB1[a]	–	–	1672 ± 256 bcdef	47.7 bcd
Americani[a]	991 ± 239	42.0	1905 ± 271 ef	50.5 cd
Petite Naine[a]	1591 ± 395	56.9	1786 ± 179 cdef	52.2 d
L52[a]	1219 ± 289	50.8	2004 ± 222 f	53.2 d
Williams[b]	1292 ± 280	52.1	1858 ± 250 def	53.6 d
L852[a]	986 ± 136	34.6	–	–
Zechalv[b]	1545 ± 199	52.9	–	–
L835[a]	1371 ± 322	57.3	–	–

Values are the mean of the nematode densities of 5–6 replicates: means in a column followed by the same letter do not differ ($P = 0.05$) according to a Duncan's multiple range test on [ln+1] transformed data.
Multiplication rate = total number of *R. similis* in the root system/400 (the initial inoculum level).
[a] Plants obtained from the tissue culture laboratory Vitropic (Montpellier, France).
[b] Plants obtained from the tissue culture laboratory Rahan Meristem (Israel).

2.2. Field trial

A field trial was conducted at Rivière Noire, in the north of Martinique, on the eastern side of the Pelé volcano at an elevation of 260 m. The soil was an Andosol that had developed on volcanic ashes. This sandy soil (78–82% sand, 8–11% silt and 10–12% clay) had a pH of 5.7 and contained 8.6% organic matter. Soils of this kind are characteristic of elevated areas in Martinique (rainfall > 4000 mm/year), where they represent about 25% of the banana plantations. The experimental design was a randomized complete block with 10 replicates and 19 cultivars. A new hybrid, FB920, that previously exhibited resistance to plant-feeding nematodes (Quénéhervé et al., 2009a) and diseases (Salmon et al., 2005) was included. Each plot consisted of three plants of one cultivar that occupied a surface area of about 16 m^2 (density of 1905 plants·ha^{-1}) that were surrounded by a belt of border plants (cv. Gal); the border plants minimized the interaction between cultivars of different sizes (giant, average and dwarf selections). The 19 banana cultivars were planted in July 2004. Roots were sampled between 5 and 30 cm depth, close to the fruit-bearing plant in mid-March 2005 (when at least 50% of the plants had flowered), October 2005 and January 2006. The first sampling date was representative of the first production cycle and the second and third dates were representative of the second production cycle; one date could not be used for the second production cycle because flowering had become asynchronous. Nematodes were extracted from roots (a 50-g subsample, fresh weight) in a mister as described for the growth chamber trials. Nematode numbers were determined with a counting dish and a stereomicroscope and were expressed as nematode densities per 100 g of fresh roots.

Banana plants were measured (plant height and pseudostem circumference at 1 m in height) at the flowering stage (opening of the last hand) for each production cycle. Yield parameters (bunch weight, percentage of harvested bunches, mortality and duration of

vegetative and productive cycles) were recorded for each production cycle.

All data were analyzed using a Fisher's test in an analysis of variance. Nematode densities were transformed (ln +1) before mean comparison. When results were significant ($P \leq 0.05$), mean values for cultivars were compared with a Duncan's multiple range test. We tested the relationship between screening data and field trial data for both *R. similis* and *P. coffeae* by calculating Pearson's correlation coefficients using the log-transformed nematode densities for each cultivar.

The entire database was comprised of 720 samples, with 5,784,685 specimens of plant-feeding nematodes identified to species, and 1710 horticultural measurements.

3. Results

3.1. Growth chamber trials

For *R. similis* in the first screening test, neither densities per g of root nor multiplication rates significantly differed among cultivars (Table 1). Densities per g of root ranged from 986 (cv. L852) to 1591 (cv. Petite Naine), and multiplication rates ranged from 34.6 (cv. L852) to 57.3 (cv. L835). In the second screening test, densities of *R. similis* per g of root and multiplication rates differed among cultivars (Table 1); densities per g of root ranged from 782 (cv. MA13) to 2004 (cv. L52), and multiplication rates ranged from 21.5 (cv. MA13) to 53.6 (cv. Williams).

For *P. coffeae* in the first screening test, densities per g of root ranged from 957 (cv. L52) to 2015 (cv. Williams) but did not significantly differ among cultivars (Table 2). Multiplication rates did significantly differ in the first screening, and ranged from 24.9 (cv. MA13) to 69.5 (cv. Williams). In the second screening test, densities of *P. coffeae* per g of root and multiplication rates differed among cultivars; number per g of root ranged from 1111 (cv. MA13) to 2715 (cv. GB1), and multiplication rates ranged from 29.6 (cv. MA13) to 61.0 (cv. GB1).

Table 2
Nematode densities in roots and multiplication rate of *Pratylenchus coffeae* on selections or cultivars of *Musa* spp. (genome AAA) 45 days after inoculation with 400 nematodes per plant under controlled conditions.

Cavendish cultivar	Screening 1		Screening 2	
	P. coffeae/g fresh root	Multiplication rate	*P. coffeae*/g fresh root	Multiplication rate
MA13[a]	1044 ± 300	24.9 a	1111 ± 136 a	29.6 a
L52[a]	957 ± 214	29.0 a	1742 ± 240 ab	33.8 ab
L852[a]	1138 ± 275	32.4 ab	–	–
Petite Naine[a]	1182 ± 228	36.3 ab	1463 ± 181 ab	37.9 ab
L835[a]	1317 ± 199	37.0 ab	–	–
Zechalv[b]	1249 ± 116	40.0 ab	–	–
Poyo[a]	1652 ± 220	45.3 ab	1299 ± 215 a	43.3 abc
Americani[a]	1695 ± 511	48.4 abc	1596 ± 155 ab	47.5 abcd
L93[a]	1641 ± 217	53.5 bc	2214 ± 208 bc	62.4 d
Williams[a]	2015 ± 216	69.5 c	1834 ± 170 ab	57.4 cd
L35[a]	–	–	1638 ± 193 ab	33.9 ab
L33[a]	–	–	1685 ± 231 ab	34.6 ab
L902[a]	–	–	1738 ± 341 ab	34.8 ab
MB2[a]	–	–	1, 366 ± 283 ab	37.9 ab
NE1[a]	–	–	1277 ± 108 a	45.2 abcd
Jobo[a]	–	–	2222 ± 310 bc	52.0 bcd
GB1[a]	–	–	2715 ± 429 c	61.0 cd

Values are the mean of the nematode densities of 5–6 replicates: means in a column followed by the same letter do not differ ($P = 0.05$) according to a Duncan's multiple range test on [ln+1] transformed data.
Multiplication rate = total number of *P. coffeae* in the root system/400 (the initial inoculum level).
[a] Plants obtained from the tissue culture laboratory Vitropic (Montpellier, France).
[b] Plants obtained from the tissue culture laboratory Rahan Meristem (Israel).

3.2. Field trial—nematode infestation

At flowering in the first cycle, densities of the two endoparasitic nematodes, *R. similis* and *P. coffeae*, per 100 g of root significantly differed among cultivars (Table 3). Densities of *R. similis* were relatively low (<1900/100 g) for hybrid FB920 and Cavendish cv. MA13 and relatively high (>9000/100 g) for cvs. Petite Naine, L93, and William. Densities of *P. coffeae* did not significantly differ among the Cavendish cultivars but were significantly lower in the hybrid FB920 Good correlation was found between density results from laboratory and field trial with significant Pearson's coefficients equal to 0.60 for *R. similis* ($P = 0.017$) and to 0.87 for *P. coffeae* ($P < 0.001$).

Densities of *Helicotylenchus multicinctus* (from 680 up to 2731 individuals) and *Meloidogyne* sp. (from 2315 up to 8892 juveniles) per 100 g of root did not statistically differ among the cultivars.

Because the infestation of roots by *R. similis* and *P. coffeae* was severe during the first production cycle (in the absence of any chemical treatment), the nematode densities in the second cycle were not compared.

3.3. Field trial—horticultural results

Severe toppling during the first production cycle resulted in low percentage of bunches harvested for all Cavendish cultivars; these values ranged from 3% (cv. L33) to 63% (cv. NE1) (Fig. 1). In contrast, more than 90% of the bunches of the hybrid FB920 were harvested in the first production cycle (Fig. 1). Delay in flowering of banana plants was rare during the first cycle.

The percentages of harvested bunches during the second cycle were still low for the Cavendish cultivars and ranged from 11% (cv. L93) to 34% (cv. GB1). This percentage was also small (17%) for the hybrid FB920 (Fig. 2). For all Cavendish cultivars, delays in the

Table 3
Nematode densities in roots at the first flowering period of *Musa* spp. (genome AAA) cultivars and of the synthetic hybrid FB920 in the field trial at Rivière Noire, Martinique.

Cultivar	Nematode infestation (number/100 g fresh roots)			
	Radopholus similis	*Pratylenchus coffeae*	*Helicotylenchus* spp.	*Meloidogyne* spp.
Synthetic hybrid				
FB920[c]	1130 c	453 b	1076	2315
Cavendish cultivars				
MA13[a]	1851 b	1823 a	1328	4466
Zelig[b]	5710 ab	3555 a	1610	3756
Jobo[a]	8280 ab	3296 a	1276	3573
Poyo[a]	4561 ab	1748 a	1230	2433
L35[a]	6375 ab	4141 a	1574	3476
L33[a]	4628 ab	3265 a	2731	6299
GB1[a]	4011 ab	3117 a	2186	3086
MB2[a]	4178 ab	3230 a	1357	3743
L902[a]	6239 ab	2541 a	1611	8892
L52[a]	4968 ab	3470 a	1458	7202
FF[a]	5920 ab	2132 a	1355	6641
Gall[b]	6565 ab	1651 a	2145	5490
Americani[a]	6037 ab	2424 a	1458	4450
NE1[a]	5577 ab	3815 a	1383	3018
Jaffa[b]	8824 ab	5543 a	1746	3744
William[a]	11,309 ab	3303 a	1725	3410
Petite Naine[a]	9310 a	4113 a	1009	6592
L93[a]	10,458 a	3496 a	680	2322

Values are the mean of the nematode densities of 10 replicates: means in a column followed by the same letter do not differ ($P = 0.05$) according to a Duncan's multiple range test on [ln+1] transformed data.
[a] Plants obtained from the tissue culture laboratory Vitropic (Montpellier, France).
[b] Plants obtained from the tissue culture laboratory Rahan Meristem (Israel).
[c] Plants obtained from CIRAD (Montpellier, France).

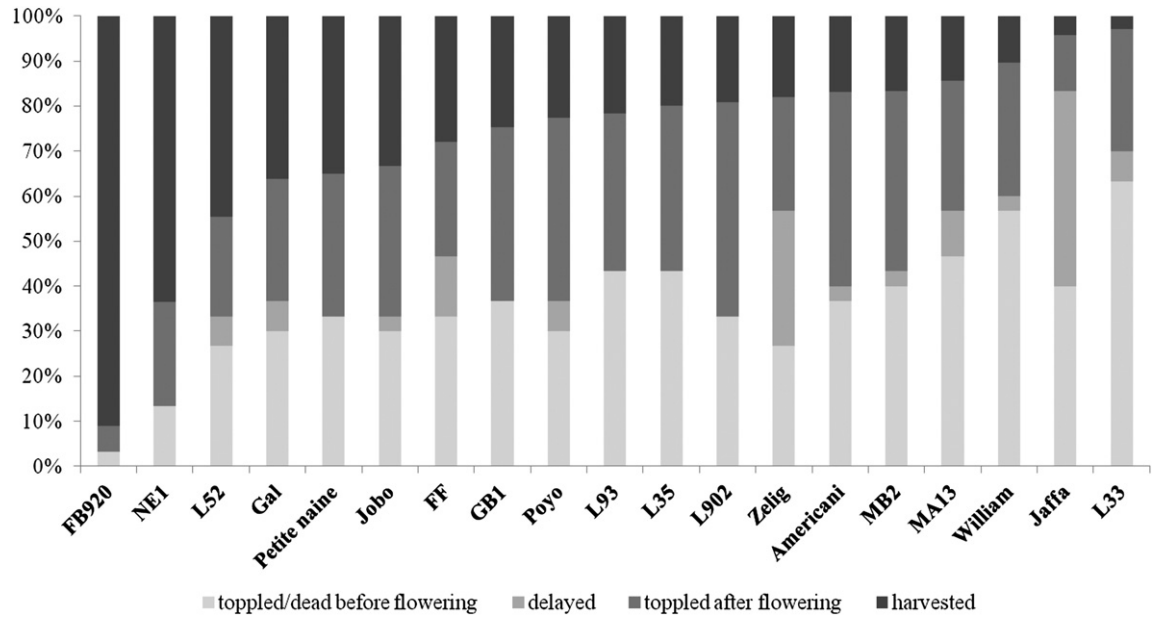

Fig. 1. Proportional yield characteristics for each of the 18 banana cultivars (*Musa* spp. genome AAA) and one synthetic hybrid FB920 entry during the second production cycle of the field trial at Rivière Noire, Martinique.

vegetative and productive stages were the principal causes of non-harvest during this second cycle; the percentage of plants with delayed development ranged from 31% (cv. GB1) to 66% (cv. L93) (Fig. 2). For hybrid FB920, in contrast, toppling was the main reason why banana bunches were not harvested in the second production cycle (Fig. 2).

The duration interval from planting to first flowering (PFI) significantly differed among the Cavendish cultivars and ranged from 263 days (cv. L35) to 316 days (cv. Jaffa) (Table 4). The PFI was shorter for the synthetic hybrid FB920 than for most Cavendish cultivars for the first production cycle (Table 4) and was shorter for the synthetic hybrid FB920 than for all Cavendish cultivars for the second cycle (Table 5). The duration interval from planting to harvesting after the first flowering (PHI) significantly differed among the Cavendish cultivars and ranged from 332 days (cv. MA13) to 383 days (cv. Americani).

Height and circumference parameters of banana plants measured at the second flowering confirmed the significant dwarfism of the cv. Petite Naine and the taller size of the cv. Poyo, with all other Cavendish cultivars ranging between these extremes (from 155 to 261 cm high) (Table 5). Compared to these Cavendish cultivars, the new hybrid FB920 was taller in both production cycles but had a smaller pseudostem circumference in the second cycle (Table 5).

The average weights of bunches harvested during the first cycle significantly differed among the Cavendish cultivars and ranged

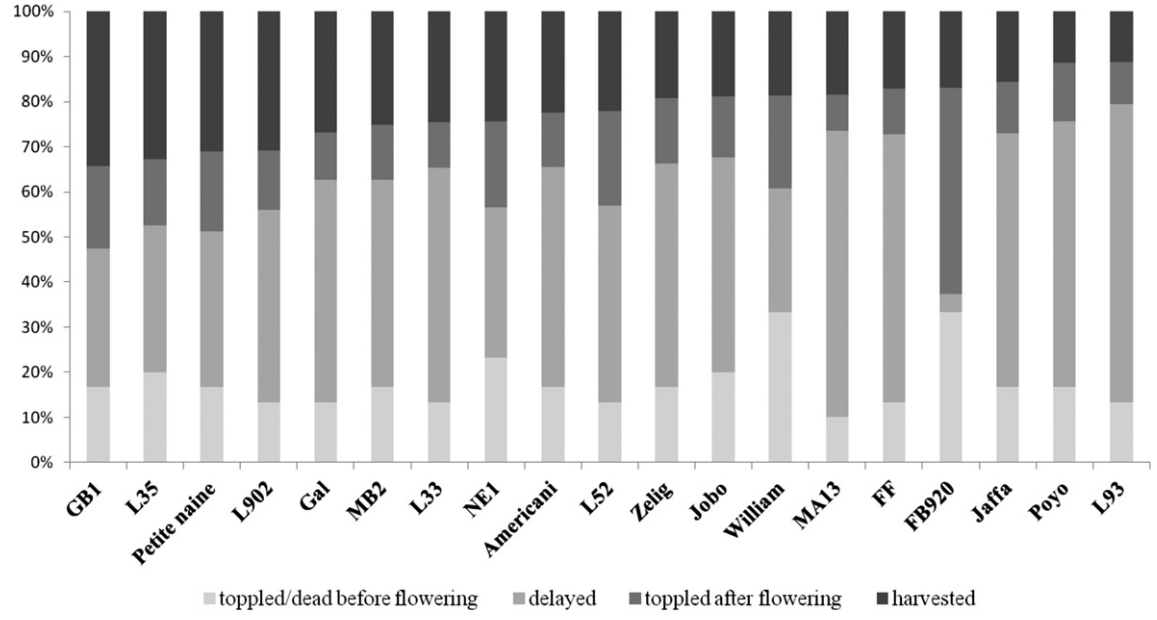

Fig. 2. Proportional yield characteristics for each of the 18 banana cultivars (*Musa* spp. genome AAA) and one synthetic hybrid FB920 entry during the second production cycle of the field trial at Rivière Noire, Martinique.

Table 4
Horticultural characteristics of *Musa* spp. (genome AAA) cultivars and of the synthetic hybrid FB920 during the first production cycle of the field trial at Rivière Noire, Martinique.

Cultivar	PFI (days)	PHI (days)	Plant height (cm)	Plant circumference (cm)	Bunch weight (kg)
Synthetic hybrid					
FB920	245 c	332 b	213.3 a	30.9 bcd	11.4 b
Cavendish cultivar					
MA13	301 a	332 b	138.8 cd	30.8 bcd	18.5 ab
Zelig	295 a	358 ab	139.4 bcd	31.8 abcd	13.1 b
Jobo	287 ab	364 a	133.5 d	29.9 d	17.7 ab
Poyo	284 ab	361 a	146.2 bcd	30.3 cd	19.9 ab
L35	263 bc	335 ab	159 bcd	36.5 abcd	19.8 ab
L33	289 ab	359 ab	138.3 cd	30.9 bcd	20.2 ab
GB1	276 ab	340 ab	172.7 b	37.5 a	22 a
MB2	281 ab	368 a	149.0 bcd	32.7 abcd	21.6 a
L902	280 ab	366 a	161.9 bcd	36.2 abcd	16.6 ab
L52	287 ab	335 ab	169.0 bc	37.5 a	19.8 ab
FF	302 a	347 ab	144.8 bcd	31.3 abcd	16 ab
Gal	277 ab	345 ab	139.5 bcd	32.7 abcd	16.9 ab
Americani	292 a	383 a	148.0 bcd	31.7 abcd	9.6 b
NE1	281 ab	340 ab	148.1 bcd	33.3 abcd	16.6 ab
Jaffa	316 a	373 a	165.2 bcd	37.5 ab	21.8 a
William	279 ab	361 a	168.7 bc	36.8 abc	19.5 ab
Petite Naine	281 ab	345 ab	131.8 d	36.3 abcd	16.5 ab
L93	291 a	347 ab	140.2 bcd	31.4 abcd	15.2 ab

Values are the means of various numbers of replicates; the number of replicates differs among the cultivars because of banana plant mortality and the delayed duration of vegetative and productive cycles; means in a column followed by the same letter do not differ ($P = 0.05$) according to a Duncan's multiple range test.
PFI: plantation −flowering interval (in days); PHI: plantation −harvest interval (in days).

from 9.6 kg (cv. Americani) to 22 kg (cv. GB1) (Table 4). The average bunch weight for hybrid FB920 was only 11.4 kg, which was significantly lower than that of most Cavendish cultivars. Because of the low number of harvested plants during the second cycle, our dataset was limited and did not allow detecting significant differences among bunch weights (Table 5).

Table 5
Horticultural characteristics of *Musa* spp. (genome AAA) cultivars and of the synthetic hybrid FB920 during the second production cycle of the field trial at Rivière Noire, Martinique.

Cultivar	PFI (days)	PHI (days)	Plant height (cm)	Plant circumference (cm)	Bunch weight (kg)
Synthetic hybrid					
FB920	475 b	592	320.3 a	39.1 d	14.4
Cavendish cultivar					
MA13	600 a	622	192.1 def	44.2 bcd	26.5
Zelig	573 a	648	195.3 cde	49.5 ab	9.9
Jobo	601 a	623	214.5 cde	47.2 abc	25
Poyo	600 a	609	261.1 b	48.4 abc	28.6
L35	562 a	613	202.4 cde	47.1 abc	19.8
L33	593 a	637	200.5 cde	46.3 abc	19.6
GB1	582 a	630	213.3 cde	48.1 abc	27.3
MB2	584 a	651	199.3 cde	45.7 abc	9.2
L902	567 a	626	204.4 cde	48.3 abc	19
L52	567 a	637	205.7 cde	48.1 abc	13.9
FF	550 a	633	192.8 de	44.7 bc	21.4
Gal	600 a	634	190.6 ef	47.5 abc	12.9
Americani	602 a	651	239.2 bc	43.8 cd	12.5
NE1	576 a	651	191.1 def	46.9 abc	14.7
Jaffa	597 a	633	222.8 cd	53.2 a	30.8
William	569 a	633	207.9 cde	46.3 abc	25
Petite Naine	586 a	627	155.6 f	47.6 abc	15.5
L93	574 a	616	202.5 cde	47.4 abc	19

Values are the means of various numbers of replicates; the number of replicates differs among the cultivars because of banana plant mortality and the delayed duration of vegetative and productive cycles; means in a column followed by the same letter do not differ ($P = 0.05$) according to a Duncan's multiple range test.
PFI: plantation −flowering interval (in days); PHI: plantation −harvest interval (in days).

4. Discussion

One of the main ways to reduce the global use of pesticides in intensive agriculture is to plant cultivars with genetic resistance to pests or diseases. Plant-feeding nematodes are important agricultural pests worldwide, and the search for varietal resistance and/or tolerance to damaging species involves numerous economically important crops (Starr et al., 2002). Banana is no exception in this regard, and there has been increasing interest in breeding resistance or tolerance to nematodes (Quénéhervé et al., 2009a, 2009b; Lorenzen et al., 2010) and also to other diseases and pests, such as black Sigatoka (Bakry et al., 2009) and the black weevil (Ortiz et al., 1995). Despite considerable advances in the optimization of cultural practices, intensively managed banana fields still require frequent nematicide applications to control *R. similis* and *P. coffeae* (Quénéhervé, 2009).

Currently, most dessert bananas cultivated for export belong to the Cavendish subgroup (*Musa* spp. genome AAA) and are not thought to differ in their nematode resistance and tolerance; all are considered to be highly susceptible to or intolerant of plant-feeding nematodes (Champion, 1963; Stover, 1972). Until the current study, research had not been conducted to investigate cultivar-related susceptibility to nematodes within this Cavendish subgroup. Our study was aimed to detect possible differences in susceptibility to nematodes among various cultivars of the Cavendish subgroup (obtained from mass field selections in Martinique and Guadeloupe) by conducting two screenings under controlled conditions and one field trial. A new synthetic hybrid, FB920, was also included in the field trial to validate prior results (Tixier et al., 2008) concerning its resistance to nematodes.

Although in our study all Cavendish cultivars were susceptible to both *R. similis* and *P. coffeae* under controlled and field conditions, susceptibility differed among cultivars. A main finding was that cv. MA13 was significantly less susceptible to *R. similis* than other selected cultivars in both the growth chamber and field. In contrast, some variation in susceptibility to *P. coffeae* was evident in the growth chamber but was not statistically significant in the field. Differences in susceptibility to *Meloidogyne* spp. and *H. multicinctus* were not detected.

Results from the growth chamber trials and the field trial were generally similar and suggested that cv. MA13 is less susceptible than other selections and commercial cultivars to *R. similis* and *P. coffeae*. Compared to cv. MA13, commercial cvs. Petite Naine and Williams were relatively susceptible to *R. similis* and *P. coffeae*. Given the repeatability of the measurements and the correlation between the results from the growth chamber and field trials, young, *in vitro*-propagated plants appear to be useful for the reproducible screening for susceptibility of banana cultivars to nematodes. The use of such plants in selection and breeding programs should facilitate the rapid assessment of resistance and/or tolerance in the laboratory before field experiments are conducted.

Consideration of both nematode densities in roots and horticultural results provided complementary information on the cultivar-related susceptibility to nematodes. We documented considerable damage (e.g., toppling, delayed flowering, reduced yield) to all Cavendish cultivars due to severe nematode infestations. During both production cycles, densities of *R. similis* and *P. coffeae* frequently exceeded 1000 individuals per 100 g of fresh roots, which is the usual threshold level for which a control method is advised in intensive banana cultivation (Lassoudière, 2007), especially in countries with frequent, strong winds such as those in the Caribbean. These severe nematode infestations greatly reduce the nutrient assimilation and the anchorage of banana roots, which explains the high numbers of toppled plants or plants with delayed development in both production cycles. High nematode densities

cause damages that accumulate over time and that range from a hidden, initial lengthening of the vegetative phase, which is often unrecognized, to the irreversible reduction of plantation longevity (Quénéhervé, 1993). In our study, the banana plants were not guyed (as is usually done for banana cultivated for export) because we wanted to observe the different damage levels (guying would reduce the effects of poor anchorage) and we wanted to mimic the absence of guying typical of smallholder production of bananas and plantains. In only two cycles, our field trial confirmed that nematodes initially increase the duration of the vegetative phase and then reduce yield such that the field is likely to be abandoned unless appropriate nematode management measures are instituted. Although the field trial did not include control plots with reduced nematode densities, previous research has demonstrated that when nematodes are controlled, the development delays, toppling, and reduced yields reported here do not occur (Gowen et al., 2005).

Nematode root infestation was lower in cv. MA13 than in the other selections and cultivars but cv. MA13 still incurred significant damage because of the high nematode densities in the soil and the absence of guying during gusty winds. MA13, however, remains an interesting choice among Cavendish cultivars with usual cultural practices (Chabrier and Quénéhervé, 2003) because of its reduced susceptibility to nematodes.

FB920 is a new, synthetic, triploid hybrid from the *acuminata* group (genome AAA); it is resistant to yellow Sigatoka (*Mycosphaerella musicola*) and black leaf streak disease (*Mycosphaerella fijiensis*) and is tolerant of lesion nematodes (Salmon et al., 2005; Quénéhervé et al., 2009b). Field data and modeling of pest dynamics in banana fields indicated that FB920 has greater resistance than Cavendish cultivars to *R. similis* (Tixier et al., 2008), highlighting the potential of FB920 for reducing long-term pesticide applications. The result that FB920 reduced densities of *R. similis* and *P. coffeae* was largely confirmed in our field trial. In contrast to the Cavendish cultivars, most FB920 plants experienced reduced toppling and were harvested during the first cycle. During the second cycle, however, FB920 incurred substantially toppling mainly due to its tallness and the gusty winds. Unlike all the Cavendish cultivars, only a low number of FB920 plants showed delayed development, confirming its resistance to nematodes. Despite the good organoleptic and physico-chemical properties of its banana fruits (Bugaud et al., 2009), some FB920 horticultural characteristics including large plant size, small bunch size, lack of bunch conformity and post-harvest problems (Bugaud, pers. communication) will likely prevent its commercial development. These characteristics of FB920, however, should not be important problems for smallholder production and local consumption.

5. Conclusion

The different levels of susceptibility to nematodes documented here suggest the possibility of selection for nematode tolerance within the Cavendish subgroup. The correlation between results obtained from the growth chamber trials and the field trial indicates that growth chamber screening with young *in vitro*-propagated plants is a good predictor of cultivar-related susceptibility to nematodes and should facilitate screening and breeding programs. Although resistance and/or tolerance to nematodes and other pests and diseases is an important characteristic of new cultivars, such cultivars and new synthetic banana hybrids must not have undesirable characteristics. For example, although hybrid FB920 is resistant to nematodes and several diseases, it is also characterized by relatively weak production and a tendency to topple because of its height. As noted earlier, these problems will likely prevent its commercial development. Still, its resistance to Sigatoka diseases and nematodes should make FB920 very valuable to small producers of dessert bananas worldwide. Because the Cavendish subgroup still represents the current 'standard' with respect to dessert bananas for export, our finding that a selection within that subgroup, cv. MA13, has reduced susceptibility to plant-feeding nematodes is significant; cv. MA13 warrants additional research. Most of the countries producing bananas are now trying to reduce their use of pesticide due to environmental and human safety using diverse pest management methods (Quénéhervé, 2009). Therefore, any feature, which can reduce nematode damage, should contribute to the global reduction of pesticide usage.

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