Evaluation of parental banana varieties and new hybrids regarding potential yield and resistance to Sigatoka and nematode in India

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Evaluation of parental banana varieties and new hybrids regarding potential yield and resistance to Sigatoka and nematode in India.

Abstract — Introduction. Banana and plantains rank fourth among the most important food crops of the world, and India holds the position of the largest producer. A study was undertaken to evaluate the potential yield of new synthetic banana hybrids based on bunch weight and fruit quality. It also assessed the nematode damage, Sigatoka leaf spot disease and parthenocarpy stability. **Materials and methods**. Thirteen new hybrids and eleven parental bananas of dessert type were used and evaluated in the first vegetative generation. Plant growth parameters, viz., pseudostem height and girth, number of leaves, and suckers per plant were measured at the flowering stage and the damage of roots by nematode and intensity of the Sigatoka leaf spot disease were assessed at the harvest stage. The content of total soluble solids, and reducing, non-reducing and total sugars in the fruit was estimated. **Results**. All the hybrids exhibited parthenocarpy and there was no reversion from parthenocarpy to non-parthenocarpy. The plant height and girth and the leaf number varied among the hybrids significantly. The maximum bunch weight was recorded for H-212 (ABB) which showed a regular suckering habit, very high content of total soluble solids and reducing sugars, and more leaves without leaf spot infection than the other hybrids; moreover, H-212 is a female sterile dessert-type banana and it is tolerant to nematode and resistant to Sigatoka. The reproduction factor of *Radopholus similis* on H-211 (AA), H-213 (ABB) and H-02-01 (AA) was significantly lower than on H-203 (AA), H-209 (ABB) and H-205 (AA). **Conclusions**. Our studies distinguished one triploid ABB hybrid H-212 with high yield and fruit quality, and no sanitary problems; it can be released for commercial cultivation to banana growers.

India / *Musa* (bananas) / *Musa* (plantains) / variety trials / yield components / quality / fruits / disease resistance / blotches / nematodes

Évaluation de bananiers parentaux et de nouveaux hybrides vis-à-vis de leurs rendements potentiels et de leur résistance à la cercosporiose et aux nématodes, en Inde.

Résumé — Introduction. Les bananiers et plantains sont en quatrième place des principales productions agricoles du monde, et l'Inde en est le plus grand producteur. Une étude a été entreprise pour évaluer le rendement potentiel de nouveaux hybrides de bananiers en se basant sur le poids de régime et la qualité du fruit. Elle a également évalué les dommages imputables aux nématodes et à la cercosporiose, ainsi que la stabilité de la parthénocarpie des génotypes. **Matériel et méthodes**. Treize nouveaux hybrides et onze parents de bananiers de type dessert ont été évalués en première génération végétative. Des paramètres de croissance de la plante, tels que la taille et le périmètre du pseudo-tronc, et le nombre de feuilles et de rejets par plant, ont été mesurés au stade de floraison et les dommages sur racines dus aux nématodes ainsi que l'effet de la cercosposriose sur les feuilles ont été évalués au stade de la récolte. La teneur des fruits en solides solubles totaux, sucres réducteurs, non réducteurs et totaux a été estimée. **Résultats**. Tous les hybrides ont montré de la parthénocarpie et il n'y pas eu de réversion de cette parthénocarpie. Au sein des hybrides, la hauteur et la circonférence de la plante, ainsi que le nombre de feuilles ont varié significativement. Le poids de régime maximum a été enregistré pour l'hybride H-212 (ABB) qui a eu un comportement régulier pour la production de rejets, une teneur très élevée en solides solubles totaux et en sucres réducteurs, et plus de feuilles saines que les autres hybrides ; par ailleurs, H-212 est un bananier femelle stérile de type dessert, il est tolérant aux nématodes et résistant à la cercosporiose. Les facteurs de reproduction de *Radopholus similis* sur H-211 (AA), H-213 (ABB), H-02-01 (AA) ont été significativement inférieurs à ceux sur H-203 (AA), H-209 (ABB) et H-205 (AA). **Conclusions**. Nos études ont mis en évidence l'hybride H-212, triploïde ABB, ayant de hauts rendements, des fruits de bonne qualité et aucun problème sanitaire. Il pourrait être proposé aux plantations industrielles de bananiers.

Inde / *Musa* (bananes) / *Musa* (plantains) / essai de variété / composante de rendement / qualité / fruits / résistance aux maladies / cercosporiose / nématode

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1. Introduction

Banana and plantains are fourth among the most important food crops in the world. India, where around 200 cultivars of diploid and triploid types are available [1], is the largest producer of banana (16.81 Mt) followed by Ecuador (8.03 Mt). The diploid banana cultivars available in India are reported to produce poor bunch weight. Therefore the triploid bananas are cultivated on a large scale for commercial purposes. Apart from India, triploid bananas are also cultivated in other Asian, African and American countries. Nevertheless, in India as in other countries, commercial cultivars are being affected by plant parasitic nematodes, *Fusarium* wilt disease and Sigatoka leaf spot disease (*Mycosphaerella musicola* Leach).

The bananas cultivated in soils of India are being infested by three major species of nematode, viz., *Radopholus similis, Pratylenchus coffeae* and *Helicotylenchus multicinctus* [2]. The nematode and Sigatoka leaf spot damage in the commercial cultivars causes yield loss of up to 62% and 60%, respectively, in the banana production [3]. These problems are currently being controlled by using nematicides and fungicides but these chemicals leave a lot of residues in the soil and fruits. Hence, developing new banana cultivars with multiple resistances to nematode and Sigatoka leaf spot has become imperative for the banana breeders of the world. Nevertheless, banana breeding has been limited due to its triploid nature, parthenocarpy and sterility factors. However, despite these breeding barriers, breeding programmes were started at the Honduran Federation for Agriculture Investigation, Honduras (FHIA), and International Institute for Tropical Agriculture, Nigeria (IITA); they released many plantain hybrids of tetraploids, since the breeders could not develop triploids that can substitute existing commercial cultivars. Developing tetraploids in banana breeding is very easy and they are 90% akin to the female parents. Many of the new varieties released from the FHIA and ITTA are plantains.

In India, for the development of the new banana hybrids, banana breeding was initiated to develop male parents with fertile pollen, high bunch weight, and resistance to nematode and Sigatoka leaf spot. During this early phase, many male parents were developed with either high bunch weight with poor pollen or low bunch weight with high pollen production but resistant to nematode and Sigatoka leaf spot. During the second phase of the breeding programme, many banana hybrids were developed with natural diploids and synthetic diploids and they were first screened for parthenocarpy fruit bunch character in the seedling generation. Thirteen parthenocarpy hybrids were selected.

In the banana breeding programme, the breeders could observe the change in parthenocarpy fruit development to non-parthenocarpy fruits, but only parthenocarpy fruits are edible in dessert-type bananas. Therefore the thirteen new banana hybrids of dessert type were evaluated for their stability in yield, parthenocarpy, and resistance to the nematode, *R. similis,* and to the Sigatoka leaf spot disease in the first vegetative generation.

2. Materials and methods

Our study was conducted at the Department of Fruit Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu State, India, from June 2000 to February 2002.

Coimbatore is located at alt. 426.72 m, lat. 11° N, long. 77° E. The temperature varies from (31.11 to 21.90) °C; relative humidity is of 85.17% during morning hours and 49.30% during noon hours; total rainfall was 697.96 mm per year during the period of the experiment. The soil texture of the experimental location is sandy clay loam (56.30% sand, 37.80% clay and 11.30 % silt).

The materials of the study consisted of six diploid AA hybrids, three AB diploid hybrids, two AAB triploids, two ABB triploids and eleven parental banana clones of dessert type (*table I*).

2.1. Experiment characteristics

The hybrids were planted in a randomised block design with five replications in a nematode-infested field.

Since culture of the leaf spot pathogen *Mycosphearella musicola* (perfect stage: *Cercospora musae* Leach) was not possible,

Table I.
Phenological characters of 24 banana hybrids or parents observed at the shooting stage.

Hybrid with parentage or parents	Genome	Pseudostem height (cm)	Pseudostem girth (cm)	No. leaves / plant	No. suckers / mat	Days to flowering	Days to harvest	No. seeds / fruit	No. pollen / anther
H-203: (Matti × Anaikomban) × Ambalakadali	AA	101	28.20	13.10	2.10	290	405	0.52	12000
H-204: (Matti × Anaikomban) × Pisang Lilin	AA	224	56.31	17.07	4.20	191	363	0.48	16000
H-205: (Matti × Anaikomban) × Ambalakadali	AA	187	38.40	13.21	5.17	381	504	0.33	8000
H-208: (Matti × Namarai) × Anaikomban	AA	306	68.11	17.22	7.01	255	375	0.69	10000
H-02-01: Ambalkadali × Anaikomban	AA	187	46.00	14.04	4.40	250	365	1.00	8000
H-211: (Bareli Chinia × Pisang Lilin × Robusta) × Pisang Lilin	AA	290	64.42	18.10	6.21	203	297	–	10000
H-02-08: (Bareli Chinia × Pisang Lilin × Robusta) × Eraichivazhai	AB	288	80.40	17.11	2.06	210	380	0.07	220
H-02-11: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	AB	226	60.70	15.31	2.03	124	270	–	–
H-02-12: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	AB	210	56.00	11.25	5.01	131	300	0.07	10100
H-209: (Bareli Chinia × Pisang Lilin × Robusta) × Ambalakadali	AAB	192	50.14	20.15	1.00	195	309	1.31	3010
H-210: (Bareli Chinia × Pisang Lilin × Robusta) × Anaikomban	AAB	185	48.23	15.40	2.17	258	387	1.50	8550
H-212: Karpooravalli × Pisang Lilin	ABB	311	66.60	20.14	7.24	270	392	–	110
H-213: Karpooravalli × Pisang Lilin	ABB	335	70.20	18.44	5.30	228	363	0.09	2100
Ambalakadali	AA	216	54.50	15.28	10.10	258	346	–	11850
Anaikomban	AA	211	51.20	14.30	5.24	177	303	–	10500
Pisang Lilin	AA	126	31.50	10.35	3.10	177	289	–	14200
Eraichivazhai	AA	204	48.50	15.40	3.11	256	380	–	11700
H-59: (Matti × Anaikomban)	AA	230	49.21	13.50	9.17	362	479	–	46300
H-65: (Matti × Anaikomban)	AA	253	58.25	11.10	3.27	404	534	–	3450
H-66: (Matti × Pisang Lilin)	AA	231	57.00	13.20	6.37	240	367	–	34050
H-89: (Matti × Namarai)	AA	268	29.30	9.50	2.02	270	392	–	8900
H-110: (Matti × Tongat)	AA	141	36.35	13.20	3.03	236	347	–	35425
H-201: (Bareli Chinia × Pisang Lilin × Robusta)	AB	153	39.40	13.45	5.11	177	289	–	425
Karpooravalli	ABB	368	84.00	13.45	3.13	330	473	–	–
Standard error deviation	–	21.20	16.10	4.00	2.12	27.42	24.13	–	–
Critical difference (p = 0.05)	–	42.33	32.00	8.12	4.30	54.96	48.50	–	–

banana breeders have screened the banana types against Sigatoka leaf spot under natural field conditions, utilising the guidelines for plot layout developed at INIBAP, France [4]. Based on their guidelines, the susceptible cultivar Rasthali (AAB) was planted in two rows between the plots.

Suckers of uniform size were selected. Superficial tissues along with roots not treated by nematicide and insecticide were removed and they were planted in a 30-cm^3 pit at a spacing of (1.8 × 1.8) m. The plants were irrigated with 20 L of water per day through a drip system, and NPK fertilisers [(110-35-330) g] were applied with the nitrogen and potassium at weekly intervals in 36 equal splits starting from the 9th week through a drip system with a fertigation unit.

The chemical, biological and cultural control measures against nematode and Sigatoka leaf spot were not taken up. Desuckering of plants was carried out at monthly intervals in order to encourage the growth of the mother plant. Phenological characters such as plant height, stem girth, number of leaves and suckers per plant were measured at shooting (flowering). The height of the pseudostem was measured from the junction of pseudostem and corm to the axil of the youngest leaf. The girth of the pseudostem was measured at 30-cm height from the junction of the pseudostem and corm. The total number of leaves present at shooting was counted. The sucker production and suckering habit of each hybrid was studied. The yield potential was studied by measuring the bunch weight, and number of hands and fingers in the bunch.

2.2. Analysis of fruit quality

To assess the fruit quality, the [pulp:peel] ratio, total soluble solids, reducing sugars, total sugars and non-reducing sugars were measured.

Fully ripe fruit was weighed and peeled; after weighing the peel, the pulp weight was calculated by the difference between the fruit weight and the peel weight, and the [pulp:peel] ratio was computed.

Total soluble solids were determined by using a Carl-Zeiss hand refractometer and it was expressed as a percentage after conversion at 21 °C.

The reducing sugars were estimated by the Nelson-Somogyi method [5]. The sugars in the known quantity of pulp were extracted with 80% ethanol by repeated centrifugation, and the supernatant was collected and evaporated. The known volume of water was added and 0.1 mL of the sample was removed, and the volume was made up to 2 mL. Then, 1 mL of alkaline copper tartrate reagent was added, the samples were cooled, and 1 mL of arsenomolybdic acid reagent was added. The samples were made up to 10 mL using distilled water and the colour development was read at 620 nm.

The total sugars were estimated by the anthrone method [5]. One mL of ethanol extract was reacted with 4 mL of the anthrone reagent and kept in a water bath for 10 min; the colour intensity was measured at 625 nm after cooling.

The non-reducing sugar content was derived by subtracting reducing sugar content from total sugar content.

2.3. Disease parameters

The infected leaves on each plant were observed at harvest and graded from 0 to 6 (*table II*) [6]. The infection index was calculated using the formula: infection index = [(number of leaves in each grade × the grade value) / (number of grades – 1)] × total number of leaves scored × 100.

The hybrids were categorised based on the observation of the youngest leaf spotted (YLS) [7], by following the scale: very susceptible when YLS is below 6.0; susceptible when YLS is between 6.0 and 9.0, or 6.0 and 8.5 if YL_{33}[1] < 11.5; resistant when YLS is between 9.1 and 9.9, or 8.6 and 9.9 if YL_{33} > 11.5; highly resistant when YLS ≥10.0 or if total functional leaves are inferior to YLS (with no matured spots).

2.4. Nematode parameters

Populations of *R. similis* in the soil at planting and harvest and in the roots at harvest were assessed. The soil samples were taken by 72 subsamples. The initial nematode

[1] YL_{33}: numerical leaf portion with more than one-third of leaf area killed by *Mycosphaerella musicola*.

Table II.
Value scale to assess the Sigatoka disease grade of the banana genotypes studied.

Grade of the disease	% of lamina with symptoms
0	0
1	Less than 1
2	1 to 5
3	6 to 15
4	16 to 33
5	34 to 50
6	51 to 100

population (Pi) in all the blocks was on average 297 individuals per 200 cm^3 of soil. Samples of 200 cm^3 of soil and 15 g of roots were collected from a 30-cm^3 sample of top soil, 25 cm from the the mother plant corm [7].

Roots were washed free of soil particles, then cut into small pieces, thoroughly mixed, and three aliquots of 10 mL collected from each plant were stained in boiling acid fuchsia lactophenol for population counts [8].

Nematodes from 200 g of soil from each plant were extracted by the Cobb's wet sieving and sedimentation technique for estimating the total nematode soil population [9]. The population threshold level was evaluated on a 1 to 5 scale, where 1 or immune corresponds to 0 nematode per g of roots; 2 or resistant corresponds to 1–50 nematodes·g^{-1} of soil; 3 or tolerant: 51–75 nematodes·g^{-1} of soil; 4 or susceptible: 76–100 nematodes·g^{-1} of soil; 5 or highly susceptible: > 100 nematodes·g^{-1} of soil [10]. The reproduction factor (RF = final nematode population / initial nematode population) [11] was determined for each hybrid and parent cultivar.

2.5. Statistical analysis

The data recorded on various characters were subjected to the Fisher's method of analysis of variance (ANOVA) and interpretations of data as given by Gomez and Gomez [12]. The level of significance used in the F and *t* tests was $p = 0.05$. Critical difference values were calculated whenever the F test was significant.

3. Results

3.1. Phenological characters

Among the characters studied, the pseudostem height and girth varied from (101 and 28.20) cm to (368.0 and 84.00) cm (*table I*). The Karpooravalli genotype showed the highest values. The pseudostem height and girth was high for H-213 and H-212 too, while H-203 recorded the lowest values and was also found to be lower than its parents H-59 and Ambalakadali.

Number of leaves per plant varied from 9.50 to 20.14; H-209 showed the highest value and H-89 the smallest value. Among the hybrids, H-209 and H-212 recorded the highest number of leaves, while the lowest was recorded in H-02-12. Seven hybrids (H-209, H-212, H-213, H-211, H-208, H-02-08 and H-204) were higher in number of leaves than Eraichivazhai, which registered the highest number of leaves among the parents. Number of suckers per plant varied from 1 to 10.10; Ambalakadali and H-209 genotypes showed, respectively, the highest and the smallest values. The number of suckers per plant was high in H-212 and low in H-209. None of the hybrids produced a higher number of suckers than the parental cv. Ambalakadali (*table I*).

3.2. Cycle duration

Among the 24 genotypes evaluated, number of days to flowering and harvest varied from 124 and 270 (for H-02-11) to 404 and 534 days (H-65), respectively (*table I*).

3.3. Yield and quality

The fruit bunch weight varied from (1.3 to 13.33) kg; H-203 and Karpooravalli genotypes showed the lowest and the highest values (*table III*). Among the thirteen hybrids studied, H-212 recorded the maximum bunch weight of 12.52 kg. However, its bunch weight was lower than its female parent (Karpooravalli) and higher than its male parent (Pisang Lilin). H-213 had the maximum bunch weight, and registered a moderate number of hands compared with its parents. Among the diploid hybrids evaluated, H-204 produced 11.60 kg bunch weight with the

Table III.
Bunch and quality traits of 24 banana hybrids or parents studied regarding their yield potential.

Hybrid with parentage or parents	Bunch weight (kg)	No. hands / bunch	No. fingers / bunch	Finger weight (g)	[Pulp:peel] ratio	TSS (%)	Reducing sugars (%)	Non-reducing sugars (%)	Total sugars (%)
H-203: (Matti × Anaikomban) × Ambalakadali	1.30	4.12	55.28	17.64	5.48	23.50	17.20	2.80	20.00
H-204: (Matti × Anaikomban) × Pisang Lilin	11.60	7.30	89.30	72.02	2.38	24.00	17.64	3.34	20.98
H-205: (Matti × Anaikomban) × Ambalakadali	4.50	6.01	85.50	33.39	4.82	20.10	16.20	3.10	19.30
H-208 (Matti × Namarai) × Anaikomban	6.00	10.02	143.62	29.00	3.63	22.00	18.36	3.26	21.62
H-02-01: Ambalkadali × Anaikomban	6.60	5.00	50.85	76.00	3.33	20.20	11.60	2.20	13.80
H-211: (Bareli Chinia × Pisang Lilin × Robusta) × Pisang Lilin	9.00	12.00	186.88	35.30	4.23	24.00	18.80	4.17	22.40
H-02-08: (Bareli Chinia × Pisang Lilin × Robusta) × Eraichivazhai	7.84	7.11	120.11	27.20	2.52	21.20	17.00	1.60	18.60
H-02-11: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	4.40	9.13	121.13	35.84	2.30	21.00	14.50	2.70	17.20
H-02-12: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	3.30	7.22	90.16	22.30	1.77	20.00	17.80	1.40	19.20
H-209: (Bareli Chinia × Pisang Lilin × Robusta) × Ambalakadali	10.30	6.00	78.70	49.20	2.08	19.00	14.70	3.78	18.48
H-210: (Bareli Chinia × Pisang Lilin × Robusta) × Anaikomban	8.00	6.70	105.82	37.00	0.85	20.00	15.12	3.20	24.22
H-212: Karpooravalli × Pisang Lilin	12.52	10.80	160.40	70.04	5.86	31.00	24.50	6.20	30.70
H-213: Karpooravalli × Pisang Lilin	11.20	12.30	166.20	53.00	6.97	22.00	16.80	3.84	20.64
Ambalakadali	11.80	6.15	88.25	87.40	2.64	19.00	16.90	1.80	18.70
Anaikomban	6.60	6.34	74.30	66.10	1.94	19.00	16.10	2.60	18.70
Pisang Lilin	3.89	4.38	35.44	53.00	3.36	19.00	17.20	1.50	18.70
Eraichivazhai	5.00	5.50	55.60	16.00	0.60	22.80	18.40	2.44	20.84
H-59: (Matti × Anaikomban)	8.90	9.13	138.82	42.40	3.30	24.00	16.80	4.27	21.07
H-65: (Matti × Anaikomban)	3.00	8.16	104.17	21.60	1.88	19.00	13.20	3.52	16.72
H-66: (Matti × Pisang Lilin)	5.70	7.00	21.22	33.67	0.45	23.00	16.60	4.70	21.30
H-89: (Matti × Namarai)	8.10	4.70	114.31	46.49	3.80	22.40	17.40	3.63	21.03
H-110: (Matti × Tongat)	3.80	4.20	63.42	33.40	3.22	22.60	19.00	2.30	21.30
H-201: (Bareli Chinia × Pisang Lilin × Robusta)	1.70	6.58	108.00	3.67	0.04	20.10	13.10	2.90	16.00
Karpooravalli	13.33	12.11	180.75	60.38	3.54	20.00	18.20	1.00	19.20
Standard error deviation	1.12	1.32	8.17	5.34	1.84	0.80	2.17	1.77	3.84
Critical difference (p = 0.05)	2.25	2.70	16.76	10.31	2.00	1.72	4.30	2.60	7.92

highest number of hands. Number of fingers in the bunch varied from 21.22 to 186.88; H-211 and H-66 genotypes recorded the maximum and minimum values. Among the hybrids, the maximum number of fingers was recorded in H-211 and the minimum in H-203.

H-212 and H-204 had less fingers than those of their respective female parents but more than their male parents. Finger weight varied among the 13 hybrids.

Among the 24 genotypes, the [pulp:peel] ratio varied from 0.04 to 6.97; H-213 and H-201 recorded the maximum and minimum values, respectively. Among the hybrids, the maximum [pulp:peel] ratio was recorded in H-213 and the minimum in H-210. H-212 produced a higher [pulp:peel] ratio than either of its parents. H-204, on the other hand, had a higher [pulp:peel] ratio than that of its female parent but lower than that of its male parent. Among the 24 genotypes, the TSS varied between (19 and 31)%. The maximum was recorded in H-212 (31%) which was higher than both its parents. The reducing sugar content of the fruits ranged between (11.60 and 24.50)%. H-212 recorded the maximum percent of reducing sugar, which was higher than that of both its parents, followed by H-211, which also had a reducing sugar content (18.80%) higher than both its parents. Total sugar content ranged between (13.80 and 30.70)% in the genotypes. Among the hybrids, H-212 registered higher total sugar content than its parents. The fruit qualities of all the hybrids exhibited that they were fit for dessert-type consumption.

3.4. Disease parameters

Among the 24 genotypes, the youngest leaf spotted ranged between 2.0 and 14.0 (*table IV*). The maximum value for youngest leaf spotted was registered in H-209 and the minimum value was recorded in H-02-01, followed by H-02-11, Karpooravalli and H-89. The maximum infection index of 62.50 was registered in H-02-01 and the remaining hybrids and parents recorded an infection index that ranged from 1.19 (H-209) to 26.19 (Karpooravalli). The high-bunch-yielding hybrid recorded the infection in the 10th leaf and had an infection index of 17.78. The highest index for the susceptible cultivars was more than 20.0 at harvest, which was recorded in the susceptible parent cultivars Karpooravalli, Anaikomban and Ambalakadali. Therefore, based on the YLS, the hybrid H-02-01 fell into the highly susceptible category, which had an infection index and YLS higher than Karpooravalli, Anaikomban and Ambalakadali.

3.5. Nematode parameters

Among the 13 hybrids, H-211, H-02-11 and H-02-12 were found to be resistant to nematodes (*table IV*). Among the parents, Anaikomban, Pisang Lilin, Eraichivazhai, H-110 and H-201 were found to be resistant. H-203, H-205 and H-209 among the hybrids and H-66 and H-89 among the parents were classified as highly susceptible.

The maximum reproduction factor of the *Radopholus similis* population was recorded in H-205, H-209 and H-203 among the hybrids, and H-66, H-89, H-65 and H-59 among the parents. The lowest reproduction factor of *Radopholus similis* was recorded in H-211, H-213 and H-02-01 among the hybrids, and Pisang Lilin, H-201, Anaikomban, Ambalakadali and Erachivazhai among the parents.

4. Discussion

The hybrids evaluated in this study showed that all produced parthenocarpic fruit bunches and there was no reversion from parthenocarpy to non-parthenocarpy. This indicates the stability of parthenocarpy in these hybrids.

Analysis of the results revealed that among the 13 hybrids evaluated, one hybrid (H-203) recorded the smallest plant height, pseudostem girth and bunch weight, and it had a very long cycle duration. It also recorded a high percentage of root necroses, nematode population and reproduction factor for the nematode *Radopholus similis*. However, H-203 exhibited a low infection for the leaf spot pathogen.

In banana breeding, an ideal hybrid should be dwarf, of short-cycle duration type, high-bunch-yielding, with high sugar content in fruits, with a regulated suckering habit and tolerant or resistant to nematode and Sigatoka leaf spot [13]. The dwarfness and pseudostem girth of H-203 might be due to the gene inherent from Pisang Lilin. Since its yield potential is very low, it cannot be used for cultivation.

Table IV.
Youngest leaf spotted, infection index, population and reproduction factor of *Radopholus similis* in 24 banana hybrids or parents assessed regarding their resistance to Sigatoka and nematode.

Hybrid with parentage or parents	Genome	Youngest leaf spotted	Leaf spot infection index	Nematodes / g roots	Nematode reproduction factor
H-203: (Matti × Anaikomban) × Ambalakadali	AA	6	8.33	103.4	7.19
H-204: (Matti × Anaikomban) × Pisang Lilin	AA	13	2.38	68.6	4.21
H-205: (Matti × Anaikomban) × Ambalakadali	AA	7	5.56	125.4	8.53
H-208: (Matti × Namarai) × Anaikomban	AA	11	8.33	75.2	3.94
H-02-01: Ambalkadali × Anaikomban	AA	2	62.50	88.0	3.13
H-211: (Bareli Chinia × Pisang Lilin × Robusta) × Pisang Lilin	AA	9	10.26	35.8	2.58
H-02-08: (Bareli Chinia × Pisang Lilin × Robusta) × Eraichivazhai	AB	10	4.17	68.0	4.56
H-02-11: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	AB	3	13.33	37.4	3.57
H-02-12: (Bareli Chinia × Pisang Lilin × Robusta) × Matti × Tongat	AB	5	2.78	38.0	3.46
H-209: (Bareli Chinia × Pisang Lilin × Robusta) × Ambalakadali	AAB	14	1.19	143.0	7.66
H-210: (Bareli Chinia × Pisang Lilin × Robusta) × Anaikomban	AAB	10	1.67	59.0	3.68
H-212: Karpooravalli × Pisang Lilin	ABB	10	17.78	55.2	3.47
H-213: Karpooravalli × Pisang Lilin	ABB	11	1.52	50.6	3.08
Ambalakadali	AA	8	20.44	50.1	2.93
Anaikomban	AA	5	25.93	25.2	2.09
Pisang Lilin	AA	5	3.33	19.2	1.35
Eraichivazhai	AA	5	13.89	11.0	2.21
H-59: (Matti × Anaikomban)	AA	6	4.76	84.4	5.25
H-65: (Matti × Anaikomban)	AA	5	5.56	63.4	6.15
H-66: (Matti × Pisang Lilin)	AA	6	4.76	185.4	12.07
H-89: (Matti × Namarai)	AA	4	10.00	220.0	12.01
H-110: (Matti × Tongat)	AA	6	2.78	12.0	3.08
H-201: (Bareli Chinia × Pisang Lilin × Robusta)	AB	7	6.25	22.8	1.63
Karpooravalli	ABB	3	26.19	38.0	2.59
Standard error deviation	–		1.46	13.4	0.66
Critical difference (p = 0.05)	–		3.10	27.60	1.38

Only three hybrids (H-02-01, H-212 and H-213) among the thirteen hybrids studied exhibited a regulated suckering habit and this might be due to inheritance of this character from their parents. The unregulated suckering habit of the remaining hybrids may be attributed to their inheritance of parental characters. Since banana is vegetatively propagated, the suckers are used as the planting material, hence sucker production in each hybrid is important. The hybrids with a regulated suckering habit have the potential to produce more than four suckers of uniform size. The unregulated suckering habit of hybrids produce one sucker and the subsequent sucker emergence takes 3 months; therefore uniformly aged and sized suckers cannot be obtained from these hybrids.

The H-212 (ABB) recorded maximum bunch weight and it might be due to the inherent character of its female parent Karpooravalli. The quality of the hybrids showed that the H-212 (ABB) and H-213 (ABB) registered a high [pulp:peel] ratio, indicating low peel thickness and high pulp quantity. The TSS of the fruit at the pulp squeezable stage exhibited very high value. The high TSS of H-212 was attributed to its high content of reducing, non-reducing and total sugars. It could be best for dessert consumption.

The female and male fertility of high-bunch-yielding hybrids revealed that H-212 (ABB) was found to be female sterile, a poor pollen-producer and can be grown in the farmer's field. Female sterility is an important character, which makes the banana edible; otherwise, the banana sets seeds. The stony seeds make it unfit for consumption, therefore the female sterility of new hybrids was studied. In India, the commercial cultivation in every state was carried out with many cultivars and many of the commercial cultivars are male fertile and produce viable pollen grains. Therefore if the new hybrids are female fertile and set seeds through natural pollination they will lose commercial acceptability.

The infection index of Sigatoka leaf spot was maximum in H-02-01 (AA) followed by H-212 (ABB), and the remaining hybrids exhibited a significantly lower infection index. Among the thirteen hybrids studied, three hybrids (H-02-01, H-02-11 and H-02-12) were categorised as highly susceptible and another three hybrids were categorised as susceptible because the youngest leaf spotted in these hybrids were below 6.0 and 9.0, respectively. The high-bunch-yielding hybrid, though it recorded a high infection index, had 15 leaves; the spots appeared only in 5.0, and the first 10.0 leaves from the top were free from infection even at the harvest stage. In banana, eight healthy leaves from shooting to harvest are sufficient for bunch development [7]. Therefore, based on the YLS, it has been categorised as resistant. The plantain breeding at the IITA resulted in few triploid plantains and that field evaluation indicated that TM3x was high-yielding and partially resistant to Sigatoka leaf spot [14] under field conditions.

Among the 13 hybrids, H-209 (AAB), H-203 (AA) and H-205 (AA) were susceptible because these hybrids had one susceptible cultivar as a parent in their pedigree. These hybrids had a significantly higher number of *Radopholus similis* in their roots than the others, and also a higher reproduction rate (RF). The hybrid with the highest bunch weight recorded was found to be tolerant to the population of *Radopholus similis* in the roots and its reproduction factor was 3.47, which was higher than the resistant cultivars Pisang Lilin (1.35) and H-201 (1.63).

5. Conclusion

It may be concluded that the H-212 (ABB) was one of the best dessert-type hybrids in our study as it recorded maximum bunch weight, a regulated suckering habit and higher TSS and sugars, and was female sterile and resistant to Sigatoka leaf spot and tolerant to nematode *Radopholus similis*. The quality of H-212 (ABB) when compared with quality aspects of Neypoovan revealed that H-212 was superior to Neypoovan [15]. Hence, H-212 and Neypoovan have to be evaluated simultaneously for yield, quality and resistance to Sigatoka and nematode. The next-best hybrid was H-204 (AA) but it was female fertile. Therefore it has to be improved in the future breeding programme to make it female sterile and it can also be used as a male parent since it produces viable pollen grains at a high rate.

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Variedades parentales y nuevos híbridos de banano: evaluación de los rendimientos potenciales y de su resistencia a la Sigatoka y a los nematodos en la India.

Resumen — Introducción. Los bananos y los plátanos ocupan el cuarto lugar entre los principales cultivos del mundo, y la India es el mayor productor. Se acometió un estudio para evaluar el rendimiento potencial de nuevos híbridos de banano basándose en el peso del racimo y en la calidad del fruto. También se evaluaron los daños causados por nematodos y Sigatoka, así como la estabilidad de la partenocarpia de los genotipos. **Material y métodos**. Se evaluaron trece nuevos híbridos y once progenitores de bananos de postre en la primera generación vegetativa. Se midieron diversos parámetros de crecimiento de la planta, como la altura y circunferencia del seudotallo y el número de hojas e hijos por planta en la etapa de floración, y se evaluaron los daños ocasionados por los nematodos en las raíces y por la Sigatoka en las hojas en la etapa de cosecha. Asimismo, se estimó el contenido de los frutos en sólidos solubles totales, azúcares reductores, no reductores y totales. **Resultados**. Todos los híbridos mostraron partenocarpia y no se produjo una reversión de esta partenocarpia. En los híbridos, la altura y la circunferencia de la planta, al igual que el número de hojas, presentaron diferencias significativas. El mayor peso del racimo se registró en el híbrido H-212 (ABB) que presentó un comportamiento regular en la producción de hijos, un contenido muy alto de sólidos solubles totales y de azúcares reductores, y más hojas sanas que los demás híbridos; por otra parte, H-212 es un banano femenino estéril de postre tolerante a los nematodos y resistente a la Sigatoka. Los factores de reproducción de *Radopholus similis* en H-211 (AA), H-213 (ABB) y H-02-01 (AA) fueron significativamente inferiores a los de H-203 (AA), H-209 (ABB) y H-205 (AA). **Conclusiones**. Este estudio puso de manifiesto el interés del híbrido H-212, triploide ABB, con altos rendimientos, frutos de buena calidad y sin ningún problema sanitario. Podría proponerse su cultivo en plantaciones industriales de banano.

India / *Musa* (bananos) / *Musa* (plátanos) / ensayos de variedades / caracteres de rendimiento / calidad / frutas / cercosporiose resistencia a la enfermedad / nematodos