Journal of Agriculture and Environmental Sciences
December 2022, Vol. 11, No. 2, pp. 6-18
ISSN: 2334-2404 (Print), 2334-2412 (Online)

Published by American Research Institute for Policy Development
DOI: 10.15640/jaes.v11n2a2
URL: https://doi.org/10.15640/jaes.v11n2a2

Multilocational evaluation of two plantain hybrids (FHIA 21 and PITA 3), resistant to Black Sigatoka disease and a local landrace, ORISHELE in Côte d'Ivoire

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Abstract

The field performance of two promising plantain hybrids (FHIA 21 and PITA 3) was conducted alongside a landrace ORISHELE as a control in five different growing conditions in Côte d'Ivoire. Results showed that the hybrids were very tolerant/resistant to the Black Sigatoka disease with high number of functional leaves at flowering and harvest. The hybrid 'PITA 3' was early maturing (13 months) compared to 14 months crop cycle for the landrace. The yield performance of the hybrids was superior to the landrace across the locations. FHIA 21 was high yielding with the highest bunch weight (22.40 kg), followed by 'PITA 3' (18.40 kg) while the landrace 'ORISHELE' produced the smallest bunches (9 kg). The number of fruits per bunch produced by the hybrids was also higher than those of the landrace. However, the landrace produced the longest fruit, and the finger lengths of the hybrid 'PITA 3' were the shortest one. Also, the agro-ecological conditions of the Katiola and Bondoukou sites are favorable to the growing of susceptible cultivars to Black sigatoka because the conditions of these sites are unfavorable to the development of the disease. These hybrids can be distributed to farmers to increase their production in the country.

Keywords: Musa hybrids, landrace, agronomic performance, black sigatoka, Côte d'Ivoire.

1. Introduction

Plantain (Musa spp. AAB) is an important staple crops in West and Central Africa, Latin America and Asia (Dadzie and Orchard, 1996; Robinson, 1996). Very rich in starch and it is produced all year round by small farmers. Furthermore, it is an important source of calories for nearly 70 million people in these zones (Fao, 2010). The demand for this local product is very high in rural and urban markets. Thus, plantain is an essential component of household food security in the region, where it is an important source of income for millions of producers and retailers (Nkendah and Akyeampong, 2003). In West and Central Africa, plantain is grown in the humid forest and derived, moist savannah agroecosystems, ranging from Guinea Bissau in the west of the region to the Democratic Republic of Congo (DRC) in the south-east (Norgrove and Hauser, 2014). Total annual production of plantain is reportedly 47.93 Tg (million tons) (Fao, 2020). In Côte d'Ivoire, plantain is the third most important starchy staple grown after cassava and yam, with an annual production average of 1.7 million tonnes of fruits. Estimated annual consumption in the country ranges from 80 to 120 kg per capita (Thiémélé *et al.*, 2017). Despite its great socioeconomic importance, the ivorian banana sector is still informal, characterized by traditional varieties with low productivity and susceptible to pests and diseases, yet lends itself to achieving household food security. Black sigatoka, a leaf spot disease caused by the fungal pathogen *Mycosphaerella fijiensis*, is the most critical constraint to plantain production in the region (Vuylsteke *et al.*, 1993).

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The pathogen causes yield losses ranging from 30-50% (Traoré *et al*., 2009). All plantain local cultivars are susceptible to black sigatoka (Swennen and Vuylsteke, 1993). Fungicides are available to control the disease, but they are expensive and are not environmentally friendly and thus threaten the fragile ecosystem. The best way to control black sigatoka is the use of resistant varieties. In 2009, several high yielding, pest and disease tolerant/resistant Musa cooking and dessert hybrids were introduced and evaluated in Côte d'Ivoire (Kobenan *et al*., 2009). The introduction and evaluation of these resistant hybrids could contribute to food security and increase farm income in Côte d'Ivoire. The introduced germplasm included multi-use varieties developed by the Fundacion Hondurena de Investigacion Agricola (FHIA), the International or Tropical Agriculture (IITA) and the African Center for Research on Bananas and Plantains (CARBAP) Breeding Program. Plantlets were tested on-station evaluation trial at the Centre National de Recherche Agronomique (CNRA, Côte d'Ivoire), Azaguié research station in a production area of plantain a rainfall condition (Traoré *et al*., 2008). Among these hybrids, two (FHIA 21 and PITA 3) were selected for their high yield, their tolerance to black sigatoka and their preference. However, the agronomic potential of these selected varieties still unknown across different agro-ecologies where black sigatoka has been reported. Hence, the objective of this study was to evaluate these hybrids in comparison with a landrace for their agronomic performance and adaptability under different growing conditions in Côte d'Ivoire.

2. Materials and methods

2.1. Description of the study areas: The multilocational evaluation trial was carried out in five different locations/sites in Côte d'Ivoire from 2016 to 2018. These locations have different rainfall patterns, soil, and agro-ecological zone characteristics (Table 1).

Table 1: Agro-ecological characterization of testing sites

Locations	BOUAFLE	TIASSALE	M'BAHIAKRO	BONDOUKOU	KATIOLA
Latitude	6°59' N	5°54' N	7° 28' N	8° 02' N	8° 8' N
Longitude	5°44' W	49' 59W	4° 19' W	2° 47' W	5° 6' W
Altitude (masl)*	208	65	116	343	308
Agroecological zone	Degraded rain forest	Humid forest	Lowland humid	Derived savanna	Woodland savanna
Annual rainfall (mm)	1200	1100	1097	910	900
Rainfall pattern	Bimodal	Bimodal	Bimodal	Unimodal	Unimodal
Temperature (°C) **Minimum** **Maximum**	 22 °C 29 °C.	 23 °C 30 °C	 22 °C 31 °C	 25 °C 35 °C	 25 °C 34 °C
Soil type	Red ferrallitic type with some hydromorphic domain	Ferrallitic soils from basic rocks and hydromorphic soils	Clay, granitic and sandy soil	Ferralitic more or less saturated, deep clay-sandy	Ferrallitic soil

*masl: meters above sea level;

2.2. Materials and Experimental design: Tree plantain cultivars were used in this study. They included two primary tetraploid (AAAB) plantain-like hybrids (FHIA 21 and PITA 3) and one triploid (AAB) landrace (ORISHELE). The hybrids were improved varieties from Fundación Hondureña de Investigación Agrícola (FHIA, Honduras) and International Institute of Tropical Agriculture (IITA, Nigeria) and the landrace is the most important variety popularly grown in Côte d'Ivoire (Abdou *et al*., 2019). All the hybrids are tolerant to the leaf spot disease black sigatoka (caused by *Mycosphaerella fijiensis*), and the landrace is susceptible to the disease (Kobenan *et al*., 2009). The experiment was laid out in a randomized complete block design with three replications. Thirty plants of each cultivar were planted on each plot on each replication. Plant spacing of 3 m x 2 m was used giving a plant population of 1667 plants/ha. Planting was done manually using healthy planting materials produced by the *multiplication sur souches décortiquées* (MSD) technique (Thiémélé *et al*., 2015). Crops management practices such as fertilizers and weeding were done with the exception of fungicide treatment. During the dry season, plants were irrigated with 35 mm of water weekly. Excess suckers were removed to conserve only one.

2.3. Data collection: Agronomic data were collected on plant height (cm) at flowering, pseudostem girth at 10 cm and 1 m above ground at flowering (cm), number of functional leaves at flowering and at harvest, number of days from planting to harvest, bunch weight (kg), number of hands and fruits per bunch, girth and length of the middle fruit of the second hand (cm). Mature bunches were harvested when a ripe finger was observed and the attained a round shape. The black sigatoka disease severity was evaluated at flowering of banana and the youngest necrotic leaf (PJFT) was recorded. The youngest leaf is defined as the rank of the youngest leaf showing at least 10 necrosis at stage 5 or 6 of the disease (Stover and Dickson, 1970).

2.4. Statistical analysis: Data were collected on each trial in the five sites and subjected to analysis of variance (ANOVA) using the SPSS software V. 26. When significant differences were observed, mean separation was performed using Newman and Keuls tests at 5% likelihood. Analysis of variance across different locations were performed to test the significance of genotype (G) and environment (E). Pearson's correlation was calculated to determine the association between the different variables.

3. Results

Twelve variables were measured and the descriptive statistics of minima, maxima, means, standard deviations and coefficient of variation (CV) were recorded (Table 2). The results indicate variability in the traits measured on the different varieties across the sites. Most of the traits display high coefficient of variation values: Numbers of leaves at harvest (44.34 %), Reaction to Sigatoka (PJFT) (32.87 %), Bunch weight (28.50 %), Number of fruits (27.46 %), Numbers of leaves at flowering (21.12 %), Number of hands (18.02 %), Plant height (14.09 %), Length of fruit (12.25 %), Pseudostem girth at 10 cm (11.93 %), Pseudostem girth at 1 m (11.22 %) and Girth of fruit (8.91 %). However, CV of days from planting to harvest was relatively low (5.33 %), indicating homogeneous production cycle of the varieties across the sites. The Pseudostem girth at 10 cm and 1 m varied respectively from 43 cm to 93 cm with 62.90 cm as mean and from 30 cm to 61 cm with 45.53 cm as mean. The plant height also varied to 150 cm to 395 cm with 265.05 cm as mean. The number of leaves at flowering and harvest varied respectively from 6 to 18 with 11.33 as mean and from 1 to 13 with 6.45 as mean. The bunch weight varied to 6 kg to 30 kg with 15.75 kg as mean. The number of hand and fruit varied respectively from 4 to 8 with 6.27 as mean and from 27 to 92 with 55.31 as mean. The length and girth of fruit were respectively between 15 cm and 30 cm and 10 cm to 19 cm. The duration of the production cycle also varied from 360 days to 485 days with 414.21 days as mean. The youngest necrotic leaf (PJFT) also varied to 2 to 15 with 8.57 as mean

Table 2: Minima, maxima, means, standard deviations and coefficient of variation values of the 12 variables measured

Variables	Minimum	Maximum	Mean	Std. deviation	CV (%)
Plant height	150.00	395.00	265.05	37.36	14.09
Pseudostem girth at 10 cm	43.00	93.00	62.90	7.50	11.93
Pseudostem girth at 1 m	30.00	61.00	45.53	5.10	11.22
Numbers of leaves at flowering	6.00	18.00	11.33	2.39	21.12
Numbers of leaves at harvest	1.00	13.00	6.45	2.86	44.34
Sigatoka (PJFT)	2.00	15.00	8.57	2.81	32.87
Bunch weight	6.00	30.00	15.75	4.49	28.50
Number of hand	4.00	8.00	6.27	1.13	18.02
Number of fruit	27.00	92.00	55.31	15.19	27.46
Length of fruit	15.00	30.00	23.89	2.92	12.25
Girth of fruit	10.00	19.00	14.03	1.25	8.91
Days from planting to harvest	360.00	485.00	414.21	22.07	5.33

According to Pearson coefficient, some traits showed a strong linear correlation (Table 3). The highest significant positive correlation was between numbers of leaves at flowering and youngest necrotic leaf (PJFT) cause by sigatoka disease (0.856), bunch weight and number of fruit (0.777), and pseudostem girth at 10 cm and pseudostem girth at 1 m (0.756). On the other hand, there were also high significant positive correlations like: PJFT and bunch weight (0.634) and number of fruit (0.626), numbers of leaves at harvest and number of fruit (0.609). Numbers of leaves at flowering exhibits also strong relationship with bunch weight (0.612) and number of fruit (0.604).

The results show that bunch weight is influenced by numbers of leaves at flowering (0.612), numbers of leaves at harvest (0.589), youngest necrotic leaf (PJFT) (0.634) and Number of fruit (0.777).

3.1. Growth performance of cultivars from planting to flowering across sites

Within cultivars and across sites, there were highly significant differences ($p < 0.001$) among the banana cultivars regarding plant height, pseudostem girth at 10 cm and 1 m, numbers of leaves at flowering and harvest and days from planting to harvest (Table 4). The tallest cultivar was 'ORISHELE' with a height of 343.67 cm recorded in the Bondoukou site which had the highest altitude; followed by 'PITA 3' and 'FHIA 21' in Bondoukou with the heights of 282.33 cm and 282.17 cm, respectively. The cultivar 'FHIA 21' presented the smallest height in all sites.

The most robust plant girth at 10 cm and 1 m level were generally recorded in a high-altitude site KATIOLA (308 masl) in the center of Côte d'Ivoire, with the 'FHIA 21' with 70,20 cm and 50.20 cm respectively (Table 4). In addition, it was noticed that 'FHIA 21' produced plants with bigger girth than other cultivars across sites with averages of between 64.17 and 70.20 cm for girth at 10 cm and 45.50 and 50.20 for girth at 1 m level (Table 4).

Table 3: Correlation coefficients between the 12 traits measured

Variables	Plant height	Pseudostem girth at 10 cm	Pseudostem girth at 1 m	Numbers of leaves at flowering	Numbers of leaves at harvest	Youngest necrotic leaf (PJFT)	Bunch weight	Number of hands	Number of fruits	Length of fruit	Girth of fruit	Days from planting to harvest
Plant height	1.000											
Pseudostem girth at 10 cm	0.316	1.000										
Pseudostem girth at 1 m	0.487	**0,756**	1.000									
Numbers of leaves at flowering	-0,292	0,267	-0,009	1.000								
Numbers of leaves at harvest	-0,325	0,158	-0,039	**0,558**	1.000							
Youngest necrotic leaf (PJFT)	-0,187	0,399	0,104	**0,856**	**0,599**	1.000						
Bunch weight	-0,166	0,320	0,072	**0,612**	**0,589**	**0,634**	1.000					
Number of hands	-0,034	0,037	0,000	-0,037	0,040	-0,064	0,272	1.000				
Number of fruits	-0,347	0,339	0,076	**0,604**	**0,609**	**0,626**	**0,777**	0,300	1.000			
Length of fruit	-0,026	0,065	0,089	-0,155	-0,205	-0,159	-0,157	0,332	-0,036	1.000		
Girth of fruit	0,075	0,008	-0,008	0,160	0,127	0,192	0,153	-0,082	0,042	0,085	1.000	
Days from planting to harvest	0,095	-0,046	-0,028	-0,194	-0,311	-0,233	0,046	0,260	-0,016	0,168	-0,068	1.000

Values in bold are different from 0 with a significance level α = 0.05

Table 4: Growth performance of cultivars from planting to flowering across sites

Sites	Varieties	Plant growth characteristics at flowering					
		Plant height (cm)	**Pseudostem girth at 10 cm (cm)**	**Pseudostem girth at 1 m (cm)**	**Numbers of leaves at flowering**	**Numbers of leaves at harvest**	**Days from planting to harvest (days)**
BOUAFLE	ORISHELE	267.50 b	58.80 a	45.07 a	7.83 a	2.23 a	413.80 c
	PITA 3	270.00 b	64.70 b	46.33 b	11.53 b	5.57 b	388.07 a
	FHIA 21	244.00 a	66.60 c	49.37 c	12.43 c	6.47 c	406.53 b
TIASSALE	ORISHELE	256.93 a	55.33 a	42.80 a	8.67 a	2.10 a	447.53 c
	PITA 3	273.17 b	64.73 b	46.43 b	11.00 b	7.40 b	389.80 a
	FHIA 21	251.67 a	66.70 c	49.06 c	11.87 c	7.93 c	419.93 b
M'BAHIAKRO	ORISHELE	260.83 b	54.63 a	41.50 a	9.47 a	2.17 a	409.40 b
	PITA 3	235.83 a	58.37 b	44.20 b	12.53 b	7.75 b	397.20 a
	FHIA 21	235.33 a	64.17 c	45.50 c	13.20 c	8.93 c	417.17 c
BONDOUKOU	ORISHELE	343.67 b	60.03 a	45.27 a	9.23 a	4.30 a	433.23 b
	PITA 3	282.33 a	64.40 b	46.60 b	12.87 b	8.70 b	389.90 a
	FHIA 21	282.17 a	69.10 c	49.27 c	13.37 c	9.37 c	428.13 b
KATIOLA	ORISHELE	289.30 c	63.13 a	44.47 a	8.23 a	5.07 a	440.07 c
	PITA 3	253.97 b	67.57 b	46.23 b	13.67 b	9.03 b	400.93 a
	FHIA 21	228.10 a	70.20 c	50.20 c	15.17 c	9.67 b	431.57 b

Means followed by the same letter within a column are not significantly different at $P < 0.05$

The cultivar with the highest number of leaves at flowering and harvest stage was 'FHIA 21' in Katiola, producing an average of 15.17 leaves at flowering and 9.67 at harvest, followed by 'PITA 3' in the same site with an average of 13.67 leaves at flowering and 9.03 at harvest. The lowest number of functional leaves was produced by 'ORISHELE' across the site (Table 4).

The cultivar 'PITA 3' had the lowest crop cycle across locations, followed by 'FHIA 21' and 'ORISHELE' with mean of 393.18, 420.67 and 428.81 days of culture respectively.

3.2. Yield performance of cultivars at harvesting across sites

Yield performance of cultivars was assessed in terms of number of hands per bunch, number of fruits per hand, length and girth of fruit and bunch weight. There were highly significant differences ($p < 0.001$) among the banana cultivars regarding number of hands per bunch, number of fruits per hand, length of fruit and bunch weight. On the other hand, cultivars did not show significant variations in girth of fruit (Table 5). Across the sites, the highest average number of hands (7.80) was recorded for 'FHIA 21' in Bouafle site. Other cultivars had 6.70 hands (ORISHELE) and 5.30 hands (PITA 3) at M'Bahiakro and Tassale locations respectively. The average number of fruits per bunch ranged between 77.27 for 'FHIA 21', 57.63 for 'PITA 3', and 46.08 for 'ORISHELE' (Table 5). ORISHELE (27.37 cm) had the longest fingers, followed by FHIA 21 (26.50 cm) and PITA 3 with the shortest (17.70 cm) fingers. The highest average bunch weight was recorded for FHIA 21 (22.40 kg) in the M'Bahiakro location followed by PITA 3 (18.40 kg) while ORISHELE produced the smallest bunches (9 kg) in Bouafle, Tiassale and M'Bahiakro locations. In addition, the same cultivar ORISHELE had high bunch weight in the Bondoukou and Katiola sites with 14.87 kg and 15.83 kg respectively. The same cultivar 'FHIA 21' had the highest number of hands and fruits per bunch and bunch weight in all sites, whereas the highest fruit length was recorded by the cultivar 'ORISHELE' also in all the sites. The two hybrids 'FHIA 21' and 'PITA 3' had the highest bunch weight than the landrace 'ORISHELE' in all the locations.

Table 5: Yield performance of cultivars at harvesting across sites

Sites	Varieties	Plant growth characteristics at flowering				
		Bunch weight (Kg)	**Number of hands per bunch**	**Number of fruits per bunch**	**Length of fruit (cm)**	**Girth of fruit (cm)**
BOUAFLE	ORISHELE	9.00 [a]	6.57 [b]	39.10 [a]	27.37 [c]	13.47 [a]
	PITA 3	13.67 [b]	4.83 [a]	55.53 [b]	23.57 [a]	13.73 [a]
	FHIA 21	19.03 [c]	7.80 [c]	68.57 [c]	26.50 [b]	13.50 [a]
TIASSALE	ORISHELE	9.67 [a]	6.47 [b]	38.37 [a]	27.00 [c]	14.03 [a]
	PITA 3	16.93 [b]	5,30 [a]	55.83 [b]	23.77 [a]	13.53 [a]
	FHIA 21	17.97 [b]	7.43 [c]	67.30 [c]	25.73 [b]	13.83 [a]
M'BAHIAKRO	ORISHELE	9.87 [a]	6.70 [b]	38.00 [a]	25.07 [c]	13.33 [a]
	PITA 3	18.40 [b]	5.27 [a]	57.63 [b]	17.70 [a]	14.23 [a]
	FHIA 21	22.40 [c]	7.20 [c]	77.27 [c]	22.50 [b]	14.90 [a]
BONDOUKOU	ORISHELE	14.87 [a]	6.60 [b]	41.50 [a]	24.56 [c]	14.63 [a]
	PITA 3	16.27 [b]	5.20 [a]	45.73 [b]	21.08 [a]	14.73 [a]
	FHIA 21	17.83 [c]	6.53 [b]	56.10 [c]	22.83 [b]	14.47 [a]
KATIOLA	ORISHELE	15.83 [a]	6.50 [b]	46.08 [a]	24.50 [c]	13,97 [a]
	PITA 3	16.03 [a]	4.97 [a]	53.27 [b]	21.90 [a]	13,93 [a]
	FHIA 21	18.04 [b]	6.73 [b]	72.10 [c]	23.13 [b]	13,80 [a]

Means followed by the same letter within a column are not significantly different at $P < 0.05$

3.3. Reaction of cultivars to black Sigatoka

The reaction of cultivars to black Sigatoka, caused by *Mycosphaerella fijiensis,* across the sites are presented in Figure 1. The black sigatoka disease severity was evaluated by recording the youngest necrotic leaf (PJFT). There was significant difference ($p < 0.05$) between the youngest necrotic leaves of the cultivars at flowering. The cultivar 'FHIA 21' had the highest rank of the youngest leaf (11) showing necroses of the disease, following by 'PITA 3' (10) and 'ORISHELE' (6). The high level of the free-lesion leaves of the hybrids showed their tolerance to the black sigatoka fungus.

Figure 1: Black Sigatoka disease scores on different banana cultivars under natural field conditions across the sites. The disease was assessed through the youngest necrotic leaves (PJFT). Values followed by different letters are significantly at $p < 0.05$.

Interaction effects (G x E) of genotypes (G) and environments (E) were statistically significant ($P < 0.05$ or $p < 0.01$) for plant height, numbers of leaves at flowering, numbers of leaves at harvest, bunch weight, number of hands per bunch, number of fruits per bunch, length of fruit, reaction to Black Sigatoka and days from planting to harvest, but interaction effects were not significant for pseudostem girth at 10 cm and girth of fruit (Table 6).

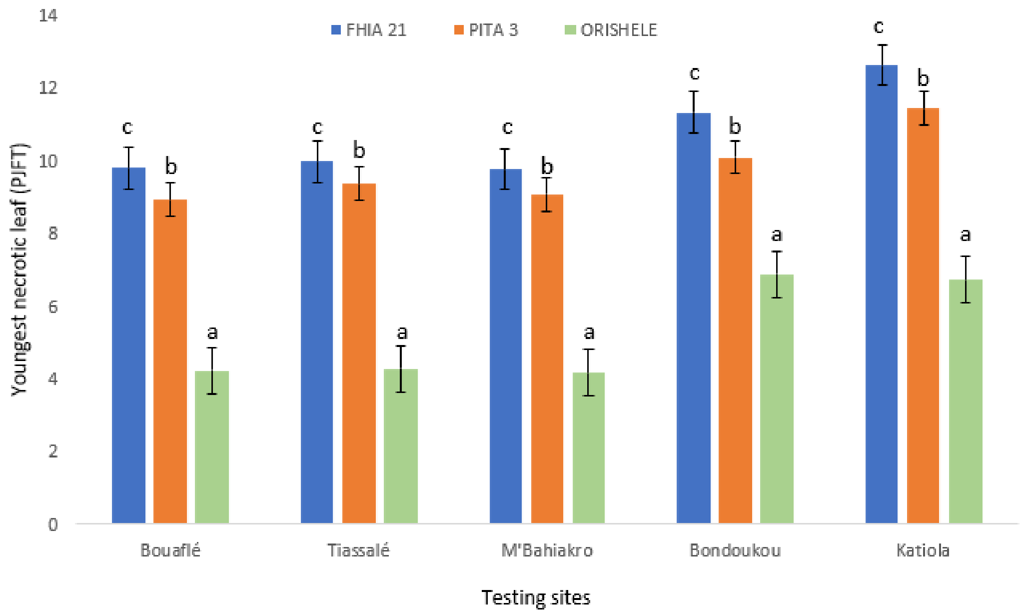

Table 6: Analysis of variance (ANOVA) of growth and yield characteristics in the sites of plantain's cultivars

Characters	MS Genetic parameters				
	Genotype (G)	Environment (E)	E x G	Error	CV (%)
Plant height (cm)	93787*	175665*	70419*	287107	14.09
Pseudostem girth at 10 cm (cm)	6147**	3060**	443 ns	14838	11.93
Pseudostem girth at 1 m (cm)	2270.70**	347.90**	130.30 ns	7663.90	11.22
Numbers of leaves at flowering	1669.95*	293.19*	156.65*	456.87	21.12
Numbers of leaves at harvest	2461.44**	582.95**	79.80**	555.23	44.34
Bunch weight (Kg)	4034.70**	617.20**	1418.90**	2980.80	28.50
Number of hands per bunch	327.41**	10.30**	27.43**	208.23	18.02
Number of fruits per bunch	525.16*	5672*	10212*	21139	27.46
Length of fruit (cm)	1189.50**	1081.80**	265.40**	1302.70	12.25
Girth of fruit (cm)	1.77 ns	60.57 ns	28.94 ns	608.40	8.91
Reaction to Black Sigatoka (PJFT)	2550.16**	519.36**	37.99**	462.27	32.87
Days from planting to harvest (days)	104552**	27125**	21192**	65993	5.33

Note: MS: mean square, CV: coefficient of variance, * = significantly different at level 0.05, ** = significantly different at level 0.01, ns = non significantly different

4. Discussion

Field evaluation of news varieties across multiple environments is the best way to evaluate their performance. Parameters such as plant height at flowering, plant height at harvest, pseudostem girth at 10 cm and 1 m above ground, number of functional leaves at flowering and at harvest, number of months to flowering and to harvest, bunch weight (kg), number of hands per bunch, number of fruits, girth, and length of the median fruit of the bunch, reaction to black sigatoka disease was evaluated for two hybrids (FHIA 21 and PITA 3) and one landrace (ORISHELE) plantain in this study across five different environments. Multi-site evaluation trials of plant cultivars are very important because it help to identify high-yielding and stable genotypes across environments. These different environmental conditions resulting in different yield responses of plantain genotypes can be attributed to the genotype's interaction with the environment observed in our study. Genotypes responded differently to different locations due to divergent edaphoclimatic conditions, particularly variations of temperature, total precipitation, and soils properties, which is in agreement with Kimunye *et al.*, (2021).

Banana plants can be characterized as short (less than 3m), medium (3 to 7m) and tall (above 7m) according to Asmar *et al.*, (2021). In the present study, the mean of height of the cultivars evaluated is 2.65 m so less than 3 m. This is an advantage for the cultivation of these three varieties. Indeed, plant height influences planting density and crop management (Aquino *et al.*, 2017). Short cultivars are usually preferred as they are less prone to toppling by strong winds, do not need support, the increase in planting density may result in greater economic return and they are easy to harvest (Goncalves *et al.*, 2018).

In our study, highest banana was obtained in the site with highest altitude, with is contrary of work to Kamira *et al.,* 2021 where tallest cultivar Pelipita' was recorded in the Burundi site which had the lowest altitude.

The results of our work revealed a genetic variation among banana genotypes in plant girth size as has been shown in several studies. Indeed, according to several studies, banana plant girth size ranging from 51.5 to 76.3 cm (Menon, 2000), 42.1 to 57.9 cm (Dzomeku *et al.*, 2007), 43 to 76.6 cm (Njuguna *et al.*, 2008), 46.45 to 76.28 cm (Sagar *et al.*, 2014), 77 to 90 cm (Kamira *et al.*, 2016), 35 to 45 cm (Thiemele *et al.*, 2017) and 42 to 71 (Kamira *et al.*, 2021). Plant girth is linked to pseudostem vigor and resistance to damage by wind. It indicates the ability of a plant to support the bunch, and insights the genetic variability for this trait among genotypes (Goncalves *et al.*, 2018). The FHIA 21 cultivar was the most vigorous of the varieties. Similar results were obtained in Ghana with Dzomeku *et al.*, (2008), on the other hand, in Mozambique conditions, low plant girths values at 10 cm (25.7 cm) and 1 m (16.2 cm) were observed (Uazire *et al.*, 2008).

There was a significant difference between the hybrids (FHIA 21 and PITA 3) and the landrace (ORISHELE) concerning the number of leaves at flowering and harvest. All the hybrids reached flowering with more than eleven functional lesion-free leaves across the sites. Indeed, at least eight active leaves per plant at flowering time is a good indicator for having big bunch (Lassoudière, 2007). The availability of this number of leaves at flowering of the hybrids contributed to their higher yield. The result is consistent with previous findings for the hybrids and different banana genotypes (Uazire *et al.*, 2008; Dzomeku *et al.*, 2008, Sagar *et al.*, 2014; Kamira *et al.*, 2016).

At all locations, it was noted that the cultivar 'PITA 3' had lowest crop cycle duration. This characteristic will be appreciated by the farmers in these conditions of climatic change. The cultivar will be able to quickly complete its cycle before the arrival of more difficult periods. Indeed, having cultivar with shortest crop cycle duration is appreciated and will increase and sustain the availability of bananas for the consumers. Farmers can be sensitized to adopt the banana cultivars with short cycle to enhance food security as reported for rice (Sall *et al.*, 2000).

In the study, the yields performance varied significantly among the three banana cultivars across the sites. The result is in line with previous findings by different authors (Kamira *et al.*, 2016; Sagar *et al.*, 2017; Goncalves *et al.*, 2018, Asmare *et al.*, 2021, Kamira *et al.*, 2021) who found varietal differences in yield components (bunch weight, number of hands and number fruits) among different banana genotypes. The yields of the hybrids 'FHIA 21' and 'PITA 3' were higher than the landrace 'ORISHELE' in all the locations. Similar results were observed by Dzomeku *et al.,* (2008) for the hybrid 'FHIA 21' and the landrace 'APEM' and by N'Guetta *et al.*, (2016) and Abdou *et al.*, (2019) for the hybrids 'FHIA 21' and 'PITA 3' and the landraces 'ORISHELE', 'CORNE 1'and 'BIG EBANGA'. Among, the hybrids, 'FHIA 21' had the biggest peudostem and also retained more functional leaves at flowering and harvest, which possibly contributes to its higher yield. Indeed, according to Lassoudiére (2007) and Moreira (1987), there is a positive correlation between diameter of the pseudostem, functional leaves at flowering and harvest and bunch size.

The increase of the bunch weight of the cultivar 'ORISHELE' in the Bondoukou (343 masl) and Katiola (308 masl) locations can be explained, on the one hand by the highest altitude of theses sites, in conformity with Kamira *et al*., (2021) who observed altitude having an association with bunch weight in RDC. He showed that the cultivars 'Apantu', 'Lahi' and 'Pelipita' produced good bunch sizes in all sites while 'Bira' and Lai got bunches of similar sizes only in the medium and highest altitude sites in DRC. This association was also observed in previous findings (Sikyolo *et al*., 2013; Sivirihauma *et al*., 2016) which concluded the effect of altitude on plantain growth and yield during production. On the other hang, the big bunch of 'ORISHELE' was due by highest of functional lesion-free leaves at flowering and harvest in these locations.

Despite the economic importance of plantains in the humid lowlands of West and Central Africa, the sustainable production is threatened by pathogens and pests, posing a risk to household income generation and food security. Black sigatoka is the most serious production constraint with edible yield loss ranging from 40 % to 50 % in the first crop cycle and 100 % in subsequent ratoons (Mobambo *et al*., 1993). The work carried out by Tuo *et al*., (2021a) highlighted the disease on all plantain landrace varieties in all surveyed areas in Côte d'Ivoire. The cultivar 'ORISHELE' expressed the symptoms of black sigatoka at all the sites. This was not surprising as the cultivar is recognized as very susceptible by several works (Traore *et al*., 2008; Thiemele *et al*., 2017; Tuo *et al*., 2022). On the other hand, in our study, the disease had less incidence on the susceptible cultivar 'ORISHELE' in Bondoukou and katiola locations, notified by a high number of rank of the youngest leaves showing necroses of the disease, 6.87 and 6.73 respectively. Similar results were observed by Thiemele et al., (2017). This less incidence of the disease was due to the climatic conditions in the two locations, especially the high temperature unfavorable to the development of the fungus. In fact, black sigatoka grows faster in humid climatic condition. Similar results have been reported by Traore (2008). The author observed more severe symptoms of the disease in rain condition than in a dry season. Compared to 'ORISHELE', 'FHIA 21' and 'PITA 3' showed minimal disease incidence, they are tolerant to black sigatoka in all the sites. The study has confirmed the report of Dadzie (1996) and Abdou et al., (2019) which indicated that these hybrids were bred against black sigatoka and with superior agronomic potential. A study by Tuo *et al*., (2021b) confirmed again the tolerance of 'FHIA 21' and 'PITA 3' against Black sigatoka disease tested under controlled conditions by inoculation with conidial suspensions of e 8 virulent isolates of *Mycosphaerella* spp. The tolerance of the hybrids to the disease and the availability of more functional leaves at flowering and harvest than the landrace cultivar 'ORISHELE' contributed to their higher yield.

5. Conclusion

To summary, this research was aimed to evaluate the agronomic performance of two new plantain hybrids resistant to black sigatoka disease (FHIA 21 and PITA 3) under different growing conditions in Côte d'Ivoire with a landrace cultivar as control (ORISHELE). The statistical analysis of the new varieties compared with control showed significant difference in plant height, pseudostem girth at 10 cm and 1 m, numbers of leaves at flowering and harvest, days from planting to harvest, reaction to black sigatoka disease, number of hands per bunch, number of fruits per hand, length and bunch weight. All the hybrids retained more sufficient free-functional leaves at flowering and harvest, high bunch and tolerant to black sigatoka disease across the different sites of evaluation than the landrace. The cultivar 'PITA 3' had the shortest production cycle, and it is an advantage for formers by producing earlier variety. Also, the agro-ecological conditions of the Katiola and Bondoukou sites are favorable to the growing of susceptible cultivars to Black sigatoka. We conclude that the hybrids 'FHIA 21' and 'PITA 3' are very promising banana cultivars with agronomic performance that shows good potential for adoption by farmers in Côte d'Ivoire to increase the production.

6. Acknowledgements

The authors would like to thank the Ivorian State for funding the study through the West Africa Agricultural Productivity Program (PPAAO/WAAPP). We also thank the National Center for Plantain Specialization (CNS-Plantain) hosted by the Centre National de Recherche Agronomique (CNRA, Côte d'Ivoire).

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