Contemporary Journal of Advancement in Food Science and Technology

Volume.8, Number 4; November-December, 2022;
ISSN: 2836-8207 | Impact Factor: 6.63
https://zapjournals.com/Journals/index.php/cjafst
Published By: Zendo Academic Publishing

ASSESSING BLACK SIGATOKA RESISTANCE IN PLANTAIN VARIETIES OF CÔTE D'IVOIRE

Dr. Amadou Traoré[1], Prof. Jean-Claude Yao Aké[2], Prof. Marie-Claire Kouassi[3], Dr. Ibrahim Coulibaly[4]

Article Info

Keywords: Plantain, Musa spp. AAB, food security, small-scale farmers, West and Central Africa.

Abstract

Plantain (Musa spp. AAB) holds significant agricultural and economic value, particularly in regions of West and Central Africa, Latin America, and Asia. This versatile crop, renowned for its high starch content, serves as a year-round staple for small-scale farmers. Its pivotal role in sustaining over 70 million individuals in these areas underscores its importance (Fao, 2010). Plantain commands a robust demand in both rural and urban markets, playing a vital role in household food security and serving as a primary source of livelihood for millions of producers and vendors (Nkendah and Akyeampong, 2003). Cultivation spans the humid forest and derived, moist savannah agroecosystems from Guinea Bissau in the west to the Democratic Republic of Congo in the southeast (Norgrove and Hauser, 2014). The annual production of plantain across these regions is estimated at 47.93 million tons (Fao, 2020). In Côte d'Ivoire, plantain ranks as the third most crucial starchy staple, trailing behind cassava and yam, boasting an annual output averaging 1.7 million tons of fruits. Per capita consumption in the country ranges from 80 to 120 kg annually (Thiémélé et al., 2017). Despite its socio-economic significance, the Ivorian banana sector remains largely informal, characterized by traditional varieties with modest yields, susceptible to pests and diseases, yet crucial for achieving household food security. Among the challenges, black sigatoka, a leaf spot

[1] Université Peleforo GON COULIBALY, UFR Sciences Biologiques, Département de Biochimie-Génétique, Unité Pédagogique et de Recherche (UPR) de Génétique, BP 1328 Korhogo, Côte d'Ivoire

[2] Programme Plantain Banane Ananas, Centre National de Recherche Agronomique (CNRA), Station Bimbresso 01 BP 1536 Abidjan 01, Côte d'Ivoire

disease incited by the fungal pathogen Mycosphaerella fijiensis, emerges as the most formidable impediment to plantain production in the region (Vuylsteke et al., 1993).

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 southeast (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).

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**	**Pseudost em girth at 10 cm**	**Pseudost e m 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

		Plant growth characteristics at flowering					
Sites	**Varieties**	**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 fruit hands per (cm) bunch**	**Number of fruits per bunch**	**Length of**	**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).

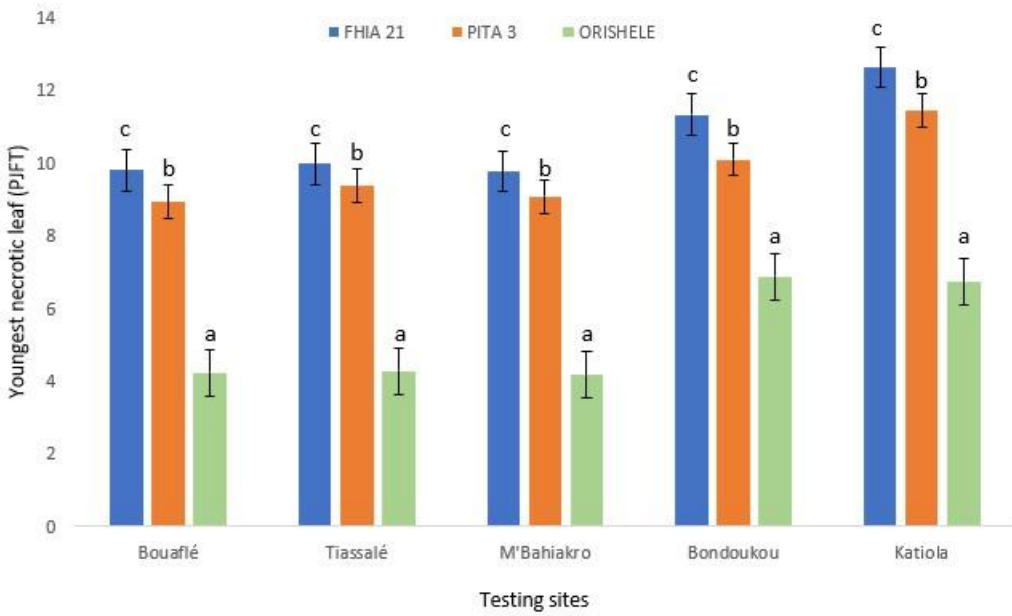

Table 6: Analysis of variance (ANOVA) of growth and yield characteristics in the sites of plantain's cultivars

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 freefunctional 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 (CNSPlantain) hosted by the Centre National de Recherche Agronomique (CNRA, Côte d'Ivoire).

7. References

Abdou, T., Lamien, N., Agogbua, J., Amah, D., Swennen, R., Traoré, S., Thiémélé, D., Aby, N., Kobenan, K.,

Gnonhouri, G. Yao, N., Astin, G., Sawadogo-Kabore, S., Tarpaga, V., Issa, W., Lokossou, B., Adjanohoun, A., Amadji, G. L., Adangnitode, S., Igue, K. A. D. & Ortiz, R. (2019). Promising HighYielding Tetraploid Plantain-Bred Hybrids in West Africa. *International Journal of Agronomy*. ID 3873198, 8 pages https://doi.org/10.1155/2019/3873198

Asmare, D., Wegayehu, A., Girma, K., Lemma, A., Tewodros, M., Awoke, M., Dereje, K., Endriyas, G., Masresha, M., Abraham, A., Jemal, B. & Mesfin, S. (2021). Evaluation of Banana (Musa spp.) Cultivars for Growth, Yield and Fruit Quality. *Ethiopian journal of agricultural sciences*. 31(3) 1-25.

Aquino, C. F., Salomão, L. C. C., Cecon, P. R., De Siqueira, D. L. & Ribeiro, S. M. R. (2017). Physical, chemical and morphological characteristics of banana cultivars depending on maturation stages. *Revista Caatinga* 30 :87–96.

Dadzie, B.K., & Orchard. J.E. (1996). Postharvest criteria and methods for routine screening of banana and plantain hybrids. Intl. Network for the Improvement of Banana and Plantain. Montpellier, France

Dzomeku, B. M., Anakomah, A. A., Quain, M. D., Lamptey, J. N. L., Anno-Nyako, F. O. & Aubyn, A. (2007). Agronomic evaluation of some IITA Musa hybrids in Ghana. *African Crop Science Conference Proceedings* 8: 559-562.

Dzomeku, B. M., Bam, R. K., Adu-Kwarteng, E., Ankomah, A. A., & Darkey, S. K. (2008). Comparative Study on the Agronomic, Nutritional Values and Consumer Acceptability of FHIA 21 (Tetraploid Hybrid) and Apen (Triploid French Plantain) in ghana. *American Journal of Food technology* 3 (3): 200-206.

Fao, (2010). (Food and Agriculture Organization). Food and agriculture indicators ESSA

Accessed on January 11,2013. http://www.fao.org/es/ess/top/country.htmlFAOFao, (2020). Food and Agriculture Organization of the United Nation.https://www.fao.org/faostat/fr/#data/QCL

Goncalves, Z. S., Invenção da, D. R. S., Ledo, C. A. S., Ferreira, C. F. & Amorim, E. P. (2018). Agronomic performance of plantain genotypes and genetic variability using Ward MLM algorithm. *Genetics and Molecular Research* 17(1): gmr16039882

Kamira, M., Ntamwira, J., Sivirihauma, C., Ocimati, W., Van Asten, P., Vutseme, L. & Blomme, G. (2016). Agronomic performance of local and introduced plantains, dessert, cooking Evaluation of banana (Musa spp.) cultivars for growth, yield and fruit quality [24] and beer bananas (Musa spp.) across different altitude and soil conditions in eastern Democratic Republic of Congo. African Journal of Agricultural Research 11(43) : 4313–4332.

Kamira, M., Simbare, A., Sivirihauma, C., Mpoki, S., Nabuuma, D. & Ekesa, B. (2021). Agronomic performance of provitamin A-rich banana cultivars in Burundi and the Democratic Republic of Congo. *African Journal of Agricultural Research*. 17(9), pp. 1209-1220

Kimunye, J., Jomanga, K., Tazuba A. F., Evans, W., Viljoen, A., Swennen, R. & Mahuku, G. (2021). Genotype X Environment Response of 'Matooke' Hybrids (Naritas) to Pseudocercospora fijiensis, the Cause of Black Sigatoka in Banana. *Agronomy* 11, 1145. https://doi.org/10.3390/agronomy11061145

Kobenan K., Traore S., Tenkouano A., & Kendia E. (2009). Evaluation of performance and resistance of banana and plantain hybrids to black leaf streak disease under organic fertilization in southern Côte d'Ivoire. *Journal of Animal & Plant Sciences*, 2009. Vol. 2, Issue 4: 174 – 181

Lassoudière, A., 2007. Le bananier et sa culture. Montpellier, Quae. 383 pp

Menon, R. (2000). Preliminary evaluation of some banana introductions in Kerala (India). *InfoMusa* 9(2) :27–28

Mobambo, K. N., Gauhl, F., Vuylsteke, D., Ortiz, R., Pasberg-Gauhl, C. & Swennen, R. (1993). Yield loss in plantain from black sigatoka leaf spot and field performance of resistant hybrids. *Field Crops Research*. 35: 35 – 42

Moreira, R. S., Hiroce, R. & Saes, L. A. (1987). Analysis of 12 nutritive elements at the edges and centers of the leaves of 50 banana cultivars Revista Brasileira de Fruticultura (BRA), 9(1):21-26

N'guetta, A., Traore, S., Yao, N. T., Aby, N., koffi, Y. D., Atsin, G. O., Otro, S. T. V, Kobenan, K., Gnonhouri, P., and A. Yao-Kouame, a. (2016). Incidence de la densité de plantation sur la croissance et le rendement du bananier plantain en Côte d'Ivoire : cas de deux hybrides (PITA 3 et FHIA 21) et deux variétés locales (Corne 1 et Orishele). *Agronomie Africaine* 27 (3) : 213 – 222

Njuguna, J., Nguthi, F., Wepukhulu, S., Wambugu, F., Gitau, D., Karuoya, M. & Karamura D. (2008). Introduction and evaluation of improved banana cultivars for agronomic and yield characteristics in Kenya. *African Crop Science Journal* 16 :35–40

Nkendah, R., & Akyeampong, E. (2003). Socioeconomic data on the plantain commodity chain in West and Central Africa, *InfoMusa* 12, 8–13

Norgrove L., & Hauser S. (2014). Improving plantain (Musa spp. AAB) yields on smallholder farms in West and Central Africa. *Food Sec.* 6: 501–514

Robinson, J.C. (1996). Bananas and plantains. CAB Intl., Wallingford, Oxon, U.K.

Sagar, B. S., Raju, B., Hipparagi, K., Patil, S. N. & Sahithya, B. R. (2014). Evaluation of banana genotypes for growth and yield under northern dry zone of Karnataka. *The Bioscan* 9 :1773–1775.

Sall, S., Norman, D., Featherstone, A. M. (2000). Quantitative assessment of improved rice variety adoption: the farmer's perspective. *Agricultural system* 66(2) :129-144.

Sikyolo, I., Sivirihauma, C., Ndungo, V., Langhe, E. D., Ocimati, W., Blomme, G. (2013). Growth and yield of plantain cultivars at four sites of differing altitude in North Kivu, Eastern Democratic Republic of Congo., in: Blomme, G., Asten, P. van, Vanlauwe, B. (Eds.), Banana Systems in the Humid Highlands of Sub-Saharan Africa: Enhancing Resilience and Productivity. *CABI*, Wallingford, pp. 48–57. https://doi.org/10.1079/9781780642314.0048

Sivirihauma, C., Blomme, G., Ocimati, W., Vutseme, L., Sikyolo, I., Valimuzigha, K., De Langhe, E., Turner, D. W. (2016). Altitude effect on plantain growth and yield during four production cycles in North Kivu, eastern Democratic Republic of Congo. *Acta Horticulturae* 1114:139- 148. https://doi.org/10.17660/ActaHortic.2016.1114.20

Stover, R. H. & Dickson, J. D. (1970). Leaf spot of bananas caused by Mycosphaerella musicola: methods of measuring spotting prevalence and severity. *Tropical Agriculture* (Trin). 47: 289-302.

Swennen R. & Vuylsteke D. (1993). Breeding Black sigatoka resistant plantains with a wild banana. Tropical Agriculture 70: 74 – 77

Thiemele, D. E. F., Issali, A. E., Traoré, S., Kouassi, K. M., Aby, N., Gnonhouri, G. P., Kobenan, J. K., Yao, T. N., Amoncho Adiko, A., & Nicodème Zakra, A. N. (2015). Macropropagation of plantain (musa spp.) cultivars pita 3, fhia 21, orishele and corne 1: effect of benzylaminopurine (bap) concentration. Journal of Plant development. 22 : 31 – 39

Thiemele, D. E. F., Traoré, S., Aby, N., Gnonhouri, P., Yao, N., Kobenan, K., Konan, E., Adiko, A., & Zakra, N. (2017). Diversité et sélection participative de variétés locales productives de banane plantain de Côte d'Ivoire. *Journal of Applied Biosciences* 114: 11324-1133

Traore, S. (2008). Contribution à l'étude de comportement d'hybrides de bananiers de dessert et de bananiers plantain (Musa sp.) vis-à-vis des parasites foliaires (mycosphaerella spp., cladosporium musae) et racinaires (zythia sp., radopholus similis, pratylenchus coffeae) en Côte d'Ivoire. Thèse de Doctorat es Sciences, Physiologie Végétale, université de Cocody Abidjan (Côte d'Ivoire), 195 pp

Traore, S., Kobenan, K., Kouassi, S. & Gnonhouri, G. P. (2009). Systèmes de culture du bananier plantain et méthodes de lutte contre les parasites et ravageurs en milieu paysan en Côte d'Ivoire. *Journal of Applied Biosciences* (19):1094-1101).

Tuo, S., Camara, B., Kassi, K. F. J. M., Kamaté, K., Ouédraogo, S., & Koné, D. (2021a). Actualisation de la distribution géographique des cercosporioses des bananiers en Côte d'Ivoire : diversité et incidence de l'agent pathogène. *Journal of Applied Biosciences* 166 : 17188– 17211

Tuo, S., Kassi, K. F. J. M., Camara, B., Ouédraogo, S. L. & Koné, D. (2021b). Biocontrol of Mycosphaerella fijiensis Morelet, the Causal Agent of Black Sigatoka of Banana Tree (Musa spp.) Using Biopesticides in Côte d'Ivoire. *Advances in Bioscience and Bioengineering*. Vol. 9, No. 4, 2021, pp. 111-123. doi: 10.11648/j.abb.20210904.13

Tuo, S., Amari, L. D. G. E., Kassi, K. F. J. M., Sanogo, S., Yeo, G., Camara, B., Ouedraogo, S. L. & Kone, D. (2022). Alternative Strategy to the Chemical Control of Mycosphaerella fijiensis Morelet, Causative Agent of Banana Trees Black Sigatoka by the Use of Biopesticides. *American Journal of BioScience*. 10(3): 106-117

Uazire, A. T., Ribeiro, C. M., Ruth Bila Mussane, C., Pillay, M., Blomme, G., Fraser, C., Staver C. & Karamura, E. (2008). Preliminary evaluation of improved banana varieties in Mozambique. *African Crop Science Journal*, Vol. 16, No. 1, pp. 17 – 25

Vuylsteke D., Ortiz R. & Ferris S. (1993). Genetic and agronomic improvement for sustainable production of plantain and banana in Sub-Saharan Africa. *African Crop Science Journal* 1: 1 – 8.