Title

Plantain hybrids for the humid forest agroecology of Central Africa — diseases and pests load, fruit yield and farmers perception

Permalink

https://escholarship.org/uc/item/7g59911s

Journal

Plant Production Science, 25(4)

ISSN

1343-943X

Authors

Lienou, Jules Appolinaire
Ngatat, Sergine
Nanga, Samuel Nanga
et al.

Publication Date

2022-10-02

DOI

10.1080/1343943x.2022.2136723

Copyright Information

Peer reviewed

Plantain hybrids for the humid forest agroecology of Central Africa – diseases and pests load, fruit yield and farmers perception

Jules Appolinaire Lienou, Sergine Ngatat, Samuel Nanga Nanga, Armand Rodrigue Pascal Doumtsop Fotio, Albert Abang Fomumbod, Apollin Fotso Kuate, Komi K. Mokpokpo Fiaboe, Cletus Fonbah, Francis Ngome Ayebesone, Emmanuel Njukwe, Abdou Tenkouano & Rachid Hanna

Published online: 01 Nov 2022.

Submit your article to this journal ↗

Article views: 1102

View related articles ↗

REGULAR PAPER

Plantain hybrids for the humid forest agroecology of Central Africa – diseases and pests load, fruit yield and farmers perception

Jules Appolinaire Lienou [a], Sergine Ngatat [a], Samuel Nanga Nanga [a],
Armand Rodrigue Pascal Doumtsop Fotio [a,b], Albert Abang Fomumbod [a], Apollin Fotso Kuate [a],
Komi K. Mokpokpo Fiaboe [a], Cletus Fonbah [c], Francis Ngome Ayebesone [d], Emmanuel Njukwe [a,e],
Abdou Tenkouano[a,e] and Rachid Hanna [a,f]

[a]Department of Plant health, International Institute of Tropical Agriculture (IITA), Messa-Yaoundé, Yaounde, Cameroon; [b]Department of Biological Sciences, Faculty of Sciences, University of Maroua, Maroua, Cameroon; [c]Department of Agronomy, Centre Africain de Recherches sur Bananiers et Plantains (CARBAP), Douala, Cameroon; [d]Department of Annual crop, Agricultural Research Institute for Development (IRAD), Yaoundé, Cameroon; [e]Department of Scientific Research and Innovations, West and Central Africa Council for Agricultural Research and Development, Dakar, Senegal; [f]Center for Tropical Research, Institute of the Environment and Sustainability, University of California, Los Angeles, California, USA

ABSTRACT

Plantain is one of the major staples contributing to food security and income generation in West and Central Africa. Local cultivars in Cameroon are susceptible to pests and diseases causing severe losses in plantain production. This study aimed at evaluating the agronomic performance and producer's perception of plantain hybrids in the humid forest of Cameroon. Field trials were established in a completely randomized block design with eight genotypes and three replicates. Data on pest and disease as well as farmer perception were collected over two growing cycles. These genotypes included seven improved and one local genotype (check). Improved genotypes were highly tolerant to the Black Sigatoka disease compared to local plantain. While root necrosis index was above 50% in local varieties, indices below 25% were recorded in hybrids. Weevil severity in local was higher (55.0 ± 5.2%) compared to 21.0 ± 4.6% to 28.5 ± 3.2% in improved plantains. Average bunch weight was higher for FHIA 21 with 17.9 ± 0.7 kg in the first and 19.7 ± 0.3 kg for the second cycle, while those of the local *Ebang* were 9.6 ± 0.5 kg and 12.8 ± 0.9 kg, respectively. FHIA 21 and CRBP 568 were the preferred varieties by farmers (68.8% and 56.3% acceptance) from an agronomic perspective. The consumers' preferences for all the genotypes varied with types of cooking. The implications of these findings for adoption by farmers and consumers as well as for the promotion of the plantain sector in central Africa are discussed.

Plantain hybrids for the humid forest agroecology of central africa – diseases and pests load, fruit yield and farmers perception

BACKGROUND
- Local plantain cultivars are susceptible to pests and diseases which cause yield losses
- Information on the adaptability, performance and farmers perception on new plantain hybrids are still scarce

METHODOLOGY
- Setting of field trials in RCBD with 8 plantain genotypes (7 hybrids from 3 institutions (IITA, CARBAP, FHIA) and 1 landrace (Ebang) in the humid forest of Cameroon
- Evaluation of Agronomic traits, pests and diseases status, yield trait at flowering and harvest, over 2 cropping cycles
- Farmer's perception of plantain genotypes with 42 participants (24 males, 18 females)
- Evaluation of 3 food preparations (boiled, Chips and pounded)

RESULTS
- Growth traits varied among the plantain genotypes, but CRBP 535 plants were the shortest during both cycles.
- Improved genotypes were highly tolerant to the Black Sigatoka disease compared to the landrace.
- Improved genotypes were tolerant to attack of plant parasitic nematode and banana weevil compared to the landrace.
- High yield was recorded in FHIA 21 and CRBP 568 during the both cycles.
- FHIA 21 and CRBP 568 were the most preferred varieties by farmers (68.8% and 56.3% acceptance) from agronomic traits.
- Consumers preference for all the genotypes varied with the types of cooking.

CONCLUSION
- Plantain hybrids presented better agronomic performance than local plantain, which supporting the knowledge of their resistance to Black Sigatoka, tolerance to weevil and nematode damage.
- All the genotypes were accepted based on 3 plantain food preparations.

Introduction

Plantains are starchy bananas that constitute over 80% of world banana (*Musa* spp.) production and are considered one of the major staple food and economic crop for about 70 million people in West and Central Africa (Goenaga et al., 2019). Worldwide, green or ripe fruits are consumed in several forms including fried, baked, roasted, pounded as fufu, porridge, and flour, and are eaten alone or together with other foods depending on local cuisines (Etebu & Young-Harry, 2011). In Cameroon and several other countries in Central Africa, plantains are essential components of food security and are important sources of income for millions of producers and retailers (Folefack et al., 2017; Nkendah & Akyeampong, 2003).

Plantain production in Cameroon is second in Africa – after the Democratic Republic of Congo – with an annual production of 4,526,029 MT (FAO, 2020). Much of the production is sold and consumed locally, with up 150 kg per capita per year (Cauthen et al., 2013; Swennen et al., 1995), but Cameroonian plantain exports to neighbouring countries like Gabon, Equatorial Guinea, and Nigeria are increasingly taking a greater share of plantain production (Nkendah et al., 2011). The demand for plantain is expected to increase with the projected increase in human population and the associated increase in food demand in sub-Saharan Africa (Dury et al., 2002; Tomekpe et al., 2011).

Botanically, plantains are giant herbaceous perennial plants that grow from underground stems (corms) and are generally propagated vegetatively, either by directly planted suckers or with seedlings generated from macro- or micropropagation (Njukwe et al., 2007; Tenkouano et al., 2006). Plantains are either naturally occurring farmer selection or synthetic triploid hybrids (AAB) from a combination of two diploid species, *Musa acuminata* Colla and *Musa balbisiana* Colla, which, respectively, contribute the A and B genomes (Singh et al., 2016). In West and Central Africa, local natural plantain selections are the most widely planted types which are mostly grown in the humid forest and moist Savannah areas with 1200 mm minimum annual rainfall (Jalloh et al., 2012; Norgrove & Hauser, 2014). A plantation can produce up to 4 cycles of bunch harvests (Lassoudière, 2007), approximately once a year but that depends on several factors such as genotypes, soil fertility, pests and diseases, and rainfall (Ssali et al., 2003).

The most important diseases of banana and plantains in Africa are three fungal leaf diseases (Yellow Sigatoka, *Eumusae* leaf spot, Black Sigatoka), one widely distributed fusarium wilt (Panama disease), and another newly introduced into Africa (Fusarium wilt Race 4), two bacterial diseases (Xanthomonas wilt, Moko disease), and two viral diseases – banana bunchy top disease and banana streak virus disease (Carlier et al., 2000; Ngatat et al., 2017; Tushemereirwe et al., 2004). Black Sigatoka, *Mycosphaerella fijiensis* Morelet, is the most widespread and most important fungal leaf disease in Africa where it is considered a major economic threat to bananas and plantains (Fullerton & Casonato, 2019; Rieux et al., 2019), with yield losses due to the disease ranging from 20% to 80%, especially during the second cycle of production (Aba et al., 2011; Mobambo et al., 1996). Local cultivars grown in West and Central Africa have been reported to be highly susceptible to Black Sigatoka disease (Tenkouano et al., 2010).

Plant-parasitic nematodes and banana weevils constitute the major worldwide pests affecting, respectively, the roots and corms of bananas and plantains (Gold et al., 1998; Hauser, 2000). Three groups of nematodes (*Radopholus similis* Cobb, *Meloidogyne* spp., and *Pratylenchus* spp.) are considered important nematode pests of bananas and plantains in Africa (Viljoen et al., 2004), with *R. similis* (the burrowing nematode) being of highest importance (Coyne et al., 2006; Speijer & Fogain, 1999). Besides their impact on declining nutrient absorption, poor anchorage, and plant lodging (Fogain, 2001; Masanza et al., 2006), nematode infestations can predispose bananas to other problems such as increased banana weevil infestation (Coyne et al., 2006; Gold et al., 1998).

Four weevil species have been reported to infest bananas and plantains worldwide, of which *Cosmopolites sordidus* (Germar) is considered of highest economic importance (Okolle et al., 2009). Banana weevil damage manifested in tunneling mostly in the corm (galleries) weakens the stability of the mat and impedes water and nutrient uptake, resulting in reduced bunch weights, plant lodging, mat disappearance, and shortened plantation life (Gold et al., 2001; Okolle et al., 2009). Damage and yield losses increase with time and crop cycle (Masanza et al., 2006). Together, nematode, weevil Black Sigatoka damage along with generally declining soil fertility contribute to increasing yield losses and reduction in plantain farm lifespan, leading to farm abandonment (Norgrove & Hauser, 2014; Okolle et al., 2009). As a result, farmers tend to establish new fields on forest lands, which adds to the environmental costs of plantain farming.

Synthetic fungicides and leaf pruning are recommended for the control of Black Sigatoka disease; however, they can add approximately 30% to the total cost of production (Etebu & Young-Harry, 2011; Kumakech et al., 2015). Black Sigatoka disease in plantains and bananas has been effectively controlled with the

application of fungicides (Barraza et al., 2011; Marín et al., 2007). Proper management of organic matter and soil fertility can reduce Black Sigatoka damage (Etebu & Young-Harry, 2011; Mobambo et al., 2008).

Plant parasitic nematode infestations in plantain can be managed with the use of clean planting material, crop rotation, fallowing and mulching with some species such as *Pennisetum purpureum* and *Tithonia diversifolia*, and synthetic nematicide (Coyne et al., 2006; Speijer & De Waele, 1997). In particular, the use of *T. diversifolia* mulch has been shown to reduce nematode damage and improve yields (Fogain, 2001; Ssali et al., 2003; Tripathi et al., 2015). Various physical methods, including steam disinfection, soil solarization, and hot water injection, have also been employed with varying success for the control of nematodes as alternatives to soil fumigation with synthetic chemicals (Su et al., 2015).

Banana weevil control is currently based on cultural practices, such as the use of clean planting material (Fogain, 2001; Okolle et al., 2009), mass trapping of adult weevils with the pheromone Cosmolure or pseudostem traps (Alpizar et al., 2012), cover crops (Carval et al., 2016) and field sanitation (Gold et al., 2001). However, high labour input and material requirements limit the adoption of weevil trapping and field sanitation (Gold et al., 1998; Tinzaara et al., 2005) and cover crops can reduce weevil numbers but not damage to plants (Carval et al., 2016). Several factors related to weevil biology, pheromone efficacy, trapping design, cropping system, and environmental factors were found to variously influence the effectiveness of pheromone baited (Beauhaire et al., 1994; Jallow & Achiri, 2016). The proper use of synthetic insecticide (organophosphates and carbamates) is effective against banana weevils but is economically not feasible for subsistence producers. In addition, the banana weevil has developed resistance to a range of commonly used chemical pesticides (Barraza et al., 2011; Gold, 1998; Jallow & Achiri, 2016).

In light of issues with labor and material costs, and environmental and human hazards of the various control options for diseases, nematodes, and weevils, host plant resistance to these biotic constraints has been regarded as the most appropriate and sustainable control strategy (Barraza et al., 2011; Polidoro et al., 2008; Tenkouano et al., 2010). Plantain hybrids with resistance to Black Sigatoka disease and good agronomic characteristics have been developed by breeding programs at the International Institute of Tropical Agriculture (IITA, Nigeria), the African Research Centre on Banana and Plantain (CARBAP, Cameroon), and the Fundación Hondureña de Investigación Agrícola (FHIA, Honduras; Dépigny et al., 2019; Tenkouano & Swennen, 2004). Most of these improved varieties have been reported to be 2–

5 times more productive than traditional plantains landraces and with considerable resistance against the Black Sigatoka disease in several countries and across a wide range of agro-ecologies (Leiva-Mora et al., 2015; Tenkouano et al., 2010; Tenkouano & Swennen, 2004). However, since the introduction of several of these hybrids into Cameroon and other countries in Central Africa, information on their adaptability and performance under the country's agroecology as well as their response to the Black Sigatoka disease and to nematodes and weevils are still sparce. Moreover, while the use of improved plantain hybrids provides an ecologically sustainable management option for pests and diseases, their acceptability by consumers remains a major challenge.

The overall objective of the present study is to evaluate the agronomic performance of eight improved plantain hybrids from three institutions – CARBAP, FHIA, and IITA – along with a widely planted local plantain over 3 years. Specifically, the study seeks (1) to determine the differences in disease infection and pest infestations, targeting Black Sigatoka, nematodes and weevils, plantain growth and survival, and fruit production and quality; and (2) to evaluate farmers' perception and ranking of plantain vegetative growth, bunch and fruit appearance, and the quality of various plantain food preparation. Together, the information obtained from the study will inform researchers' and farmers' choice of plantains and provide the country's government with the information necessary for the eventual official release of the plantains for widespread planting. Moreover, given the similarities of the environment in the bimodal rainfall humid forest agro-ecology of the study area with much of Central Africa – between the Congo and Sanaga rivers, the findings of the present study would be relevant to countries beyond Cameroon.

Materials and methods

Study area

The study was carried out at the research farms of the International Institute of Tropical Agriculture (IITA) in Nkolbisson, Cameroon (03°51.791′N; 011°27.706′E, 747 m.a.s.l.). The site is in the humid forest with bimodal rainfall agro-ecological zone with 125–175 days of rainfall distributed over 7–9 months in 2 rainfall seasons, from March through mid-July and from September through November. Average temperature and relative humidity ranged from 22.4°C to 24.6°C and from 84.5% to 89.9%, and total rainfall of 1,024.6 mm during the first cropping season, and from 23.0°C to 24.6°C and 82.7%–88.2%, and a lower total rainfall (805 mm) during

the second cropping season (Abang et al., 2021). The tropical, humid climate of the study site is favourable for plant disease development. The soil is a Rhodic Kandiudult (USDA classification), with well-drained sand clay soil in the 30 cm layer (Selatsa et al., 2009).

Plant materials

Seven improved plantain genotypes originated from the International Institute of Tropical Agriculture (IITA, Nigeria), the African Research Centre on Banana and Plantain (CARBAP, Cameroon), and the Honduran Foundation for Agricultural Research (FHIA, Honduras; Table 1). One local cultivar (*Ebang*, triploid AAB) from Cameroon was used as a check.

Experimental design and trial establishment

The trial was established in October 2012 on land that had been in a natural fallow (i.e. with spontaneous natural plant growth) for 4 yrs, which is a very common fallow system throughout the Congo Basin (Ngobo et al., 2004). The trial was set up as a randomized complete block design with three replicate blocks (experimental units) and eight plantain genotypes per block (see, Table 1 for details of the plantains). Plants of the eight genotypes were grown from disease and pest-free tissue culture plantlets produced by the IITA-Cameroon tissue culture laboratory. Six-month-old plants were planted in 30 × 30 × 30 cm holes at 3 × 2 m spacing, respectively, between and within the rows with 20 plants per experimental plot. Two kg of locally sourced poultry manure was mixed with the soil at planting time and repeated twice thereafter, in March 2013 and 2014. Average contents of nutrients in chicken manure were 1.95 ± 0.25% N, 1.42 ± 0.25% P, and 1.97 ± 0.32% K. At the start of the experiment, composite soil samples were taken from each plot by sampling the upper 25 cm with an auger at 5 different points in each plot (4 points close to each corner and one in the middle). The samples were then analysed at the IITA-Cameroon soils laboratory for pH, total N, available P, and exchangeable K by following the methodology described by Okalebo et al. (1993). The soil of the trial was characterized by pH (5.50 ± 0.19), N (0.14 ± 0.02%), P (2.69 ± 0.23%), and K (0.15 ± 0.07%). Weeding and leaf pruning were done manually as needed. There were no other interventions throughout the 28 months of the trial.

Sampling procedure

Agronomic performance
Agronomic performance of tested plantain genotypes was assessed according to the methodology described by Gaidashova et al. (2010). Data were collected during two cycles of production – on the mother plant for the first cycle and the first ratoon for the second cycle. In each block and for each genotype plot, six inner plants were evaluated at flowering and harvest stages. Agronomic performance data included four growth parameters: plant height, girth, and the number of standing and functional leaves (NSL). The number of suckers was recorded at flowering. Plant girth was measured at 100 cm above the soil level at the flowering and harvest stages. The number of functional and standing leaves counted at flowering (NSLF) were those having at least 75% of leaf area green. At harvest, the number of standing and functional leaves (NSLH) was also recorded. Six yield traits were measured at harvest including bunch weight (kg), number of hands per bunch, fruit length (cm), fruit girth (cm), and fruit weight (g).

Black Sigatoka disease damage
Black Sigatoka disease infections on tested plantain genotypes were evaluated with the pathological parameters described by Oluma et al. (2004). The youngest leaf with streaks (YLSt) and the youngest leaf spotted (YLS) were recorded at flowering. YLSt is the rank from the topmost open leaf downward, of the 1st leaf bearing disease

Table 1. Name, source, genome, and type of plantain genotypes evaluated agronomic traits and resistance to Black Sigatoka, nematodes, and weevils.

Genotypes	ITC code[a]	Origin	Institute[b]	Genome	Type
FHIA 21	1332	Honduras	FHIA	AAAB	French hybrid
PITA 23	1813	Nigeria	IITA	AAB	French hybrid
PITA 27	1816	Nigeria	IITA	AAB	French hybrid
CRBP 535	0066	Cameroon	CARBAP	AAB	French hybrid
CRBP 568	0465	Cameroon	CARBAP	AAB	French-Horn hybrid
CRBP 838	0447	Cameroon	CARBAP	AAB	French hybrid
CRBP 969	0448	Cameroon	CARBAP	AAB	French hybrid
Ebang (Local)	-	Cameroon	Local selection	AAB	False horn

[a]Bioversity International Musa International Transit Centre, Leuven, Belgium.
[b]Abbreviations: Honduran Foundation for Agricultural Research (FHIA); International Institute of Tropical Agriculture (IITA); African Research Centre on Banana and Plantain (CARBAP).

symptoms (yellowing depigmentation on lower surface). YLS is the number of the 1st (from the topmost leaf) leaf bearing at least 10 necrotic spots with dry centers (Oluma et al., 2004). YLS is an important parameter to differentiate the response of *Musa* genotypes to Black Sigatoka disease (Barekye, 2011). The position of YLS is used to indicate the severity of the disease (Tushemereirwe et al., 2011). Index of non-spotted leaves (INSL) was derived from NSL (number of standing leaves) and YLS parameters was calculated as follows:

$$INSL(\%) = \frac{100*(YLS-1)}{NSL}$$ (Selatsa et al., 2009)

This index represents the percentage of standing leaves without symptoms of Black Sigatoka (Craenen, 1998) and indicates also the severity of Black Sigatoka (Mobambo et al., 1996; Oluma et al., 2004). The leaf survival rate after the production phase was determined as the ratio of the number of standing leaves at harvest over the number of standing leaves at flowering (NSLH/ NSLF; Seydou et al., 2016).

Plant parasitic nematode damage

Root damage by parasitic nematodes was equally assessed at flowering and harvest stages following the method described by Speijer and De Waele (1997). This was done on the same plants on which agronomic data were collected. At the base of each sampled plant, a hole $(20 \times 20 \times 20\ cm^3)$ was dug to collect all exposed roots. The roots were separated into two groups – dead and functional roots. Root necrosis index (RNI) was estimated on five functional roots randomly selected from a sample. The selected roots were cut into 10 cm fragments. Each fragment was longitudinally and symmetrically divided, and the necrotic area was scored as the percentage of cortical tissue damaged by nematode infestation. Each root fragment accounted for a maximum score of 20% and the 5 root fragments accumulated to a total score of 100% in a sample. RNI was estimated using a scale of score 1–5 as follows: 1 = no damage, i.e. absence of necrosis; 2 = low attack: <25% of root cortex presents necrosis; 3 = moderate attack: 26–50% of root cortex presents necrosis, 4 = severe attack: 51–75% of root cortex presents necrosis; 5 = very high attack: >75% of root cortex presents necrosis (Loubana et al., 2007).

Banana weevil damage

Weevil damage was evaluated at harvest on six inner plants in each experimental plot. This was done according to the method described by Gold et al. (2001). The harvested plants were uprooted, and corms were isolated from the pseudostems at the collar level. A transversal section was made in the corm, 5 cm from the collar level to expose the corm surface. The number of galleries was recorded and transformed to a 0–100% score as follows: no gallery = no damage = 0; 1 or 2 galleries = 5%; 10 galleries = 10%; 30 galleries = 25%; 40 galleries = 50%; 60 galleries = 75%, and 100 galleries = 100% (Dassou et al., 2016; Gold et al., 1998).

Farmer's perception of agronomic performances of plantain genotypes

At harvest of the 1st cycle, a field day was organized to collect the perception of plantain producers of agronomic performances of the eight plantain genotypes. A total of 20 plantain producers of both sexes (35% female and 65% male) participated in the field characterization of 8 plantain genotypes at the harvest stage. Each genotype was scored for plant height and bunch size. For each characteristic, the following scale was used: 1 = Very good, 2 = Good, 3 = Poor. Then, each farmer scored his/her acceptance of the genotype based on plant height and bunch size with the following scale: 1 = Strongly agree, 2 = Agree, 3 = Disagree.

Evaluation of plantain for food preparation

At harvest, three common plantain foods (boiled, pounded, and chips) were prepared for each genotype by following the methodology described by Newilah et al. (2005). Fingers (fruits) from different bunches of a genotype were randomly selected and fruits were manually cleaned and peeled with a stainless-steel knife. For chips preparation, plantain fingers were sliced with dicer into 2 mm thick circular pulp discs and fried in refined palm oil until light brown or golden colour at an oil temperature of 165°C for 3 min. For boiled plantain, fingers were cooked in water for 30 min. Half of the boiled plantains were served directly for tasting while the other half was pounded into a traditional homogenous flexible pastry using a wooded mortar and pestle. This food is called '*Ntuba*' in Cameroon (Newilah et al., 2005). Each preparation was assessed by 42 untrained Cameroonian plantain consumers: 24 males and 18 females, aged from 22 to 58 yrs, with an average of 26 yrs of age, including the 20 plantain farmers who evaluated the plants in the field. The panelists were pre-screened; only those who consumed plantain regularly were invited to participate. A 3-point scale (1 = Good, 2 = Acceptable, 3 = Non-acceptable) was used to evaluate the plantain food preparation quality in terms of texture, taste, and general acceptance.

Statistical analysis

Data were analysed and presented per fruiting cycle for each genotype. Data with a normal distribution (plant

height, girth height, bunch weight, finger length, and circumference of finger) were subjected to analysis of variance using R software package version 3.6.3 (R Development CoreTeam, 2020). Generalized Linear Models (GLMs) with quasi-Poisson and quasi-binomial distributions of errors were used to analyse the data related to the number of standing leaves at harvest and flowering, the number of suckers, the ratio NSLH/NSLF, Index of non-spotted leaves (INSL), roots necrosis index and weevil severity, respectively. The likelihood-ratio test based on the Fisher–Snedecor test (over-dispersed data) was used to test the significance of the effects. Tukey's range test was used for multiple comparisons to determine the significant differences (at 5% probability level). Wilcoxon test was used to compare the rank of YLSt and YLS among genotypes. Data on the producer's perception and acceptability were analysed using the chi-squared test with JMP software package, version 8 (SAS, 2008).

Results

Agronomic characteristics of plantain genotypes

Plant height of all the genotypes ranged from 186.6 ± 2.8 cm to 283.7 ± 11.4 cm for cycle 1, and from 201.5 ± 8.3 cm to 369.4 ± 9.7 cm for cycle 2. CRBP 568 plants were the shortest during both cycles. Pseudostem girth of all genotypes varied between 33.6 ± 0.8 cm and 45.6 ± 1.1 cm for cycle 1, and between 40.9 ± 1.8 cm and 46.5 ± 0.8 cm for cycle 2). Plants of PITA 27 had the smallest pseudostem diameter during the 2 cycles. Plantain genotypes showed highly significant differences ($P < 0.001$) for plant height and pseudostem girth during the two cycles of production (Table 2). A higher number of suckers were recorded with PITA 27 (7.8 ± 0.8 suckers) and the lowest for CRBP 568 (4.1 ± 0.3 suckers). Sucker production was significantly different among genotypes in the first cycle (F $_{(7, 14)} = 4.6$; $P < 0.001$), but not in the second (F $_{(7, 14)} = 0.5$; $P > 0.05$).

At flowering, the number of standing and functional leaves (NSLF) for all the genotypes ranged from 7.8 ± 1.6 (PITA 23) to 10.9 ± 0.6 (CRBP 568) for the 1st cycle and from 9.1 ± 0.8 (*Ebang*) to 10.8 ± 0.1 (CRBP 969) for the 2nd cycle (Table 3). Leaf emission at flowering stage was significantly different among genotypes for the 1st cycle (F $_{(7, 14)} = 4.6$; $P < 0.001$) and for the 2nd cycle (F $_{(7, 14)} = 0.4$; $P < 0.001$). Conversely, the remaining standing and functional leaves at harvest (NSLH) for all the improved genotypes were significantly higher than those of local for the 1st cycle (F $_{(7, 14)} = 12.6$; $P < 0.001$) and 2nd cycle (F $_{(7, 14)} = 8.7$; $P < 0.001$; Table 3). The number of remaining leaves of standing and functional leaves for the improved hybrids was significantly higher than local plantain for both cycles. There was a significant reduction of standing leaves from flowering to harvest for all improved plantain, but this reduction was even more drastic in the local plantain *Ebang*. The surviving rate of leaves (equivalent to NSLH/NSLF ratio) was significantly higher on improved genotypes than local plantain for both cycles and ranged from 0.1 ± 0.0 to 0.4 ± 0.0 for the 1st cycle and 0.1 ± 0.0 to 0.4 ± 0.0 for the 2nd cycle (Table 3).

Plantain genotypes significantly influenced all yield traits for the two cycles of evaluation (Table 4). During the 1st cycle, the average number of hands per bunch for all the genotypes varied from 3.8 ± 0.2 to 7.0 ± 0.1, with finger length varying from 20.1 ± 0.8 cm to 24.4 ± 0.7 cm; and girth from 12.1 ± 0.6 cm to 14.2 ± 0.5 cm. Bunch weight ranged from 9.6 ± 0.5 kg to 17.9 ± 0.7 kg with finger weight from 136.1 ± 9.0 g to 254.2 ± 8.2 g. The yield traits of bunches for all the genotypes harvested during the 2nd cycle also showed significant differences among genotypes. Overall, PITA 27 produced the lowest number of hands while PITA 23 and FHIA 21 produced the highest number of hands for both cycles. PITA 27 also had the smallest fingers while local plantains showed the longest fingers among all the genotypes. For fruit girth, CRBP 535 was the largest for both cycles.

Table 2. Average plant height ($\pm$ SE), pseudostem girth and number of suckers of improved and local plantain genotypes at flowering for the 1st and 2nd production cycle.

Genotypes	Height (cm)		Girth (cm)		Suckers	
	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
FHIA 21	244.2 ± 11.8^b	280.8 ± 12.8^d	42.2 ± 1.3^b	41.5 ± 0.3^{bc}	5.9 ± 0.1^b	3.6 ± 1.0
PITA 23	283.7 ± 11.4^a	369.4 ± 9.7^a	41.6 ± 0.8^b	44.6 ± 0.7^{ab}	5.7 ± 0.5^{bc}	3.5 ± 0.5
PITA 27	244.2 ± 6.5^b	309.7 ± 14.5^{cd}	33.6 ± 0.8^c	40.9 ± 1.8^{bc}	7.8 ± 0.8^a	3.7 ± 0.9
CRBP 535	272.5 ± 19.2^a	307.2 ± 7.1^{bc}	44.1 ± 1.5^{ab}	45.9 ± 1.3^a	4.9 ± 0.6^{bcd}	2.5 ± 0.3
CRBP 568	186.6 ± 2.8^c	201.5 ± 8.3^e	41.9 ± 0.5^b	40.4 ± 1.7^c	4.1 ± 0.3^d	3.5 ± 0.4
CRPP 838	272.2 ± 3.5^a	333.1 ± 12.9^{abc}	45.6 ± 1.1^a	46.5 ± 0.8^a	4.6 ± 0.1^{bcd}	3.6 ± 0.7
CRBP 969	281.4 ± 5.4^a	349.4 ± 11.4^{ab}	44.1 ± 1.0^{ab}	46.9 ± 1.9^a	5.7 ± 0.5^{bc}	3.8 ± 0.5
Ebang (Local)	272.8 ± 11.9^a	323.7 ± 20.3^{bc}	41.6 ± 0.8^b	43.5 ± 1.5^{abc}	4.4 ± 0.9^{cd}	2.4 ± 0.2
F	11.1	15.0	13.7	3.4	4.6	0.5
Df	7,14	7,14	7,14	7,14	7,14	7,14
P	0.001	0.001	0.001	0.001	0.01	0.79

Means in a column followed by different letters are significantly different from each other (Tukey's range test $P < 0.05$).

Table 3. Average number of standing and functional leaves at flowering and harvest, and ratio of number of standing leaves at harvest over number of standing leaves at flowering (NSLH/NSLF) (± SE) of improved and local plantain genotypes during two cycles of production.

	NSLF*		NSLH		Ratio	
Genotypes	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
FHIA 21	9.8 ± 0.3[ab]	9.7 ± 0.3[b]	2.1 ± 0.2[bcd]	2.2 ± 0.3[b]	0.3 ± 0.0[b]	0.2 ± 0.0[b]
PITA 23	7.8 ± 1.6[b]	10.5 ± 0.2[a]	1.9 ± 0.2 [cd]	2.9 ± 0.4[ab]	0.3 ± 0.0[b]	0.3 ± 0.0[b]
PITA 27	8.7 ± 0.7[ab]	9.4 ± 0.5[c]	2.5 ± 0.0[ab]	2.6 ± 0.2[ab]	0.3 ± 0.0[b]	0.3 ± 0.0[b]
CRBP 535	8.3 ± 0.9[b]	10.6 ± 0.2[a]	2.3 ± 0.4[abc]	2.4 ± 0.5[b]	0.2 ± 0.0[b]	0.2 ± 0.0[b]
CRBP 568	10.9 ± 0.6[a]	10.4 ± 0.3[a]	2.8 ± 0.1[a]	2.9 ± 0.2[ab]	0.3 ± 0.0[b]	0.3 ± 0.0[b]
CRBP 838	9.8 ± 0.2[ab]	10.7 ± 0.3[a]	2.7 ± 0.1[a]	3.2 ± 0.2[a]	0.4 ± 0.0[a]	0.4 ± 0.0[a]
CRBP 969	9.4 ± 1.0[ab]	10.8 ± 0.1[a]	1.8 ± 0.1[d]	2.2 ± 0.2[b]	0.2 ± 0.0[b]	0.2 ± 0.0[b]
Ebang (Local)	9.2 ± 0.3[ab]	9.1 ± 0.8[d]	0.6 ± 0.1[e]	0.4 ± 0.1[c]	0.1 ± 0.0[c]	0.0 ± 0.0[c]
F	4.6	0.4	12.6	8.7	13.4	13.8
Df	7,14	7,14	7,14	7,14	7,14	7,14
P	0.001	0.001	0.001	0.001	0.001	0.001

*NSLF: number of standing leaves at flowering; NSLH: number of standing leaves at harvest; Ratio = NSLH/NSLF. Means in a column followed by different letters are significantly different from each other (Tukey's range test $P < 0.05$).

Table 4. Yields (Mean ± SE) of improved and local plantain genotypes during two cycles of production.

Cycles	Genotypes	NH*	FL (cm)	GF (cm)	FW (g)	BW (kg)
Cycle 1	FHIA 21	6.8 ± 0.1[a]	23.2 ± 0.6[ab]	13.7 ± 0.6[a]	193.7 ± 7.5[bc]	17.9 ± 0.7[a]
	PITA 23	7.0 ± 0.1[a]	21.6 ± 0.6[bc]	13.4 ± 0.1[ab]	137.9 ± 0.2[d]	14.6 ± 0.4[b]
	PITA 27	3.8 ± 0.2[d]	20.1 ± 0.8[c]	12.1 ± 0.6[b]	168.0 ± 3.8 [cd]	10.0 ± 0.8[d]
	CRBP 535	5.8 ± 0.2[bc]	23.4 ± 0.6[ab]	14.2 ± 0.5[a]	167.2 ± 7.8 [cd]	16.4 ± 0.6[a]
	CRBP 568	5.9 ± 0.1[b]	20.8 ± 0.8[c]	13.3 ± 0.8[ab]	202.1 ± 10.9[b]	12.7 ± 0.8[c]
	CRBP 838	6.8 ± 0.1[a]	20.7 ± 1.0[c]	13.3 ± 0.5[ab]	136.1 ± 9.0[d]	13.5 ± 0.3[bc]
	CRBP 969	6.1 ± 0.1[b]	21.9 ± 0.3[bc]	12.9 ± 0.3[ab]	160.2 ± 11.5[d]	14.1 ± 0.8[bc]
	Ebang (Local)	5.3 ± 0.1[c]	24.4 ± 0.7[a]	14.2 ± 0.5[a]	254.2 ± 8.2[a]	9.6 ± 0.5[d]
	F	36.0	4.5	1.5	11.1	20.0
	Df	7,14	7,14	7,14	7,14	7,14
	P	0.001	0.001	0.001	0.001	0.001
Cycle 2	FHIA 21	7.0 ± 0.2[ab]	23.8 ± 0.8[ab]	14.0 ± 0.3[a]	199.8 ± 0.6[bc]	19.7 ± 0.3[a]
	PITA 23	7.5 ± 0.2[a]	22.3 ± 0.3[b]	13.4 ± 0.8[ab]	162.2 ± 8.6[d]	17.3 ± 1.0 [b]
	PITA 27	4.2 ± 0.3[d]	21.9 ± 0.1[b]	12.6 ± 0.8[b]	172.3 ± 9.1 [cd]	14.3 ± 0.5[bc]
	CRBP 535	5.9 ± 0.1[c]	23.3 ± 0.2[ab]	14.0 ± 0.4[a]	180.6 ± 8.3[bcd]	17.0 ± 1.1[b]
	CRBP 568	5.8 ± 0.2[c]	23.1 ± 0.4[ab]	13.9 ± 0.3[ab]	213.8 ± 6.4[b]	14.1 ± 0.1 [cd]
	CRBP 838	6.1 ± 0.3[bc]	21.9 ± 0.3[b]	13.7 ± 0.5[ab]	158.6 ± 7.5[d]	15.0 ± 0.8[bc]
	CRBP 969	6.5 ± 0.2[bc]	21.8 ± 0.3[b]	13.2 ± 0.3[ab]	195.6 ± 10.5[bcd]	15.5 ± 0.4[bc]
	Ebang (Local)	5.8 ± 0.2[c]	25.2 ± 0.3[a]	13.7 ± 0.2[ab]	255.8 ± 2.5[a]	12.8 ± 0.9[c]
	F	8.9	4.1	1.6	5.7	7.4
	Df	7,14	7,14	7,14	7,14	7,14
	P	0.001	0.001	0.001	0.001	0.001

*NH: number of hands; FL: fruit length; GF: girth of fruit; FW: fruit weight, BW: bunch weight; means in a column followed by different letters are significantly different from each other (Tukey's range test $P < 0.05$).

The heaviest fruit weight was recorded on the local *Ebang* for both cycles. FHIA 21 produced the heaviest bunches the local *Ebang* lightest bunches (Table 4).

Response of plantain genotypes to the Black Sigatoka disease

Improved plantain hybrids responded differently to Black Sigatoka infection compared with the local plantain during the two cycles of evaluation. The youngest leaf with streaks (YLSt) was recorded from the third leaf on local plantain plants for both cycles. For hybrids, it was noted from the fourth to the seventh leaf in the 1st cycle ($\chi^2 = 55.7$; $P < 0.001$) and on the 4th leaf during the 2nd cycle ($\chi^2 = 47.2$; $P < 0.001$; Table 5). Youngest leaves with spots (YLS) ranked 5th on the local cultivar but 7th

on the improved genotypes for the 1st cycle ($\chi^2 = 46.3$; $P < 0.001$) and the 2nd cycle ($\chi^2 = 67.9$; $P < 0.001$). The index of non-spotted leaves (INSL) for all the genotypes ranged from 43.1 ± 1.0 to 77.8 ± 0.7% in the 1st cycle and from 41.9 ± 1.7 to 74.7 ± 1.7% for the 2nd cycle. No significant difference was found among hybrids, but they all scored higher than the local plantain *Ebang* during the two cycles.

Nematode damage of plantain roots

The level of root necrosis recorded for all plantain genotypes in the 1st cycle was significantly lower than in the 2nd cycle at the flowering and harvest stages (Figure 1). At flowering in both cycles, the number of roots damaged by nematodes on the local plantain (*Ebang*)

Table 5. Rank of the youngest leaf with streaks (YLSt) and spots (YLS) of Black Sigatoka disease (median (min-max)) and index of non-spotted leaves (INLS) (mean percentage ± SE) on plantain genotypes.

|	YLSt*		YLS		INSL (%)	
Genotypes	Cycle 1	Cycle 2	Cycle 1	Cycle 2	Cycle 1	Cycle 2
FHIA 21	6 (4–8)**	4 (3–8)	8 (5–11)	8 (6–10)	76.4 ± 5.4^{ab}	72.1 ± 2.3^a
PITA 23	5 (3–9)	4 (3–6)	6.5 (4–10)	9 (7–10)	73.0 ± 5.9^{ab}	71.6 ± 1.3^a
PITA 27	5 (4–9)	4 (3–7)	7 (5–10)	7 (6–10)	73.2 ± 0.9^{ab}	73.7 ± 1.8^a
CRBP 535	4.5 (2–7)	4 (4–6)	7 (2–10)	9 (7–9)	66.3 ± 4.5^{bc}	74.7 ± 1.7^a
CRBP 568	5 (4–8)	4 (3–7)	7.5 (5–10)	8 (6–10)	58.6 ± 5.2^c	65.2 ± 1.5^a
CRBP 838	7 (4–9)	5 (4–6)	9 (5–10)	9 (7–10)	77.8 ± 0.7^a	71.8 ± 3.9^a
CRBP 969	6.5 (4–7)	4 (4–7)	8 (5–11)	8 (7–9)	75.3 ± 4.0^{ab}	73.3 ± 1.6^a
Ebang (Local)	3 (2–6)	3 (3–4)	5 (4–6)	5 (4–6)	43.1 ± 1.0^d	41.9 ± 1.7b
F	4.6	4.4	3.3	32.3	9.04	9.9
Df	7,14	7,14	7,14	7,14	7,14	7,14
P	0.01	0.01	0.01	0.001	0.001	0.001

*YLSt: youngest leaf with streaks; YLS: youngest leaf spotted; INSL: Index of Non-Spotted Leaves; **Means in INSL column followed by different letters are significantly different from each other (Tukey's range test $P < 0.05$).

was significantly higher than on those of CRBP 535, CRBP 568, which did not present any damage at the flowering stage ($F_{(7, 14)} = 5.2$; $P < 0.001$). There was no difference in root necrosis index among the improved genotypes (Figure 1). At harvest, root damage on the local plantain *Ebang* was significantly higher than roots of FHIA 21, CRBP 535, CRBP 568, and CRBP 838 ($F_{(7, 14)} = 16.6$; $P < 0.001$; Figure 1). During the 2nd cycle, nematode root damage was higher than in the 1st cycle and varied with plantain genotypes (Figure 1). However, the root necrosis index recorded on the local plantain was higher with 51–75% of root cortex presenting necrosis, than on

improved plantains at flowering ($F_{(7, 14)} = 5.1$; $P < 0.001$) and at harvest ($F_{(7, 14)} = 4.6$; $P < 0.001$).

Weevil damages on plantain genotypes

The level of weevil damage varied among genotypes for the two cycles (Figure 2). For the 1st cycle, weevil damage on CRBP 838 was significantly higher than on other genotypes, except for FHIA 21. By contrast, during the 2nd cycle, weevil damage was higher on all genotypes but more pronounced on the local *Ebang* compared with the hybrids ($F_{(7, 14)} = 4.1$; $P < 0.001$).
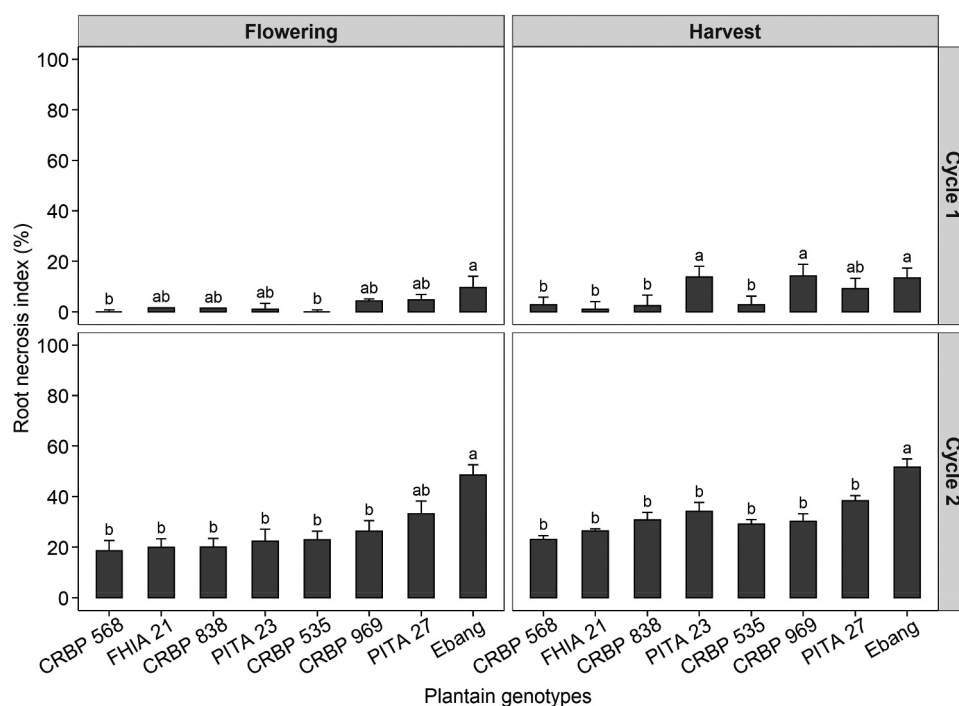
Figure 1. Root necrosis index (%; vertical hatched bar represents ± SE) of burrowing plant-parasitic nematodes on improved and local plantain genotypes at flowering and harvest stage for the first and second cycle of production. Means with different letters are significantly different (Tukey's range at $P < 0.05$).
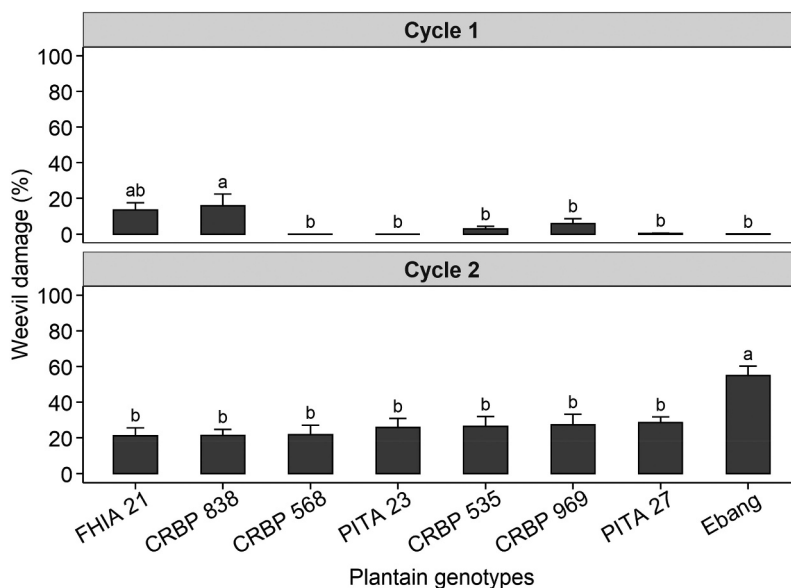
Figure 2. Damage of banana weevils (%; vertical hatched bar represents ± SE) on improved and local plantain genotypes at harvest stage for two cycles of production. Means with different letters are significantly different (Tukey range at $P < 0.05$).

Farmer's perception of plantain genotypes in the field

Plant height and bunch size of improved and local plantain genotypes were appreciated differently by producers. For plant height, the percentage of farmers that scored a genotype as 'good' ranged from 20% (CRBP 535) to 81.3% (PITA 23; Figure 3a). The shortest genotype CRBP 568 was scored as good by 33% of farmers. There was a difference in the producer's preferences for plant height ($x^2 = 26.5$; P < 0.001). The appreciation of farmers varied also for the bunch size of all the genotypes ($x^2 = 36.6$; P < 0.001). The percentage of farmers that

score bunch size for a given genotype as good ranged from 20% (CRPB 535) to 63% (PITA 23; Figure 3b).

Plantain food preparation evaluation

For the texture of the three preparations, genotype CRBP 838 scored the highest appreciation (84%) for the boiled plantain while *Ebang* was highly appreciated by 84% and 80% of producers, respectively, for the chips and pounded preparations (Figure 4a–c).

The taste of the three preparations was either scored as acceptable or good for all the genotypes. Among the
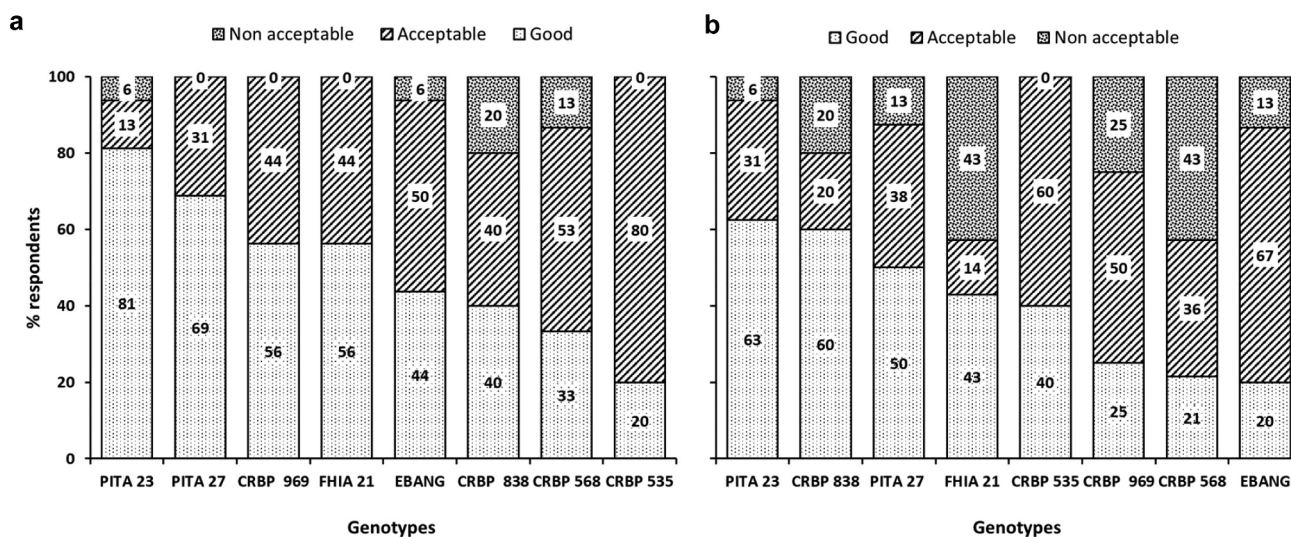

Figure 3. Farmer's perception (%) for plant height (a) and bunch size (b) traits of seven improved and one local plantain genotypes in the field at harvest stage.

genotypes with 'good' taste scored by the consumers, CRBP 838 ranked last – with 83% for boiled preparation, while PITA 23 ranked last for chip preparation (64%) and CRBP 969 (12%) for pounded preparation. FHIA 21 was scored as good by at least 96% of the consumers for the 3 preparations (Figure 4d–f). Overall, at least 78% of the consumers found all the genotypes either acceptable or good (Figure 4g–i).

Discussion

This study has quantified the growth and fruiting characteristics of eight plantain genotypes, through two fruit production cycles, and evaluated the response of the genotypes to infestation or infection by major banana pests and diseases occurring in central Africa. Overall, only CRBP 568 and FHIA 21 were within the recommended plant height of ~3 m, as taller plants require additional staking and are more vulnerable to lodging

due to winds resulting in substantial yield losses (Dzomeku et al., 2009; Noupadja et al., 2007). The shorter genotypes can further support heavier bunches without additional need for bunch and pseudostem support with wooden props (Daniels et al., 2002). Lower hanging bunches also lend themselves to partial harvest as fruits ripen progressively from top to bottom (Dzomeku et al., 2007; Seydou et al., 2016). Conversely, some farmers expressed the concern that lower hanging bunches at lower heights may favor fruit theft, which in some cases can account for 20–30% preharvest losses (Desdoigts et al., 2005; Folefack et al., 2017).

The tested plantains produced, under the conditions of our experiment, a wide range of sucker numbers. In general, the hybrids produced more suckers than the local *Ebang* plantain. PITA 27 produces the highest number of suckers per plant at the flowering stage for the first production cycle. Higher sucker production is considered an advantage as suckers are widely used for
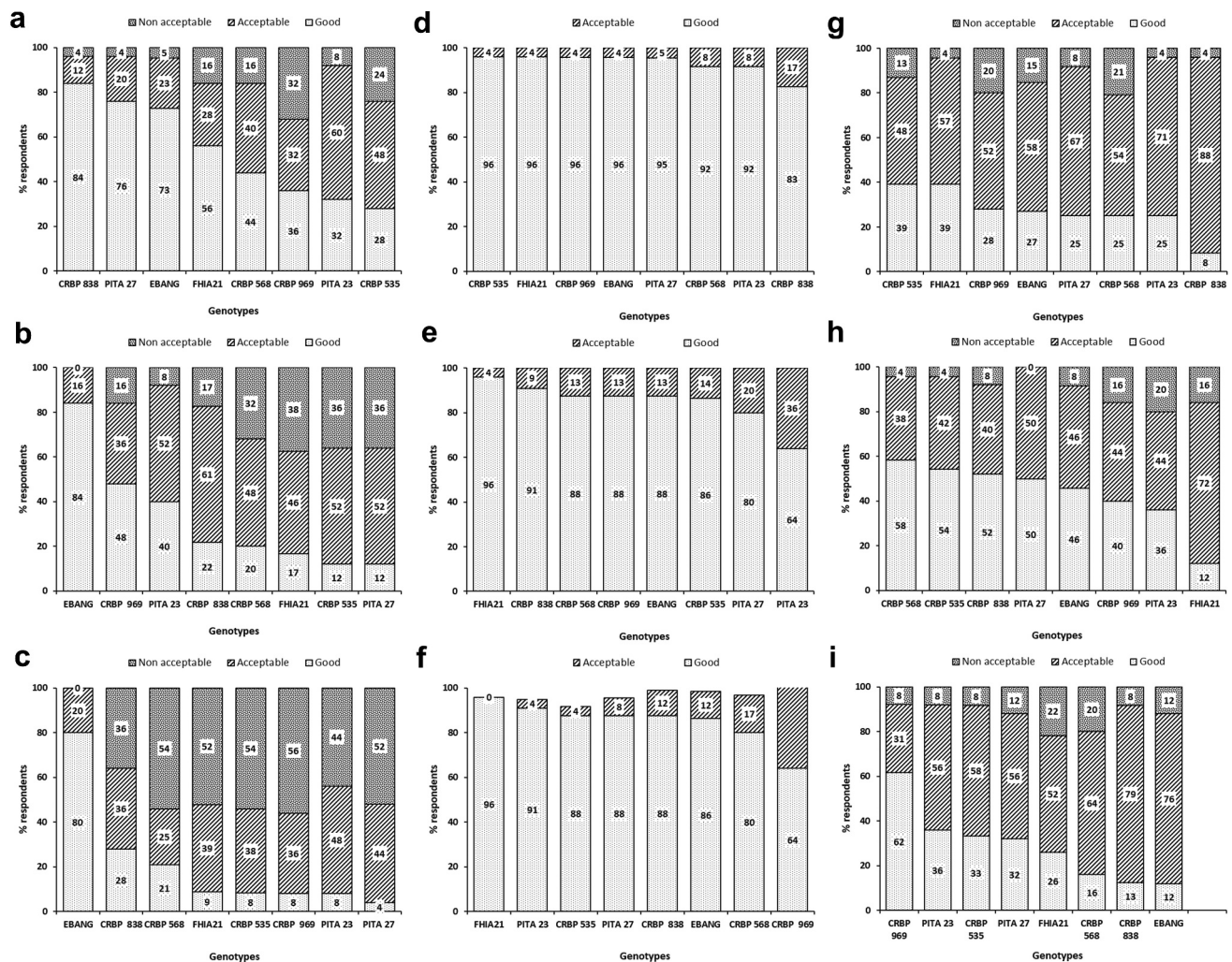
Figure 4. Consumer scoring of the Texture: boiled (a), Chips (b), pounded (c); Taste: Boiled (d), Chips (e), Pounded (f); Overall acceptance: Boiled (g), Chips (h), Pounded (i).

planting new fields or replacing old plants. Suckers are also widely traded and can be an important source of income, in addition to the sale of fruits (Folefack et al., 2017; Tenkouano et al., 2019). Higher suckering characteristics, in combination with good root and shoot development, promote the successful perennial establishment of *Musa* plants (Mukasa et al., 2005). There were also pronounced differences in pseudostem girth among plantain hybrids and the local variety *Ebang*. Larger pseudostem girth can help in sustaining yields over several production cycles (Goenaga et al., 2019). In this study, there was a significant correlation (r = 0.44) between plant girth and bunch yield.

Fruit yield of improved plantains was generally higher than that of the local plantain *Ebang*, except for fruit (finger) weight, which was higher for *Ebang* compared with all the hybrid plantains. This difference could be attributed to the group of plantain to which *Ebang* belongs. *Ebang*, like many local plantain varieties in Cameroon and the broader Central Africa, is in the false horn group of plantain characterized by large fingers, while all the improved plantains were French type, which generally have many fingers with lower finger weight, though generally higher total fruit weight than *Ebang* and similar types. Among the improved genotypes, FHIA 21 produced the heaviest bunches. The lower overall fruit yield of the local plantains could also be due to higher susceptibility to pests and diseases compared with hybrid plantains. The average bunch weight of each improved genotype reported in this study is higher than that reported from farmers' fields in Cameroon (Banful et al., 2008; Dépigny et al., 2019; Pierrot et al., 2002). It is however below the average yield of 24.7 kg recorded in the plantain Optim trial done by CARBAP (S. Dépigny et al., 2018). This yield difference could be explained by the fact that CARBAP trials were conducted in the Littoral region of Cameroon, precisely in Njombe location, which has sedimentary and volcanic fertile soils which is favourable for banana production (Sama-Lang, 2004).

Plantain breeding has focused considerably on developing resistance to Black Sigatoka with the distinct advantage of allowing plants to reach flowering while maintaining a good number of healthy and functional leaves (Adheka et al., 2018; De Langhe et al., 2005).

For all the evaluated genotypes (local and improved), little variation was observed between them for the number of leaves at flowering for both cycles. The total number of functional leaves at flowering has been reported as a good indicator of a plant's tolerance/resistance to pests and diseases and correlates strongly with bunch weight (Alvarez, 1997). All plantain genotypes had at least eight functional leaves at flowering which improved good bunch development and high-quality fruits (Erima et al., 2016). Noupadja et al. (2007) and Boyé et al. (2010) also reported that to obtain heavier bunches and to increase yields, a sufficient number of functional leaves must be present on the plant from flowering to harvest. In our case, from flowering to harvest, the number of functional leaves decreased for all the genotypes, but this reduction was more drastic for the local plantain *Ebang*. This reduction was related to the low ratio NSLH over NSLF in *Ebang*, which effectively reflects the rate of disappearance of leaves as a result of the susceptibility of *Ebang* to Black Sigatoka disease (Tenkouano et al., 2010). In general, the number of functional leaves at flowering and harvest corresponded to Black Sigatoka rankings, i.e. the most resistant (i.e. lowest disease index) had the highest number of functional leaves (Irish et al., 2013). The high value of the ratio of NSLH over NSLF of improved genotypes could be explained by the fact that they were less susceptible to Black Sigatoka disease compared with the local plantain. The level of resistance expressed by all the improved plantains, particularly FHIA 21, is similar to those of Irish et al. (2013) who reported that the FHIA hybrids were consistently more resistant and developed less disease between flowering and harvest (i.e. had more functional leaves at harvest) than other accessions. This was further supported by the rank of the youngest leaf with first symptoms (YLSt), youngest leaves spotted (YLS) and index of non-spotted leaves (INSL) recorded on improved genotypes at flowering. The position of YLSt of local plantain plants was generally close to YLS while for improved hybrids, YLSt and YLS were separated by at least two leaves. This showed the susceptibility of local genotypes to Black Sigatoka compared with the improved plantain hybrids. Additionally, the index of non-spotted leaves (INSL) was higher on improved genotypes compared with *Ebang*. Erima et al. (2016) also mentioned that the high rank of the youngest leaf with streaks, of the youngest leaf, spotted and the high number of functional leaves at flowering shows the tolerance of a genotype against Black Sigatoka. It also correlates significantly with disease development time (Craenen, 1998). This implies that most of the banana hybrids which had more than 8 leaves without spots, were tolerant to Black Sigatoka disease (Mobambo et al., 1996; Oluma et al., 2004). Therefore, the banana hybrids, because of the high index of the non-spotted leaf also had a high surface area to capture more radiant energy and greater potential for photosynthesizing and producing more assimilates which

eventually promote the growth of large plantain bunches (Erima et al., 2016).

Indeed, there was a positive correlation (r = 0.30; P < 0.001) between the number of leaves at flowering and fruit yield and also between the number of standing leaves at harvest and fruit yield (r = 0.33; P < 0.001). Erima et al. (2016) reported that the development of large and heavy banana bunches depends on the photosynthetic potential of the leaves – an increase in banana leaf area increases fruit production but this parameter will have some location specificity as photosynthetic activity is a function of leaf area and incident of solar radiation (Buah et al., 2000; Smithson et al., 2001). Large bunch weight and yield in bananas are also attributed to a higher growth rate before flowering and a high number of functional leaves at flowering and harvest (Erima et al., 2016), but genotype could be a more critical factor in determining the yield potential (Njuguna et al., 2010) which probably explains why some genotypes produced relatively smaller bunches even though they had a good number of functional leaves both at flowering and at harvest.

Nematodes can cause up to 70% losses in plantains and cooking bananas in Africa (Tripathi et al., 2015). In our study, nematode damage was less than 25% root necrosis of burrowing plant parasitic nematodes at flowering and harvest during the 1st cycle, based on the scale used by Loubana et al. (2007).

This could be attributed to the use of healthy planting material (tissue-culture seedlings) for the establishment of the trial. In the 2nd cycle, nematode damage increased for all plantain genotypes at flowering and harvest; however, the local plantain had a nearly 2-fold increase (close to 50%) in root necrosis, indicating greater nematode infestation and damage on local compared with hybrid plantains. The increase of root necrosis from the 1st cycle to the 2nd cycle in all genotypes parallels the increase in banana weevil damage over the two cycles, as was also shown by Masanza et al. (2006). Loubana et al. (2007) demonstrated that plantain yield losses, all else similar, begin to be realized with >50% nematode-caused root necrosis. Other studies, however, have shown that 6–12% root necrosis is sufficient to reduce banana yield (Speijer et al., 1994). It is therefore difficult to conclude from our study if nematode damage which did not exceed 50% necrosis would have contributed to plantain yield losses. Nematode damage would have been expected to increase through the 3rd cycle with more likely effects on plantain yields in our experiment, possibly much more in the local than in the hybrid plantains. While nematode control could be often achieved by periodic application of synthetic nematicide, which is not affordable by farmers and is generally not

environmentally safe. Therefore, plant resistance appears to be a safer alternative to nematode control (Okolle et al., 2009), hybrid plantains offer a level of tolerance that could replace the use of nematicides. Controlled studies are needed to establish the level of yield loss avoidance by hybrid plantains compared with the use of nematicides.

In our study, we relied exclusively on root necrosis symptoms to quantify nematode damage to plantains. Previous studies effectively identified six species of plant parasitic nematodes in Cameroon, namely, *Radopholus similis* (Cobb, 1893) Thorne, 1949; *Helicotylenchus multicinctus* (Cobb, 1893) Sher, 1961; *Meloidogyne* spp., *Haplolaimus pararobutus* (Schuurmans, Stekhoven & Terinissen, 1938) Sher, 1963; *Pratylenchus coffeae* (Zimmerman, 1919) Fillipjev & Schuurmans, Stekhoven, 1941, but the 6th species, *Pratylenchus goodeyi* (Sher & Allen, 1953), occurred mainly at high altitudes (>800 m; Bridge et al., 1995; Loubana et al., 2007). It appears that the lesions recorded on all genotypes corresponded to those of *R. similis* (small dark purplish-red lesions on the outer part of the roots), based on the characteristic necrotic lesions on the roots described by Speijer and De Waele (1997). Future studies would benefit from the isolation and identification of nematode species associated with the plantain genotypes.

Banana weevil damage varied similarly to that of nematodes among the plantain genotypes and cycles of production. For all genotypes, weevil damage was higher in the 2nd cycle (ratoon plant) than in the 1st cycle (mother plant), with improved hybrids appearing more tolerant than the local cultivar. Gold (1998) also reported that weevil damage is usually greater in ratoon crops and that sustained weevil attack may prolong maturation rates and reduce yield by up to 60%. Banana resistance to weevil infestation is often attributed to biophysical factors like suckering ability, corm hardness, resin/sap production, and corm dry matter content to biophysical factors like corm diameter (Kiggundu et al., 2003). In our study, plantain hybrids displayed greater suckering capacity which could explain their greater tolerance to weevil damage compared with the local variety. In the humid agroecology of the present study, and likely elsewhere in Central Africa, the average on-farm plantain production duration is estimated at three cycles with weevil damage attaining its maximum level in the last cycle which can result in plant lodging due to weevil larvae feeding activities in the corm (Gold et al., 2004). The two production cycles of our study may not, therefore, capture the full impact of weevil damage on the performance of the tested genotypes. Nevertheless, weevil damage by the 3rd production cycle would have been still lower on the hybrids

than on the local plantain, based on the observed trends over the first two production cycles.

The appreciation of agronomic traits by producers in the field was diverse. Plant height and bunch size of CRBP 568 and plant height and bunch size of FHIA 21 were highly appreciated by producers in the field which also reflects the performance of both improved genotypes. Thompson and Wainwright (2007) reported that bunch size influences consumer preference and accordingly most banana producers and consumers prefer cultivars with large bunches as well as large well-filled fingers, with a bright external and internal colour. The consistency should be neither too soft nor too hard (Dury et al., 2002). The basis of consumers' preferences for plantains is complex and goes beyond bunch size, finger size, and finger colour, as consumers may choose specific plantains for a particular meal according to their tribe or socio-cultural eating habits (Newilah et al., 2005). Dury et al. (2002) and Udomkun et al. (2021) reported that plantain is not considered by consumers as a homogeneous product and their preference for plantain varieties varies with the type of cooking or uses. In addition, the most important factor influencing Cameroonian consumers' choice of plantain and its products is taste (Udomkun et al., 2021). Therefore, the field performance of a genotype would not guarantee that it will be effectively adopted by producers without sufficient knowledge of the culinary use of the fruits. Following the responses from consumers based on three food preparations, none of the genotypes was rejected, but consumer appreciation varied according to preparation. Although there were some differences in plant agronomic traits, the taste of the tested genotypes was equally appreciated by consumers. Some preparations such as pounded form, however, should be variety-specific (e.g. FHIA 21), corresponding to farmers' expectations.

In this study, we determined the response and infection status of eight plantain genotypes to one leaf disease and two root pests. We did not report on the response of the plantains to other diseases such as Fusarium wilts, Xanthomonas wilt, Moko disease, banana bunchy top disease, and banana streak virus disease because these diseases were not present in the area where the study was conducted. However, the banana bunchy top disease is widely spread in the plantain fields in some localities of the South region of Cameroon, with higher severity in Abang Minko'o locality, which is situated at around 270 km from the trial site (Yaoundé town) in the Centre region (Ngatat et al., 2017).

Conclusion

This study presented agronomic traits and consumers' acceptability of eight plantain genotypes in the humid forest area of Cameroon. These genotypes differed significantly in most of the parameters such as plant height which was diversely interpreted by farmers. The number of functional and standing leaves at flowering and harvest was higher in the hybrids, supporting the knowledge of their resistance to Black Sigatoka compared with the local plantain *Ebang*. The higher number of leaves, along with their tolerance to weevil and nematode damage, may have accounted, at least in part, for higher yields of the hybrids compared with the local plantain *Ebang*. Consumer preference showed that none of the varieties were rejected based on three plantain food preparations. The deployment of improved plantain genotypes will be more powerful and enhance the farmer gains in terms of fruit yield, income, food security, longer plantation longevity, and potential benefits in terms of forest conservation since more food would be produced on the same land that the farmers presently produce using local plantain varieties. Together, high fruit yield, resistance to Black Sigatoka, tolerance to banana weevil and nematode damage, and consumer acceptance should open the way to the release of the hybrids to producers and their introduction into other countries in Central Africa with similar humid ecology to the study area.

Disclosure statement

Funding

ORCID

Jules Appolinaire Lienou http://orcid.org/0000-0002-5622-3460
Sergine Ngatat http://orcid.org/0000-0002-5786-3865
Samuel Nanga Nanga http://orcid.org/0000-0003-4281-8284
Armand Rodrigue Pascal Doumtsop Fotio http://orcid.org/0000-0001-7070-8440
Albert Abang Fomumbod http://orcid.org/0000-0002-2791-9557
Apollin Fotso Kuate http://orcid.org/0000-0002-5247-7519

Komi K. Mokpokpo Fiaboe http://orcid.org/0000-0001-5113-2159
Cletus Fonbah http://orcid.org/0000-0002-5776-2554
Francis Ngome Ayebesone http://orcid.org/0000-0001-7969-3011
Emmanuel Njukwe http://orcid.org/0000-0002-1575-1814
Rachid Hanna http://orcid.org/0000-0002-5715-0144

References

Aba, S., Baiyeri, K., & Tenkouano, A. (2011). Impact of poultry manure on growth behaviour, black Sigatoka disease response and yield attributes of two plantain (Musa spp. AAB) genotypes. *Tropicultura*, *29*(1), 20–27. http://www.tropicultura.org/text/v29n1/20.pdf

Abang, A. F., Fotso Kuate, A., Nanga Nanga, S., Okomo Esi, R. M., Ndemah, R., Masso, C., Fiaboe, K. K. M., & Hanna, R. (2021). Spatio-temporal partitioning and sharing of parasitoids by fall armyworm and maize stemborers in Cameroon. *Journal of Applied Entomology*, *145*(1–2), 55–64. https://doi.org/10.1111/jen.12827

Adheka, J. G., Dhed'a, D. B., Karamura, D., Blomme, G., Swennen, R., & De Langhe, E. (2018). The morphological diversity of plantain in the Democratic Republic of Congo. *Scientia Horticulturae*, *234*(October 2017), 126–133. https://doi.org/10.1016/j.scienta.2018.02.034

Alpizar, D., Fallas, M., Oehlschlager, A. C., & Gonzalez, L. M. (2012). Management of cosmopolites sordidus and metamasius hemipterus in banana by pheromone-based mass trapping. *Journal of Chemical Ecology*, *38*(3), 245–252. https://doi.org/10.1007/s10886-012-0091-0

Alvarez, J. (1997). Introduction, evaluation, multiplication and dissemination of FHIA hybrids in Cuba. *InfoMusa*, *6*(2), 10–13. https://eurekamag.com/research/003/182/003182426.php

Banful, B., Hauser, S., Ofori, K., & Kumaga, F. (2008). Nematodes and weeds control effects of Pueraria phaseoloides and flemingia macrophylla fallows on establishment. *Survival and Yield of Plantain*, *14*(1), 1–14. https://doi.org/10.4314/wajae.v14i1.44704

Barekye, A. (2011). Appraisal of methods for assessing black Sigatoka resistance in diploid banana populations. *African Journal of Plant Science*, *5*(15). https://doi.org/10.5897/ajps10.201

Barraza, D., Jansen, K., van Wendel de Joode, B., & Wesseling, C. (2011). Pesticide use in banana and plantain production and risk perception among local actors in Talamanca, Costa Rica. *Environmental Research*, *111*(5), 708–717. https://doi.org/10.1016/j.envres.2011.02.009

Beauhaire, J., Ducrot, P. H., Malosse, C., Rochat, D., Ndiege, I. O., & Otieno, D. O. (1994). Identification and synthesis of sordidin, a male pheromone emitted by Cosmopolites sordidus. *Tetrahedron Letters*, *36*(7), 1043–1046. https://hal.inrae.fr/hal-02715229

Boyé, M. A. D., Turquin, L., Gnahoua, J. B., Coulibaly, D., Aké, S., & Anno, A. (2010). Performances agronomiques de bananiers plantain Musa AAB cv Corne 1 issus de rejets déshydrates pendant un mois. *Journal of Animal & Plant Sciences*, *7*(1), 767–778. http://www.m.elewa.org/JAPS/2010/7.1/5.pdf

Bridge, J., Price, N. S., & Kofi, P. (1995). Plant parasitic nematodes of plantain and other crops in Cameroon, West Africa. *Fundamental and Applied Nematology*, *18*(3), 251–260. https://horizon.documentation.ird.fr/exl-doc/pleins_textes/fan/42732.pdf

Buah, J. N., Kawamitsu, Y., Yonemori, S., & Murayama, S. (2000). Field performance of in vitro-propagated and sucker-derived plants of banana (Musa spp.). *Plant Production Science*, *3*(2), 124–128. https://doi.org/10.1626/pps.3.124

Carlier, J., Zapater, M. F., Lapeyre, F., Jones, D. R., & Mourichon, X. (2000). Septoria leaf spot of banana: A newly discovered disease caused by mycosphaerella eumusae (Anamorph Septoria eumusae). *Phytopathology*, *90*(8), 884–890. https://doi.org/10.1094/PHYTO.2000.90.8.884

Carval, D., Resmond, R., Achard, R., & Tixier, P. (2016). Cover cropping reduces the abundance of the banana weevil *Cosmopolites sordidus* but does not reduce its damage. *Biological Control*, *99*, 14–18. https://doi.org/10.1016/J.BIOCONTROL.2016.04.004

Cauthen, J., Jones, D., Gugerty, M. K., & Anderson, C. L. (2013). *Banana and Plantain value chain: West Africa EPAR Brief No. 239 Josh Cauthen, Dan Jones, Mary Kay Gugerty, & C. Leigh Anderson. 239*, 1–25.

Coyne, D., Kajumba, C., & Kagoda, F. (2006). *Nematode management at the International Institute of Tropical Agriculture in East Africa*. December 2003, 141–148.

Craenen, K. (1998). *Technical manual on black Sigatoka disease of banana and plantain* (pp. 23). International Institute of Tropical Agriculture.

Daniels, D., Gómez Kosky, R., & Reyes Vega, M. (2002). Plant regeneration system via somatic embryogenesis in the hybrid cultivar FHIA-21 (Musa sp. AAAB group). *Vitro Cellular & Developmental Biology - Plant*, *38*(4), 330–333. https://doi.org/10.1079/IVP2002299

Dassou, A. G., Carval, D., Dépigny, S., Fansi, G., & Tixier, P. (2016). Dataset on the abundance of ants and Cosmopolites sordidus damage in plantain fields with intercropped plants. *Data in Brief*, *9*, 17–23. https://doi.org/10.1016/j.dib.2016.08.027

De Langhe, E., Pillay, M., Tenkouano, A., & Swennen, R. (2005). Integrating morphological and molecular taxonomy in Musa: The African plantains (Musa spp. AAB group). *Plant Systematics and Evolution*, *255*(3–4), 225–236. https://doi.org/10.1007/s00606-005-0346-0

Dépigny, S., Noupadja, P., Tomekpe, K., Bonneviot, P., Lescot, T., & Bakry, F. (2018). 'CARBAP K74': A triploid plantain-like hybrid designed to promote sustainable plantain-based cropping systems. *Acta Horticulturae*, *1196*(January 2018), 63–70. https://doi.org/10.17660/ActaHortic.2018.1196.7

Dépigny, S., Wils, E. D., Tixier, P., Cilas, C., Lescot, T., Jagoret, P., & Keng, M. N. (2019). Plantain productivity : Insights from Cameroonian cropping systems. *Agricultural Systems*, *168*(October 2018), 1–10. https://doi.org/10.1016/j.agsy.2018.10.001

Desdoigts, E., Kwa, M., Fogain, R., Temple, L., Lang, P. S., Bikoï, A., & Achard, R. (2005). A multidisciplinary monitory centre by smallholders in Cameroon to identify factors limiting plantain production. *Fruits*, *60*(4), 237–244. https://doi.org/10.1051/FRUITS:2005030

Dury, S., Bricas, N., Tchango-Tchango, J., Temple, L., & Bikoi, A. (2002). The determinants of urban plantain consumption in

Cameroon. *Food Quality and Preference*, *13*(2), 81–88. https://doi.org/10.1016/S0950-3293(01)00061-1

Dzomeku, B. M., Armo-Annor, F., Adjei-Gyan, K., Ansah, J., & Nkakwa, A. (2009). Improving crop protection on banana farms in Ghana. *Acta Horticulturae*, *828*(828), 389–394. https://doi.org/10.17660/ActaHortic.2009.828.40

Dzomeku, B. M., Quain, M. D., Lamptey, J. N. L., Anno-Nyako, F. O., Aubyn, A., & Darkey, S. K. (2007). Agronomic and sensory evaluation of some IITA hybrids in Ghana. *International Journal of Agricultural Research*, *2*(3), 307–311. https://doi.org/10.3923/ijar.2007.307.311

Erima, R., Ssebuliba, J. M., Nankinga, C. M. K., Ragama, P., Barekye, A., & Tushemereirwe, W. (2016). Yield performance of East African highland banana hybrids on farmers fields under high disease pressure. *African Journal of Agricultural Research*, *11*(13), 1141–1149. https://doi.org/10.5897/ajar12.1610

Etebu, E., & Young-Harry, W. (2011). Control of black Sigatoka disease: Challenges and prospects. *African Journal of Agricultural Research*, *6*(3), 508–514. https://doi.org/10.5897/AJAR10.223

FAO. (2020). *FAOSTAT statistics database 2020*. http://vfaostat.fao.org/site/567/default. 23 March 2021. Food and Agriculture Organization of the United Nations

Fogain, R. (2001). Nematodes and weevil of bananas and plantains in Cameroon: Occurrence, importance and host susceptibility. *International Journal of Pest Management*, *47*(3), 201–205. https://doi.org/10.1080/09670870010021108

Folefack, D. P., Fongang, F. G. H., M, A. K., Ebongue, J. P., Bikoi, A., & Noupadja, P. (2017). Analysis of the plantain supply system of markets in the city of Douala. *Journal of Economics and Sustainable Development*, *8*(6), 141–157. https://www.researchgate.net/publication/316167415

Fullerton, R. A., & Casonato, S. G. (2019). The infection of the fruit of 'Cavendish' banana by Pseudocercospora fijiensis, cause of black leaf streak (black Sigatoka). *European Journal of Plant Pathology*, *155*(3), 779–787. https://doi.org/10.1007/s10658-019-01807-x

Gaidashova, S., Karemera, F., & Karamura, E. (2010). Agronomic performance of introduced banana varieties in lowlands of Rwanda. *African Crop Science Journal*, *16*(1), 9–16. https://doi.org/10.4314/acsj.v16i1.54321

Goenaga, R., Irish, B., & Marrero, A. (2019). Yield and fruit quality traits of two plantain cultivars grown at two locations in Puerto Rico under black leaf streak disease pressure. *HortTechnology*, *29*(6), 958–966. https://doi.org/10.21273/HORTTECH04425-19

Gold, C. S. (1998). Banana weevil: Ecology, pests status and prospects of integrated control with emphasis on East Africa. In *Proceedings of a Symposium on Bio- logical Control in Tropical Crop Habitat. Third International Conference on Tropical Entomology*. 30 Oct 4 Nov. 1994. *Nairobi, Kenya*., 49–74

Gold, C. S., Kagezi, G. H., Night, G., & Ragama, P. E. (2004). The effects of banana weevil, Cosmopolites sordidus, damage on highland banana growth, yield and stand duration in Uganda. *Annals of Applied Biology*, *145*(3), 263–269. https://doi.org/10.1111/J.1744-7348.2004.TB00382.X

Gold, C. S., Night, G., Speijer, P. R., Abera, A. M. K., & Rukazambuga, N. D. T. M. (1998). Infestation levels of banana weevil, Cosmopolites sordidus Germar (Coleoptera: Curculionidae), in banana plants established from treated

propagules in Uganda. *African Entomology*, *6*(2), 253–263. https://hdl.handle.net/10520/AJA10213589_230

Gold, C. S., Pena, J. E., & Karamura, E. B. (2001). Biology and integrated pest management for the banana weevil Cosmopolites sordidus (Germar) (Coleoptera: Curculionidae). *Integrated Pest Management Reviews*, *6*(2), 79–155. https://doi.org/10.1023/A:1023330900707

Hauser, S. (2000). Effects of fertilizer and hot-water treatment upon establishment, survival and yield of plantain (Musa spp., AAB, French). *Field Crops Research*, *66*(3), 213–223. https://doi.org/10.1016/S0378-4290(00)00071-X

Irish, B. M., Goenaga, R., Rios, C., Chavarria-Carvajal, J., & Ploetz, R. (2013). Evaluation of banana hybrids for tolerance to black leaf streak (Mycosphaerella fijiensis Morelet) in Puerto Rico. *Undefined*, *54*, 229–238. https://doi.org/10.1016/J.CROPRO.2013.09.003

Jalloh, A., Roy-Macauley, H., & Sereme, P. (2012). Major agro-ecosystems of West and Central Africa: Brief description, species richness, management, environmental limitations and concerns. *Agriculture, Ecosystems & Environment*, *157*, 5–16. https://doi.org/10.1016/j.agee.2011.11.019

Jallow, M., & Achiri, D. T. 2016. Performance of three trap types for monitoring plantain weevil (Cosmopolites sordidus, Germar) in plantain cropping systems in Ghana. *9*(2): 17–23. https://doi.org/10.9790/2380-09211723

Kiggundu, A., Gold, C. S., Labuschagne, M. T., Vuylsteke, D., & Louw, S. (2003). Levels of host plant resistance to banana weevil, cosmopolites sordidus (Germar) (Coleoptera: Curculionidae), in Ugandan Musa germplasm. *Euphytica*, *133*(3), 267–277. https://doi.org/10.1023/A:1025725124849

Kumakech, A., Lyngs Jørgensen, H. J., Edema, R., & Okori, P. (2015). Efficient screening procedure for black Sigatoka disease of banana. *African Crop Science Journal*, *23*(4), 387–397. https://doi.org/10.4314/acsj.v23i4.8

Lassoudière, A. (2007). Le bananier et sa culture. *Le bananier et sa culture*, 383. https://books.google.cm/books?id=4m46DsrxYiIC

Leiva-Mora, M., Alvarado-Capó, Y., Acosta-Suárez, M., Cruz-Martín, M., Roque, B., & Méndez, E. (2015). Components of resistance to assess Black Sigatoka response in artificially inoculated Musa genotypes. *Rev. Protección Veg.*, *30*(1), 60–69.

Loubana, P.-M., Sarah, J.-L., Sakwe, P. N., Mavoungou, J. F., Gnonhouri, P., Boisseau, M., & Fouré, E. (2007). Study of the genetic of plant parasitic nematodes on bananas and plantains in Central and West Africa. *Crop Research, Technology Dissemination and Adoption to Increase Food Supply, Reducing Hunger and Poverty in Africa : 8th African Crop Science Society Conference*, 27 October 2007, El-Minia, Egypt.

Marín, D. H., Romero, R. A., Guzmán, M., & Sutton, T. B. 2007. Black Sigatoka: An increasing threat to banana cultivation. *87*(3): 208–222. https://doi.org/10.1094/PDIS.2003.87.3.208

Masanza, M., Gold, C. S., Van Huis, A., & Ragama, P. E. (2006). Effects of crop sanitation on banana weevil, cosmopolites sordidus (Germar) (Coleoptera: Curculionidae), populations and crop damage in Uganda. *African Entomology*, *14*(2), 267–275. https://doi.org/10.1016/j.cropro.2004.08.005

Mobambo, K. N., Gauhl, F., Pasberg-Gauhl, C., & Zuofa, K. (1996). Season and plant age effect evaluation of plantain for response to black Sigatoka disease. *Crop Protection*, *15*(7), 609–614. https://doi.org/10.1016/0261-2194(95)00144-1

Mobambo, K. N., Zuofa, K., Gauhl, F., Adeniji, M. O., & Pasberg-gauhl, ca. (2008). Effect of soil fertility on host response to black leaf streak of plantain (Musa spp., AAB group) under traditional farming systems in Southeastern Nigeria. 40(1): 75–80. https://doi.org/10.1080/09670879409371858

Mukasa, H. H., Ocan, D., Rubaihayo, P. R., & Blomme, G. (2005). Relationships between bunch weight and plant growth characteristics of Musa spp. assessed at farm level. MusAfrica, 16, 2–3. https://www.scopus.com/record/display.uri?eid=2-s2.0-64649086656&origin=inward&txGid=e7b243bec122a9a77506472073cbce79

Newilah, G. N., Tchango, J. T., Fokou, É., & Etoa, F. (2005). Processing and food uses of bananas and plantains in Cameroon. Fruits, 60(4), 245–253. https://doi.org/10.1051/fruits:2005031

Newilah, G. N., Tchango Tchango, J., Fokou, É., & Etoa, F. X. (2005b). Processing and food uses of bananas and plantains in Cameroon. Fruits, 60(4), 245–253. https://doi.org/10.1051/FRUITS:2005031

Ngatat, S., Hanna, R., Kumar, P. L., Gray, S. M., Cilia, M., Ghogomu, R. T., & Fontem, D. A. (2017). Relative susceptibility of Musa genotypes to banana bunchy top disease in Cameroon and implication for disease management. Crop Protection, 101, 116–122. https://doi.org/10.1016/J.CROPRO.2017.07.018

Ngobo, M. P., Weise, S. F., & McDonald, M. A. (2004). Revisiting the performance of natural fallows in Central Africa. Scandinavian Journal of Forest Research, Supplement, 19(4), 14–24. https://doi.org/10.1080/14004080410034029

Njuguna, J., Nguthi, F., Wepukhulu, S., Wambugu, F., Gitau, D., Karuoya, M., & Karamura, D. (2010). Introduction and evaluation of improved banana cultivars for agronomic and yield characteristics in Kenya. African Crop Science Journal, 16(1), 35–40. https://doi.org/10.4314/acsj.v16i1.54333

Njukwe, E., Tenkouano, A., Amah, D., Sadik, K., Pérez, M., Nyine, M., & Dubois, T. (2007). Macropropagation of banana and plantain: training manual. https://cgspace.cgiar.org/handle/10568/91415

Nkendah, R., Ako, E., Tamokwe, B., Nzouessin, C., Njoupouognigni, M., Melingui, E., & Azeufouet, A. (2011). Cameroun. Le commerce transfrontalier informel des produits agricoles et horticoles. Undefined, 324, 34–49. https://doi.org/10.4000/ECONOMIERURALE.3083

Nkendah, R., & Akyeampong, E. (2003). Données socioéconomiques sur la filière plantain en Afrique Centrale et de l'Ouest. InfoMusa, 12(1), 8–13. https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Infomusa__La_revue_internationale_sur_bananiers_et_plantains_970.pdf

Norgrove, L., & Hauser, S. (2014). Improving plantain (Musa spp. AAB) yields on smallholder farms in West and Central Africa. Food Security, 6(4), 501–514. https://doi.org/10.1007/s12571-014-0365-1

Noupadja, P., Tomekpe, K., & Youmbi, E. (2007). Évaluation d'hybrides tétraploïdes de bananiers plantains (Musa spp.) résistants à la maladie des raies noires créés au Cameroun. Fruits, 62(2), 77–88. https://doi.org/10.1051/fruits:2007001

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (1993). Fractionation of organic matter by particle size. In Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (Eds.) 'Laboratory methods of soil and plant analysis: A working manual' (pp. 66–68). TSBF_KARI-UNESCO.

Okolle, J. N., Fansi, G. H., Lombi, F. M., Patrick, Lang, S., & Loubana, P. M. (2009). Banana entomological research in Cameroon: How far and what next?. African Journal of Plant Science and Biotechnology, 3(1), 1–9. https://www.academia.edu/25103758/Banana_Entomological_Research_in_Cameroon_How_Far_and_What_Next

Oluma, H. O. A., Onekutu, A., & Onyezili, F. N. (2004). Reactions of plantain and banana cultivars to black Sigatoka leaf spot disease in three farming systems in the Nigerian Guinea savanna/Reaktion von Mehl. und Obstbananen auf die Schwarze Sigatoka-Krankheit in drei Anbausystemen in der nigerianischen Gui. In März, 111. https://link.springer.com/article/10.1007/BF03356142

Pierrot, J., Achard, R., Temple, L., Abadie, C., & Fogain, R. (2002). Déterminants de la production de plantain dans le sud-ouest du Cameroun: Intérêt d' un observatoire Fruits 57(2), 75–86 . https://doi.org/10.1051/fruits

Polidoro, B. A., Dahlquist, R. M., Castillo, L. E., Morra, M. J., Somarriba, E., & Bosque-Pérez, N. A. (2008). Pesticide application practices, pest knowledge, and cost-benefits of plantain production in the Bribri-Cabécar Indigenous Territories, Costa Rica. Environmental Research, 108(1), 98–106. https://doi.org/10.1016/J.ENVRES.2008.04.003

R Development CoreTeam. (2020). A language and environment for statistical computing. R Found Statistical Computing. http://lib.stat.cmu.edu/R/CRAN/doc/manuals/r-devel/fullrefman.pdf

Rieux, A., Hostachy, B., De Lapeyre de Bellaire, L., Martin, Y., Maratchia, G., Dupuis, A., Ioos, R., Jeandel, C., & Hubert, J. (2019). First report of black Sigatoka disease in banana caused by Mycosphaerella fijiensis on reunion Island . New Disease Reports, 39(1), 12. https://doi.org/10.5197/j.2044-0588.2019.039.012

Sama-Lang, P. (2004). Soil and water conservation in banana production between Mount Cameroon and Bambutus mountain. 13th International Soil Conservation Organisation Conference, 210, 1–6.

SAS. (2008). Statistical Analysis Systems Institute. Version 9.1.

Selatsa, A. A., Tenkouano, A., Njukwe, E., Noël, R., & Paula, I. (2009). Morphological diversity of plantain (Musa sp . L . AAB Group) in Cameroon : relationships to farmer ' s cultural practices. The African Journal of Plant Science and Biotechnology, 3(1), 51–58. https://www.academia.edu/en/25103821/Morphological_Diversity_of_Plantain_Musa_sp_L_AAB_Group_in_Cameroon_Relationships_to_Farmers_Cultural_Practices

Seydou, T., Elisée, A. L. N. D. G., Brahima, C., Sibirina, S., Fatogoma, S., Kouabenan, A., Léonard, O. S., & Daouda, K. (2016). Assessment of banana and plantain behavior under natural infestation by Mycosphaerella fijiensis, morelet in Southern Côte d'Ivoire. Journal of Agronomy, 15(4), 151–164. https://doi.org/10.3923/ja.2016.151.164

Singh, B., Singh, J. P., Kaur, A., & Singh, N. (2016). Bioactive compounds in banana and their associated health benefits - A review In Food chemistry (pp. 1–11. Vol. 206). Elsevier Ltd. https://doi.org/10.1016/j.foodchem.2016.03.033

Smithson, P. C., Mcintyre, B. D., Gold, C. S., Ssali, H., & Kashaija, I. N. (2001). Nitrogen and potassium fertilizer vs. nematode and weevil effects on yield and foliar nutrient status of banana in Uganda. Nutrient Cycling in Agroecosystems, 59(3), 239–250. https://doi.org/10.1023/A:1014462923539

Speijer, P. R., & De Waele, D. (1997). Screening of Musa germplasm for resistance and tolerance to nematodes. In *INIBAP technical guidelines 1* (pp. 1–48). International Network for the Improvement of Banana and Plantain.

Speijer, P. R., & Fogain, R. (1999). Musa and Ensete nematode pest status in selected African countries. Mobilising IPM for sustainable banana production in Africa. 23–28 November 1998 Nelspruit, South Africa Frison, E. A., Gold, C. S., Kamura, E. B., Sikora, R. A. (eds.) (Montpellier, France, INIBAP), 99–108. DOI:10.13140/RG.2.1.1903.4082

Speijer, P. R., Gold, C. S., Kashaiya, I. N., & Kararmura, E. B. (1994). *Assessment of nematode damage in East African highland banana systems*. https://cgspace.cgiar.org/handle/10568/100930

Ssali, H., McIntyre, B. D., Gold, C. S., Kashaija, I. N., & Kizito, F. (2003). Effects of mulch and mineral fertilizer on crop, weevil and soil quality parameters in highland banana. *Nutrient Cycling in Agroecosystems*, *65*(2), 141–150. https://doi.org/10.1023/A:1022184927506

Su, L., Ruan, Y., Yang, X., Wang, K., Li, R., & Shen, Q. (2015). Suppression on plant-parasitic nematodes using a soil fumigation strategy based on ammonium bicarbonate and its effects on the nematode community. *Scientific Reports*, *5*(1). https://doi.org/10.1038/srep17597

Swennen, R., Vuylsteke, D., & Ortiz, R. (1995). Phenotypic diversity and patterns of variation in West and central African plantains (Musa Spp., AAB group Musaceae). *Economic Botany*, *49*(3), 320–327. https://link.springer.com/article/10.1007/BF02862352

Tenkouano, A., Faturoti, B. O., & Baiyeri, P. K. (2010). On-farm evaluation of Musa hybrids in Southern Nigeria. *Tree and Forestry Science and Biotechnology*, *4*(2), 30–34. https://doi.org/10.1155/2019/3873198

Tenkouano, A., Hauser, S., Coyne, D. L., & Coulibaly, O. (2006). *Clean planting materials and management practices for sustained production of banana and plantain in Africa*. https://cgspace.cgiar.org/handle/10568/91360

Tenkouano, A., Lamien, N., Agogbua, J., Amah, D., Swennen, R., Traoré, S., Thiemele, 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., & Ortiz, R. (2019). Promising high-yielding tetraploid plantain-bred hybrids in West Africa. *International Journal of Agronomy*, *2019*, 1–8. http://www.globalsciencebooks.info/Online/GSBOnline/images/2010/TFSB_4(SI2)/TFSB_4(SI2)30-34o.pdf

Tenkouano, A., & Swennen, R. L. (2004). *Progress in breeding and delivering improved plantain and banana to African farmers*. https://cgspace.cgiar.org/handle/10568/95965

Thompson, P., & Wainwright, H. (2007). Determining correlations between price and quality characters of perishable commodities in Bolivia. *Journal of Food Quality*, *14*(2), 99–105. https://doi.org/10.1111/j.1745-4557.1991.tb00051.x

Tinzaara, W., Gold, C. S., Kagezi, G. H., Dicke, M., Van Huis, A., Nankinga, C. M., Tushemereirwe, W., & Ragama, P. E. (2005). Effects of two pheromone trap densities against banana weevil, Cosmopolites sordidus, populations and their impact on plant damage in Uganda. *Journal of Applied Entomology*, *129*(5), 265–271. https://doi.org/10.1111/J.1439-0418.2005.00962.X

Tomekpe, K., Kwa, M., Dzomeku, B. M., & Ganry, J. (2011). CARBAP and innovation on the plantain banana in Western and Central Africa. *International Journal of Agricultural Sustainability*, *9*(1), 264–273. https://doi.org/10.3763/ijas.2010.0565

Tripathi, L., Babirye, A., Roderick, H., Tripathi, J. N., Changa, C., Urwin, P. E., Tushemereirwe, W. K., Coyne, D., & Atkinson, H. J. (2015). *Field resistance of transgenic plantain to nematodes has potential for future African food security*. https://doi.org/10.1038/srep08127

Tushemereirwe, W. K., Gold, W. K., Speijer, P. R., & Holderness, M. (2011). Foliar diseases of banana in Uganda: Results from a diagnostic survey. *African Crop Science Journal*, *1*(2), 145–149. https://doi.org/10.4314/acsj.v1i2.69904

Tushemereirwe, W. K., Kangire, A., Ssekiwoko, F., Offord, L. C., Crozier, J., Boa, E., Rutherford, M., & Smith, J. J. (2004). First report of Xanthomonas campestris pv. musacearum on banana in Uganda. *Plant Pathology*, *53*(6), 802. https://doi.org/10.1111/J.1365-3059.2004.01090.X

Udomkun, P., Masso, C., Swennen, R., Innawong, B., Kuate, A. F., Alakonya, A., Lienou, J., Ibitoye, D. O., & Vanlauwe, B. (2021). Consumer preferences and socioeconomic factors decided on plantain and plantain-based products in the central region of Cameroon and Oyo State, Nigeria. *Foods*, *10*(8), 1955. https://doi.org/10.3390/FOODS10081955

Viljoen, A., Kunert, K., Kiggundu, A., Escalant, J. V., & Bornman, C. H. (2004). Biotechnology for sustainable banana and plantain production in Africa: The South African contribution. *South African Journal of Botany*, *70*(1), 67–74. https://doi.org/10.1016/S0254-6299(15)30308-2