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Review Article

Promising high-yielding tetraploid plantain bred-hybrids in West Africa

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Abstract

The devastating threat of black leaf streak disease caused by *Pseudocercospora fijiensis* on plantain production in West Africa spurred the development of resistant hybrids. The goal of this research-for-development (R4D) undertaking was assessing the development and dissemination of two plantain hybrids PITA 3 and FHIA 21 bred in the 1980s by the International Institute of Tropical Agriculture (IITA, Nigeria) and the Fundación Hondureña de Investigación Agrícola (FHIA, Honduras) respectively. In Côte d'Ivoire, plantain growers selected PITA 3 and FHIA 21 based on their improved agronomic characteristics and between 2012 and 2016, they were massively propagated and distributed to farmers in Benin, Burkina Faso, Côte d'Ivoire and Togo under the West Africa Agricultural Productivity Program (WAAP) coordinated by the West and Central Africa Council for Agricultural Research and Development (CORAF). In 2016, the National Centre for Agronomic Research in Côte d'Ivoire included the hybrids in the improved cultivar directory. This R4D activity illustrates how three decades of crossbreeding, selection, and distribution led to local acceptance. It also highlights how a CORAF-led partnership harnessed CGIAR research-for-development. The dissemination and acceptance of these plantain hybrids will enhance the sustainable intensification in plantain-based farming systems across the humid lowlands of West Africa.

Keywords: Black leaf streak disease; CORAF; FHIA; IITA; high edible yield; host plant resistance; plantain hybrid; PITA; tetraploid

Introduction

Plantain (*Musa spp*. AAB) is an important starchy staple triploid ($2n = 3x = 33$) crop and a key component of the farming systems in the humid lowland ecologies of West and Central Africa. This region harbors the world's greatest variability of plantains, and it is, therefore considered a secondary center of plantain diversification [1–3]. In addition to being a staple food for rural and urban consumers, plantain is also a source of income for the smallholders [4] who produce them in compound gardens where application of manure and household refuse ensures continuous high productivity for many years [5, 6]. Plantains are also produced in fields under shifting cultivation and bush fallow with edible (or fruit) yields declining rapidly after first production cycle due to disease pressure and por management practices. Although fruit is produced throughout the year, the major harvest comes in the dry season spanning the months of December through March, when most other starchy staples are in short supply or difficult to harvest [7]. Hence, plantain plays an important role in bridging the hunger gap [5, 8]. Africa is one of the major plantain-producing continents of the world, accounting for approximately 32% of worldwide production. Plantain is the third most important crop in Nigeria [4], Ghana [9] and eastern Democratic Republic of Congo [2]. Similarly, in Côte d'Ivoire, the production of plantains is estimated at 1.6 million metric tons (MT), thus making it the third food crop after yam and cassava. In West Africa, the major producing countries are Ghana, Cameroon, Nigeria and Côte d'Ivoire [2].

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 [10]. Black leaf streak disease caused by *Pseudocercospora fijiensis* [11] is the most serious production constraint with edible yield loss ranging from 33% to 50% in the first crop cycle and 100% in subsequent ratoons [12, 13]. Other key pests are the banana weevil (*Cosmopolites sordidus*) [10, 14] and various parasitic nematodes [10]. These pests destroy the corm and root system thereby reducing anchorage, nutrient uptake and provide entry points for pathogens [5, 10]. Increase in population pressure which has led to shortened fallow periods and declining soil fertility is also a constraint in large scale plantain production. Breeding plantains for host plant resistance to pathogens and pests has been regarded as the most appropriate control strategy since chemical control is expensive and environmentally hazardous for the subsistence growers in the region. Plantain hybrids with host plant resistance to black leaf streak and other pests plus good agronomic characteristics have been developed by breeding programs such as the Institute of Tropical Agriculture (IITA), the Centre de Recherches Régionales sur Bananiers et Plantains (CRBP) in Cameroon and the Fundación Hondureña de Investigación Agrícola (FHIA) in Honduras ([15-17]. The development of these plantain hybrids is a major achievement by breeders since triploid plantains ($2n = 3x = 33$ chromosomes) were generally considered intractable to genetic improvement due to their triploid nature which results in almost complete sterility [15].

Plantain breeding in IITA began in 1987 and within five years of breeding, 20 tetraploid Tropical *Musa* Plantain hybrids (TMPx) were developed and fourteen of the best hybrids were registered in the public domain [18]. In 1994, IITA received the 7th King Baudouin award in recognition of its contribution to breeding plantains for black sigatoka resistance and advances in *Musa* genetics. IITA in collaboration with national partners evaluated these hybrids in several African countries for edible yield and its stability across sites and cropping cycles along with durability of host plant resistance to *Pseudocercospora fijiensis* [19]. Several hybrids were selected as promising for further cultivar release in West Africa countries [20, 21]

In West Africa, improved plantain hybrids bred by IITA (PITA 3) and FHIA (FHIA 21) are increasingly being grown by farmers due to their resistance to pathogens and pests, edible yield and stability, rapid cycling and acceptable fruit processing attributes. PITA 3 and FHIA 21 have been released as new cultivars in Côte d'Ivoire and are grown by farmers in Benin, Burkina Faso and Togo after series of multilocation evaluation trials. This paper highlights the development and dissemination of these two plantain tetraploid hybrids in francophone West Africa, which was implemented and coordinated by West and Central Africa Council for Agricultural Research and Development (CORAF) under the West Africa Agricultural Productivity Program (WAAP).

Producing and Sharing Plantain Hybrids for West Africa

Hybrid origin

The development of IITA plantain tetraploid hybrids ($2n = 4x = 44$) was described previously [22]. A total of 113 plantain cultivars were screened for female fertility but the tetraploid plantain hybrids were derived from only four cultivars (Bobby Tannap, French Reversion, Mbi-Egome and Obino L'Ewai) that belong to the French plantain subgroup [22, 23]. PITA 3 is a plantain hybrid that was produced by crossing the seed fertile medium size 'Obino L'Ewai' and the wild diploid ($2n = 2x = 22$) banana 'Calcutta 4'. This cross made in

November 1989 at the IITA High Rainfall Station in Onne (southeastern Nigeria) produced 41 seeds. The seeds were germinated *in vitro* and TMPx 5511-2 (later released as PITA 3) was selected after early evaluation and preliminary yield on-station trials (Fig. 1). From 1993 to 1995, PITA 3 was evaluated alongside other 11 promising tetraploid hybrids in multilocational evaluation trials (METs) in Cameroon, Ghana, Nigeria and Uganda for the production stability and adoption across environments [19]. PITA 3 was further included in advanced testing along with eight tetraploids in the first IITA's Advanced *Musa* Yield Trial (AMYT) in Burundi, Côte d'Ivoire, Ghana, Kenya, Nigeria and Zanzibar. The hybrids in AMYT were evaluated over a period of two cropping cycles (mother plant and ratoon) in a randomized complete block design with four replications of five plants each and plant spacing of 3m × 2m [6, 19]. The objective was to identify elite bred-germplasm for potential release as new cultivars by each country according to their specific regulations.

FHIA 21 is a French plantain hybrid developed by the breeding program of the *Fundación Hondureña de Investigación Agrícola* (FHIA) at La Lima (Honduras) from a cross between the French plantain AVP-67 and the diploid banana SH-3142 in 1983 (Fig. 2). It was selected in 1986 from several first-generation seedlings. SH-3142 is a bred diploid derived from crossing the SH-1734 bred diploid onto the diploid 'Pisang Jari Buaya' banana, collected in Papua New Guinea. The diploid bananas from the FHIA genebank included in the pedigree of SH-1734 are 'Lidi', 'Sinwobogi' and the wild fully-seeded *Musa acuminata* subsp. *errans* wild, which were collected in Sumatra, Papua New Guinea and the Philippines, respectively.

Following a participatory selection trial in Western Côte d'Ivoire in 2007, FHIA 21 and PITA 3 were selected for dissemination by the National Centre for Agronomic Research (CNRA) under the WAAP program. FHIA 21 and PITA 3 were mass propagated in Côte d'Ivoire using *in vivo* multiplication techniques and distributed from 2012 to 2016 to 10 plantain producer groups located in seven zones of this country.

Field evaluation varietal mixture trials

PITA 3 was introduced to Côte d'Ivoire in 1993 by IITA in partnership with the Centre National de Recherche Agronomique (CNRA) for evaluation in an AMYT. In southern Côte d'Ivoire PITA 3, FHIA 21 and three local cultivars were assessed in the field for tolerance to black sigatoka leaf disease [25] and response to nematodes (*R. similis* and *P. coffeae*) [26]. In Ghana FHIA 21 was also evaluated for agronomic performance [27, 28]. In 2013, the agronomic performance of FHIA 21, PITA 3 and Orishele was also investigated in a varietal mixture trial under natural black leaf streak disease infestation [29].

Hybrid multiplication and distribution

From 2012 to 2016, PITA 3 and FHIA 21 were massively propagated (Fig. 3) and distributed to farmers in several regions of Côte d'Ivoire, Benin, Burkina Faso and Togo under WAPP coordinated by CORAF. The effect of different concentration of benzyl amino purine (BAP) on macro-propagation of the two hybrids and two local cultivars Orishele and Corne 1 was assessed to enhance sucker multiplication [30].

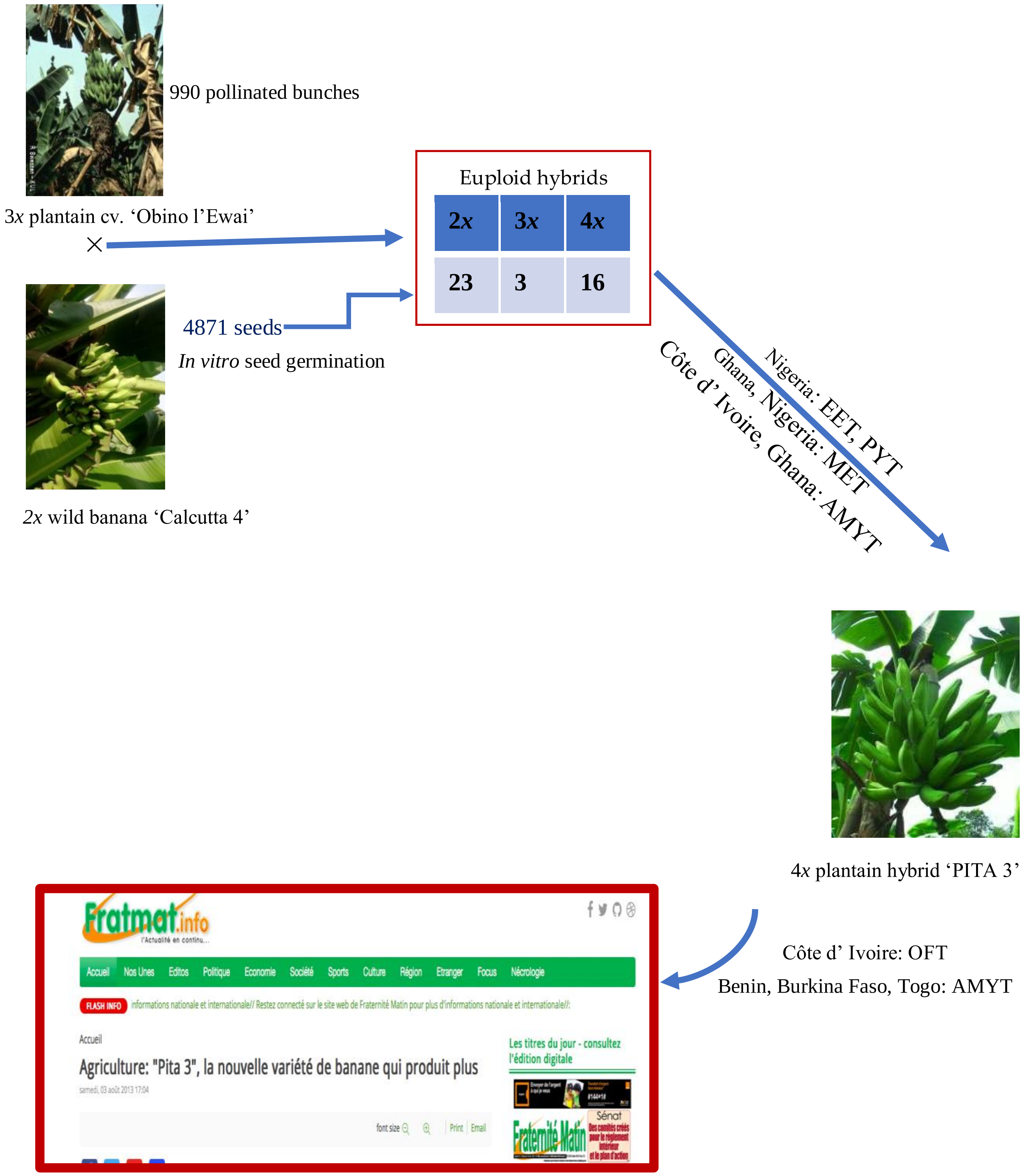

Figure 1. The making of 'PITA 3' – a tetraploid (4*x*) primary hybrid bred by the International Institute of Tropical Agriculture (IITA, Nigeria) in partnerships with CSIR/MOFA/Univ. Ghana (Ghana), CNRA (Côte d' Ivoire), INERA (Burkina Faso) and INRAB (Benin) – as a new plantain cultivar for West Africa. Source for crossing data: [18, 19, 22]. EET = early evaluation trial using nonreplicated plots of 3 or 4 plants, PYT = preliminary yield trial with 2 reps of 4 or 5 plants, MET = multilocational environmental trial with 2 reps of 5 plants across at least 2 sites and over 2 crop cycles, AMYT = advanced *Musa* yield trials as per MET but also testing crop husbandry practices, OFT = on farm testing of hybrid(s) along with crop husbandry prior cultivar release

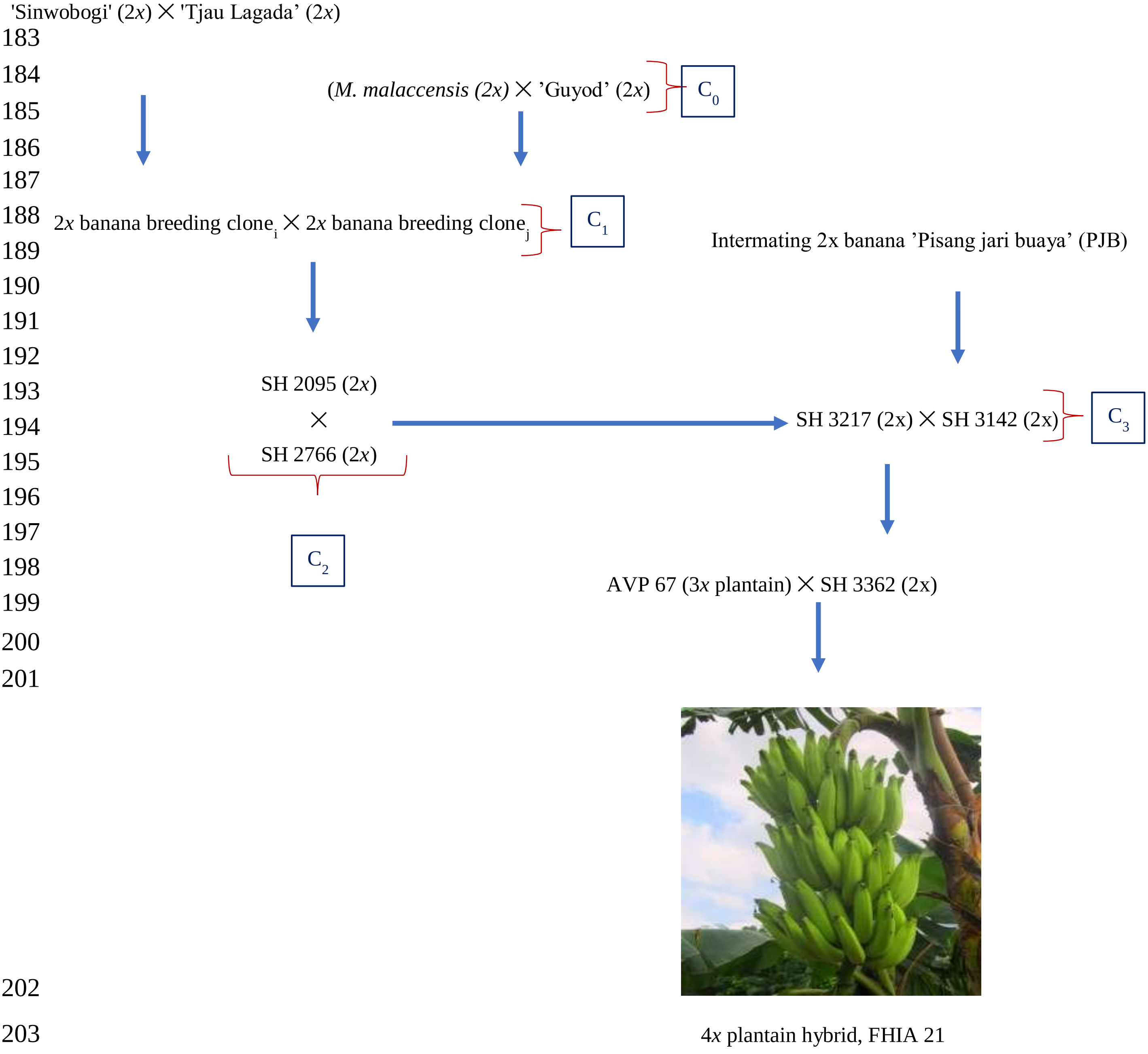

Figure 2. Development of primary tetraploid (4*x*) 'FHIA 21' by FHIA, Honduras, which was, after further multilocation testing in West Africa, released as new cultivar in Benin, Burkina Faso, Côte d' Ivoire and Togo, as well as named "Apem hemaa' in Ghana. Its male diploid (2*x*) banana parent ensued after three cycles of phenotypic recurrent selection (C_i) at 2x ploidy level in Honduras with a germplasm influx from PJB in C_3 and interploidy crossing with triploid (3x) plantain AVP 67 (code for a plantain grown in Honduras and available at FHIA genebank). Source for pedigrees of 2*x* bananas in C_i: [24]

Figure 3. Seedlings of PITA 3 (top) and FHIA 21 grown in the nursery prior to distribution and field transplanting in Côte d'Ivoire

Field Trials and Palatability Testing

In country and varietal mixture trials

PITA 3 and FHIA 21 bred in the 1980s and distributed in the 1990s were selected based on their host plant resistance to *Pseudocercospora fijiensis*, pendulous bunch orientation, large bunch, parthenocarpic fruit development and improved ratooning that ensures rapid cycling. PITA 3 consistently out-yielded the medium sized French plantain cultivars (Obino L'Ewai and Bobby Tannap) in all the on-site early evaluation trials and multilocation trials [19]. On-farm fruit yields are estimated at 20 t ha^{-1} and 30 t ha^{-1} for PITA 3 and FHIA 21 respectively. The results obtained by Tuo *et al.* [29] indicate that PITA 3 and FHIA 21 were the most tolerant to black leaf streak disease with yields of 18.5 and 21.22 t $ha^{–1}$, respectively; while the plantain cultivar 'Orishele' was the most sensitive and least productive with a yield of 11.49 t $ha^{–1}$ in the first crop cycle [25]. The number of hands per bunch was the same for the three accessions while the number of fruits varied significantly (57 ± 2.4 for PITA 3, 71.6 ± 3 for FHIA 21 and 33.4 ± 3.5 g for 'Orishele'). Conversely, the fruit weight of 'Orishele' (221 ± 11) was significant above that of PITA 3 (159 ± 6 g) and FHIA 21 (152 ± 10 g). The number of functional leaves at flowering was significantly higher in the hybrids (13 ± 0.5 for PITA 3 and 13.4 ± 0.4 for FHIA 21) than the plantain cultivar 'Orishele' (9.2 ± 0.2). Similarly, the number of functional leaves at harvest was significantly different among hybrisds and cultivar: 6.4 ± 0.4, 4.6 ± 0.2 and 1 ± 0.1 for FHIA 21, PITA 3 and 'Orishele', respectively [25]. In Ghana, FHIA-21 (named 'Apem hemaa') was superior to the local cultivars both in agronomic traits and fruit productivity [28]. The result of the host plant response to nematodes revealed that FHIA 21 is resistant to *R. similis* and susceptible to *P. coffeaei,* while PITA 3 is susceptible to both parasitic nematodes in Côte d'Ivoire [26]. The results observed in the varietal mixture trial showed significant differences between the number of functional leaves at flowering and harvest, the bunch weight and fruit traits of the plantain cultivar 'Orishele'. The varietal combination of resistant and susceptible genotypes influenced the disease pressure in the trial plot and enhanced the yield of the landrace [30].

The bunch mass (or weight) and fruit yield potential of FHIA 21, PITA 3 and a giant French plantain cultivar 'Big Ebanga' in Côte d'Ivoire, Burkina Faso and Benin are shown in Figures 4, 5 and 6 respectively. Both plantain hybrids have a faster ratoon cycling and are more sustainable than the plantain cultivar, whose fruit yield decline after the first crop cycle. In Benin the average fruit yield of local plantains in farmers field was 4 to 7 t ha^{-1} thus making both hybrids the most preferred by farmers. PITA 3 had acceptable cooking qualities when utilized to prepare the local plantain recipes (foutou, alloco, foufou and ragout) in Côte d'Ivoire, and when boiled green and fried when ripe as dodo in Nigeria [19]. In Ghana, FHIA 21 ranked best in terms of yield, palatability for ampesi (a local dish) and commercial potential [27].

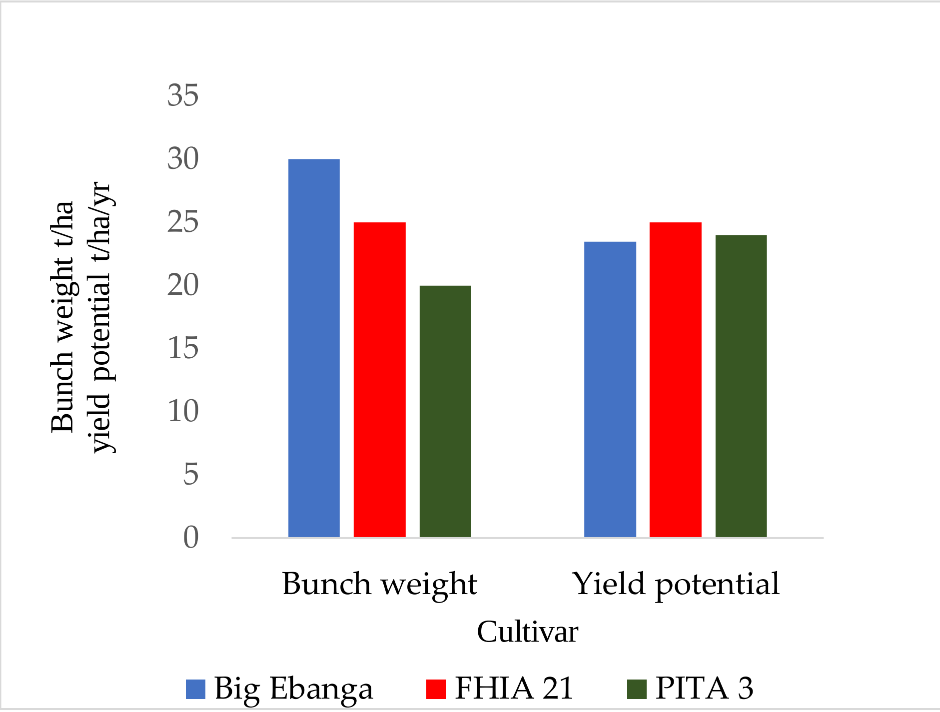

Figure 4. Bunch harvest (t ha^{-1}) and yield potential (bunch weight ha^{-1} year^{-1}) of medium size tetraploid plantain hybrids FHIA 21 (ratoon cycle: 12 months), PITA 3 (ratoon cycle: 10 months) along with giant French plantain 'Big Ebanga' (ratoon cycle: +15 months) in Côte d'Ivoire

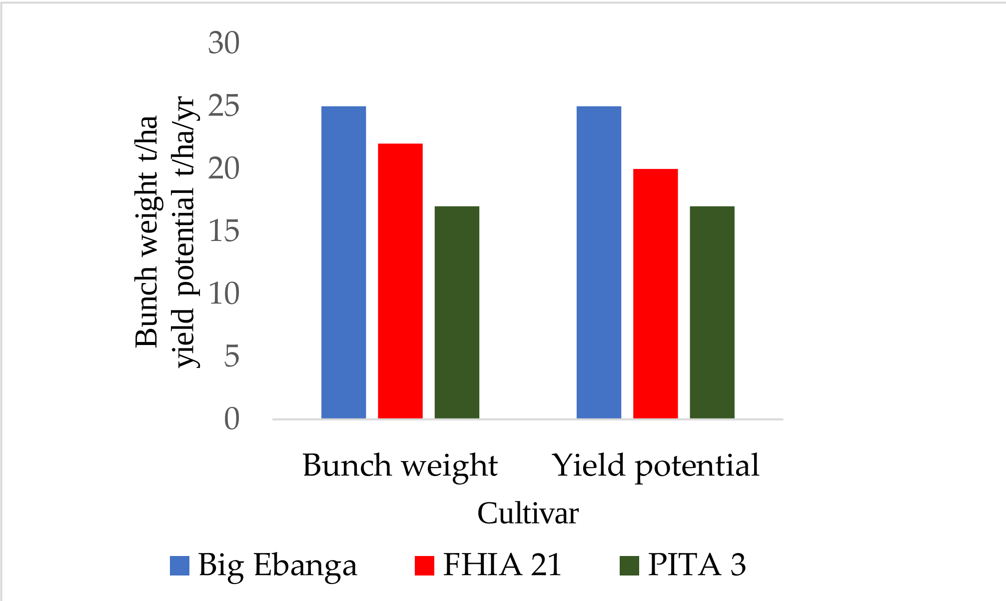

Figure 5. Bunch harvest (t ha^{-1}) and yield potential (bunch weight ha^{-1} year^{-1}) of medium size tetraploid plantain hybrids FHIA 21 (growth cycle: 13 months), PITA 3 (growth cycle: 12 months) along with giant French plantain 'Big Ebanga' (growth cycle: 12 months) recorded in 120 m^{2} plots at Bobo Dioulasso, Burkina Faso

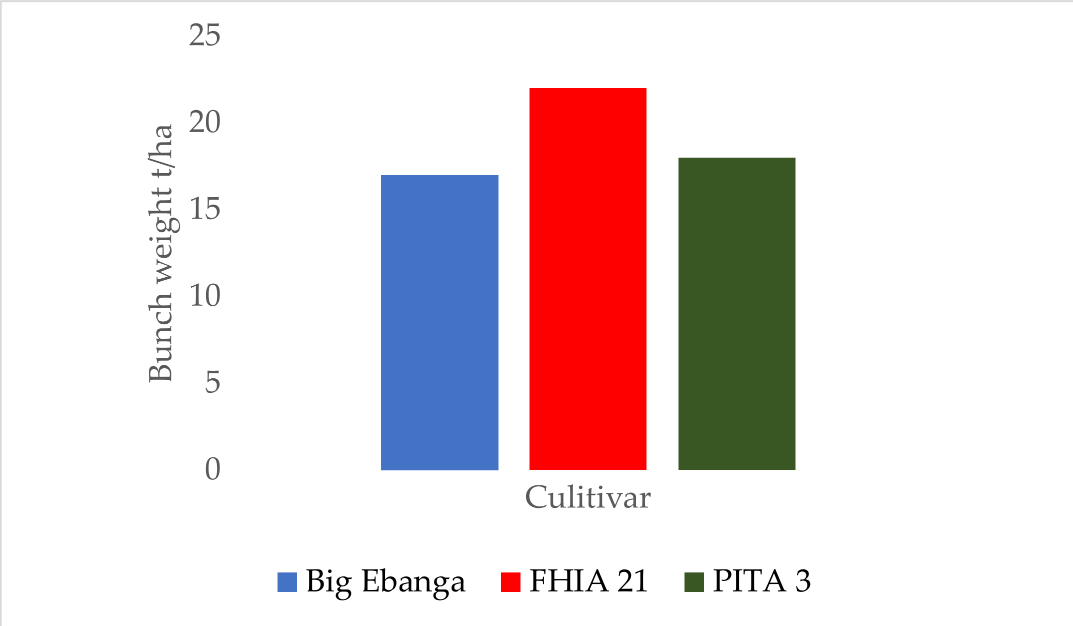

Figure 6. Bunch harvest (t ha^{-1}) of medium size tetraploid plantain hybrids FHIA 21, PITA 3 along with giant French plantain 'Big Ebanga' at advanced yield trial using 3 replications at a plant density of 6 m^2 in Benin. The average yield of plantain on family farms in this country remains very low: from 4 to 7 t ha^{-1}

Hybrid multiplication and dissemination

In the context of improving the productivity of plantain in Côte d'Ivoire, CNRA selected and started disseminating two tetraploid plantain hybrids FHIA 21 and PITA 3, for both their high fruit productivity and host plant resistance to black leaf streak. The large-scale distribution of these hybrids was carried out between 2012 and 2016 in several regions of Côte d'Ivoire. The distribution of PITA 3 and FHIA 21 from 2012 to 2016 in Côte d'Ivoire is shown in figure 7. Approximately 92,680 PITA 3 and FHIA 21 seedlings were distributed free of charge to more than 160 producer groups between 2012 and 2014. The effect of 40 mg l^{-1} BAP on macro-propagation showed that PITA 3 produced the highest number of shoots per corm compared to the plantain cultivars [30].

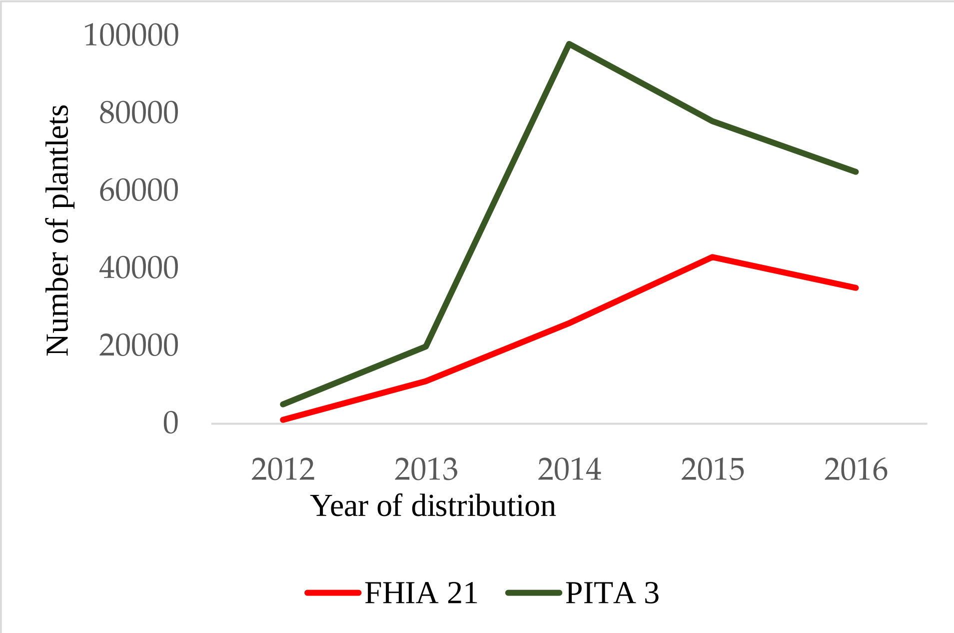

Figure 7. Distribution of *in vivo* plants of plantain tetraploid hybrids PITA 3 and FHIA 21 released from 2012 to 2016 in Côte d'Ivoire

Advances in Deploying Plantain Breeding Outputs in West Africa

Major progress has been made by the plantain and banana breeding programs in developing high yielding resistant plantain hybrids [31, 32]. The tetraploid hybrids PITA 3 and FHIA 21 phenotypically resemble their respective female plantain parents but exhibit shorter plant height, rapid cycling, better fruit productivity and regulated suckering behavior, which are highly desirable characteristics for perennial plantain production. The plantain hybrids are female- and male-fertile and can be also utilized as parents in $4x \times 2x$ crosses to produce secondary triploid hybrids.

IITA in Nigeria, CARBAP in Cameroon and FHIA in Honduras, have made available to plantain growers hybrids that are resistant or tolerant to black-leaf streak disease [15-17]. PITA 3 and FHIA 21 plantain hybrids evaluated in various West African sites had better fruit productivity [19, 33] and sucker production [31] than local cultivars. This on station evaluation was followed by participatory selection trials with all the introduced hybrids and the plantain cultivars such as 'Big Ebanga' and 'Orishele'. The criteria for selection was their bunch weight and fruit taste when processed into local dishes. Based on their fruit productivity and after cooking characteristics, PITA 3 and FHIA 21 were selected by the growers. As part of a research project on the sustainable improvement of the plantain sector in West Africa these hybrids were massively propagated and distributed to farmers in several regions of Côte d'Ivoire, Benin, Burkina Faso and Togo under WAAP coordinated by CORAF. In 2016, CNRA included PITA 3 and FHIA 21 in the varietal directory of improved cultivars of Côte d'Ivoire, which shows that the hybrids have acceptable agronomic and taste attributes

The utilization of the plantain hybrids in mixed cropping with local cultivars in Côte d'Ivoire was very effective in reducing black leaf streak disease pressure on the susceptible local cultivars, thereby raising the number of functional leaves at flowering that translated into increasing fruit yield [29]. The same approach was used for large scale distribution of improved hybrids in Nigeria and Cameroun where bunch weights increased from 4.9 kg to 7.1 or 8.1 kg in sole and mixed cropping, respectively. This strategy for hybrid dissemination preserves genetic diversity while exposing farmers to high yielding resistant hybrids for adoption [16, 34].

Conclusion

In the past three decades, significant progress has been made in breeding high yielding disease resistant plantain hybrids with fruit eating quality similar to some West African plantain cultivars. The fruit productivity and rapid cycling of plantain tetraploid hybrids PITA 3 and FHIA 21 indicate that they have a high adoption potential and may impact on plantain production in the humid lowland agroecology of West Africa. The dissemination and acceptance of these plantain hybrid cultivars by growers will enhance the sustainable intensification in plantain-based farming systems therein; i.e., increasing steady harvests of plantain fruit from existing farmlands and orchards.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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