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Selection of (Deli × Angola Novo-Redondo) Selfed × La Mé Progenies for Improved Oil Palm Productivity

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Abstract

Introgression of Angola Novo-Redondo origin into the Deli origin was achieved for the first time in Côte d'Ivoire. Unfortunately, the genetic variability of (Deli × Angola Novo-Redondo) genitors selected was a challenge facing seed production. The best (Deli × Angola Novo-Redondo) genitor LM 5448 T was selfed expecting more stable genotypes for improved oil palm productivity. (Deli × Angola Novo-Redondo) selfed × La Mé progenies were planted at Ehania in Côte d'Ivoire. At maturity, they presented 8% rise over the controls' mean (155.72 kg palm^{-1} yr^{-1}) for total bunch weight (TBW). ANOVA revealed difference between (Deli × Angola Novo-Redondo) selfed genitors for bunch production, vertical growth rate, and bunch characteristics. DMRT showed that progenies overlapped each other indicating their genetic resemblance, a feature supported by the low CV values (3-8%) of all the parameters measured. Progenies LM 22723, LM 22835, and LM 23169 whose increase over controls' means for TBW and bunch number were 11% and 12%, respectively, and whose mean Fusarium index was 56 should be selected for commercial seed production. Estimated breeding values of LM 15516 D and LM 15311T, Group A parents of the 3 progenies would help predicting planting materials' performances.

Keywords: bunch production, bunch characteristics, breeding value, oil yield, seed production

1. Introduction

Oil palm (*Elaeis guineensis* Jacq.) is a perennial plant species found in wild or subspontaneous form in African rainforests. The plant is cultivated for the oil extracted from the mesocarp and kernel of the fruit (Hartley, 1988) for food and non-food uses. Friends of the Earth (2018) reported, after an assessment of global palm oil consumption, that 71% of palm oil is for food (*e.g.*, cooking oil, margarine, processed foods, and chocolate), 24% for consumer products (*e.g.*, cosmetics, detergents, candles) and 5% for energy (electricity, heating, fuels). In fact, palm oil demand is a function of both the growing increase in food and non-food uses and in world population. In 2018, the African population reached 1.215 billion. One of the factors that contributes to a sustainable increase in Africa's population is the considerable fight against common and endemic diseases. Better preventive measures developed to limit the incidence of human immunodeficiency virus (HIV) and malaria led to a sustainable increase in the continent's population (Bakoumé et al. 2018). In 2018, the continent's demand for oil and fats was estimated at 30.64 million tons (Bakoumé et al. 2018). Oil production accounted for about 8% of the demand (2.434 million tons). The use of high yielding plant material coupled with best management practices is essential to meet this growing demand for palm oil. This involves opting for the *tenera* oil palm, a hybrid (sh^+/sh^-) resulting from a cross between the *dura*, homozygous (sh^+/sh^+) with a thick shell of more than 2 mm, and the *pisifera*, homozygous (sh^-/sh^-) without a shell. In fact, the *tenera* type produces at least 25-30% more palm oil than the *dura* type. *Pisifera* has generally sterile and abortive female inflorescences (Bakoumé, 2016).

Since the early 1900s, genetic improvement of local populations through phenotypic mass selection has been initiated to increase the productivity of palm plantations. Unfortunately, the yield increment from mass selection was very low (Bakoumé et al. 2016). Oil palm research in Côte d'Ivoire has adopted the reciprocal recurrent selection (RRS) scheme. This scheme simultaneously improves Deli origins (Group A) made up of *dura* palms and African origins (Group B) of *pisifera* and *tenera* palms. The two cycles of RRS completed from 1960 to 1995 led to more than 36% oil yield increase compared to the first inter-origin progenies (Gascon et al., 1988). Climatic changes induced by deforestation has resulted in pronounced drought spell in Africa including Côte d'Ivoire. Few consequences for oil palm agriculture include yield depression, planting of new areas (more deforestation) for more palm oil production, and early replanting of oil palm fields with tall palms. Furthermore, moving oil palm seedlings from one area to another has favoured the dispersal of Fusarium wilt all over the oil palm distribution area in Africa including Côte d'Ivoire. Fusarium wilt also known as fusariose in Africa is caused by *Fusarium oxysporum* f.sp. *elaeidis*, a soil-borne fungal pathogen. The disease either kills infected palms or enfeebles the plant. In infected oil palm field, more than 50% of the palms can be lost (Bakoumé, 2016). Therefore, new challenges facing oil palm research and oil palm development in Côte d'Ivoire and Africa as well are the increase or at least stabilization of palm oil yield potential of planting materials, extension of the economic life of oil palm fields and control of Fusarium wilt. The ultimate mitigation measure to the above-mentioned challenges for oil palm research are breeding for palm oil yield increment or stability, slow oil palm growth rate, and crop tolerance to Fusarium wilt.

Breeding is a genetic adjustment of plants to social, cultural, economic, technological and environmental aspects (Chaudhary, 1984). In Côte d'Ivoire, breeding in oil palm is at its third cycle. In plants, including oil palm, the significant improvement in yield has been accompanied by a drastic reduction in the genetic base of the parent material because of severe phenotypic choices. In the oil palm breeding scheme in Côte d'Ivoire, only five palms selected from a survey carried out in the Bingerville region including the botanical gardens and the Bingerville wild palm grove were represented in the La Mé population (Cochard et al., 2000) until the end of the last century. The latter was the sole source of all Group B male genitors for commercial seed production. The narrow genetic base of the La Mé origin led to the enrichment of Group B with Sibiti origin, among few others. On the other hand, Group A is represented by the Deli origin only. Furthermore, all oil palm seeds supplied to farmers in Côte d'Ivoire are derived from less than a dozen Deli *dura*, which are female parents of *tenera* hybrids. Broadening of the genetic base of Group A of Deli *dura* using Angola origin was anticipated in 1971 with the introduction of 6 selected oil palm genitors from the Angolan natural palm groves of Novo-Redondo (3 genitors) and Salazar (3 genitors). Previous works in Group A showed considerable bunch and oil productions and relatively high tolerance to Fusarium wilt of (Deli × Angola) × La Mé progenies. Furthermore, they revealed a high variability within the progenies of Deli × Angola crosses for bunch and oil yield and their components and height growth (Adon, 1995).

In the present study, (Deli × Angola Novo-Redondo) genitor LM 5448 T, the best among those tested in at a previous stage (Adon et al., 2021), was self-pollinated (selfed) to produce (Deli × Angola Novo-Redondo) selfed descendants crossed with La Mé and Sibiti × La Mé testers. The trial EH GP3 has evaluated (Deli × Angola Novo-Redondo) selfed × La Mé and (Deli × Angola Novo-Redondo) selfed × (Sibiti × La Mé) progenies to select the most stable (Deli × Angola Novo-Redondo) selfed genotypes for bunch and oil yields, slow vertical growth rate, and tolerance to Fusarium wilt for the production of commercial seeds for oil palm growers.

2. Materials and Methods

2.1 Plant Material

A total of 27 genitors were used in the progeny trial. Group A was represented by 15 genitors, including 10 from LM 5448 T selfed (4 *tenera*, 3 *dura*, and 3 *pisifera*), 4 Deli *dura* selected in Dabou (Côte d'Ivoire), and LM 5448 T, a descendant of a (Deli × Angola Novo-Redondo) cross. Group B involved 12 genitors of which 10 belonged to the La Mé origin (Côte d'Ivoire), including 7 *dura* and 3 t*enera*, and 2 *dura* genitors descendants of the intra-group cross (Sibiti × La Mé) produced at La Mé. 25 progenies from (Group A × Group B) crosses were produced including 19 progenies from (Deli × Angola Novo-Redondo) selfed × La Mé crosses, 3 [(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)] crosses, and 3 (Deli × La Mé) crosses (Table 1). The 3 progenies from (Deli × La Mé) crosses were trial controls. The crossing design was a North Carolina II (NC II). The genetic trial was established at Ehania in 2002. Ehania is located in the southeast of Côte d'Ivoire, 140 km from Abidjan, in the Aboisso Division. The climate is sub-equatorial, characterized by 4 seasons i.e. 2 rainy seasons and 2 dry seasons. The annual rainfall is 1700-2200 mm. The average annual temperature is 22 - 31 °C and the relative humidity is estimated at 80%. The average annual sunshine is estimated at 1800 hours. The soils vary in texture from sandy-clay with more than 15% of fine elements to clayey with less than 80% of clay. The soils are deep and the pH is between 4.5 and 7. The original vegetation was a dense forest (Coulibaly, 2001). The experimental design is a 5 × 5 balanced lattice with 6 replicates and 16 trees per elementary plot. The planting density was 143 trees per hectare arranged in an equilateral triangle of 9 m side.

Table 1. Details of oil palm progeny trial EH GP3 planted at Ehania (Côte d'Ivoire)

Progeny number in the trial	Progeny	Cross	Inter-group combination type
1	-	*LM 2 T* × **DA 10 D**	La Mé × Deli*
2	LM 24077	*LM 2 T* × **DA 115 D**	La Mé × Deli*
3	LM 22412	*LM 5476 D* × LM 5448 T**	La Mé × (Deli × Angola Novo-Redondo)
4	LM 21983	*LM 2448 T* × **LM 2536 D**	La Mé × Deli*
5	LM 22991	*LM 6536 D* × **LM 13508 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
6	LM 22963	*LM 5468 D* × **LM 13508 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
7	LM 23256	*LM 6356 D* × **LM 13508 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
8	LM 23169	*LM 5468 D* × **LM 13511 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
9	LM 22723	*LM 5475 D* × **LM 13511 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
10	LM 22822	*LM 5466 D* × **LM 13513 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
11	LM 22957	**LM 13513 T** × *LM 6356 D*	(Deli × Angola Novo-Redondo) selfed × La Mé
12	LM 23528	*LM 11311 D* × **LM 13515 T**	(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)
13	LM 23166	*LM 6356 D* × **LM 13515 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
14	LM 22795	*LM 5475 D* × **LM 13515 T**	(Deli × Angola Novo-Redondo) selfed × La Mé
15	LM 22972	*LM 3390 T* × **LM 13509 D**	(Deli × Angola Novo-Redondo) selfed × La Mé
16	LM 22835	**LM 13516 D** × *LM 5005 T*	(Deli × Angola Novo-Redondo) selfed × La Mé
17	LM 22966	*LM 5466 D* × **LM 13517 P**	(Deli × Angola Novo-Redondo) selfed × La Mé
18	LM 23957	*LM 6536 D* × **LM 13517 P**	(Deli × Angola Novo-Redondo) selfed × La Mé
19	LM 22993	LM 5468 D × **LM 13519 P**	(Deli × Angola Novo-Redondo) selfed × La Mé
20	LM22794	*LM 5475 D* × **LM 13519 P**	(Deli × Angola Novo-Redondo) selfed × La Mé
21	LM 23731	*LM 13524 D* × **LM 13523 P**	(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)
22	LM 23982	*LM 11311 D* × **LM 13523 P**	(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)
23	LM 23306	*LM 5475 D* × **LM 13523 P**	(Deli × Angola Novo-Redondo) selfed × La Mé
24	LM 22480	**LM 13518 D** × *LM 5911 T*	(Deli × Angola Novo-Redondo) selfed × La Mé
25	LM 22454	**LM 13518 D** × *LM 5005 T*	(Deli × Angola Novo-Redondo) selfed × La Mé

Note. In bold (**LM 13508 T**) group A genitor from (Deli × Angola Novo-Redondo) selfed; in bold and underlined (**LM 2536 D**) group A genitor from Deli origin; in italics (*LM 2 T*) group B genitor from La Mé origin; in italics and underlined (*LM11311D*) Group B genitor from (La Mé × Sibiti) cross; *: (Group B × Group A) control combinations; **: (Deli × Angola Novo-Redondo) genitor selfed whose descendants were used in the La Mé × (Deli × Angola Novo-Redondo) selfed and (La Mé × Sibiti) × (Deli × Angola Novo-Redondo) selfed inter-group combinations.

2.2 Parameters Recorded

2.2.1 Bunch Number and Total Bunch Weight

Bunch number (BN) and corresponding total weight (TBW) were recorded on per tree basis during each of the 3 harvesting rounds carried out per month from 2012 to 2015. The average bunch weight (ABW) was deducted from the total weight of bunches and the number of bunches using the following arithmetic formula:

$$PMR = PTR/NR \quad (1)$$

Progeny's bunch yield (BY) was performed using the following formula:

$$BY = TBW \times D \times 0.95 \quad (2)$$

Where, BY is the bunch yield, TBW is annual mean individual total bunch weight, D is planting density (D = 143 in the progeny trial), 0.95 is a coefficient estimating that palms morphologically abnormal and palms weakened by diseases and/or pest attacks are equivalent to a loss of 5% of the trees per hectare planted.

2.2.2 Bunch Characteristics

Two bunches harvested, one in the rainy season and the other in the dry season, only from *tenera* palms of each progeny were analysed to determine the percentage of fruit to bunch (F/B), the percentage of mesocarp (or pulp) to fruit (M/F), and the oil to mesocarp ratio (O/M). Data collected helped in estimating the industrial oil extraction rate (OER) and oil yield (OY) using the following formulas:

$$OER = F/B \times M/F \times O/M \times 0.855 \quad (3)$$

$$OY = BY \times OER \quad (4)$$

Where, 0.855 is a factor that takes into account various losses of oil during its extraction in the palm oil mill.

2.2.3 Vertical Growth Rate (VGR)

The palm height was measured at 6 years after planting at the axil of leaf 33. Leaf 33 is located approximately at the level of the ripe bunches and very often bears a rotten male inflorescence. The height of the palm tree was then read at ground level (Jacquemard, 1980). The growth rate was determined by the following formula:

$$VGR = H/(n - 3.75) \quad (5)$$

Where, VGR is the vertical growth rate, H is the palm height, n is age of the palm in years, 3.75 (years) is the age at which the growth in height starts, since before this age the palm grows transversely to ensure that the root bulb is well embedded in the soil.

2.2.4 Fusarium Index

A sample of 160 seedlings per progeny aged 2 months was used for the test of tolerance to Fusarium wilt. A few roots were exposed and scraped to create lesions, rinsed with distilled water. Then, 20 ml of inoculum of a cultivated strain of *Fusarium oxysporum* f. sp. *elaeidis* containing about 5×10^5 spores/ml were poured onto the roots. After spore inoculation, the roots were covered with soil. Recording of symptoms and stunted seedlings began one month after inoculation. After 5 months, the pseudo-bulb of each seedling was sectioned to allow visualisation of tissues' browning, an internal symptom, which indicates the presence of the pathogenic fungus in the seedling. The Fusarium wilt status of each progeny tested was related to the average percentage of seedlings showing external and/or internal symptoms in the whole test. A progeny Fusarium Index (FI) was determined as follows:

$$FI = \frac{\text{Percentage of infected seedlings of the progeny}}{\text{Percentage of infected seedlings of all progenies}} \times 100 \quad (6)$$

The threshold for the estimation of progeny tolerance to Fusarium wilt was set at 100. Thus, progenies with FI > 100 were considered susceptible to the disease and those with FI < 100 were qualified tolerant.

2.3 Statistical Analysis

The Student's unpaired t-test was used to compare each of the (Deli × Angola Novo-Redondo) × La Mé, (Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti), (La Mé × Deli) combinations to (Deli × Angola Novo-Redondo) selfed × La Mé for (i) bunch yield and its components, (ii) vertical growth rate, and (iii) bunch characteristics.

Analyses of variance were performed to determine the combining abilities of [(Deli × Angola Novo-Redondo) selfed] genotypes, Deli, La Mé, and (Sibiti × La Mé) testers. The following general linear model described by Salami and Agbowuro (2016) was used for bunch production and its components, vertical growth rate, and bunch characteristics:

$$Y_{ijk} = \mu + m_i + f_j + mf_{ij} + e_{ijk} \quad (7)$$

Where, Y_{ijk} is the value of the offspring of the cross between male sire i and female sire j in replicate k, μ is the trial mean, m_i is the effect of male parent i, f_j is the effect of female parent j, mf_{ij} is the interaction between male i and female j, e_{ijk} is the within-plot residual.

Grouping of mean values of the progenies was performed using Duncan's Multiple Range Test (DMRT). Breeding values of [(Deli × Angola Novo-Redondo) selfed] genitors were estimated as defined by Corley and Tinker (2003).

3. Results and Discussion

3.1 Comparison of Different Combination Types

Each of the combinations La Mé × (Deli × Angola Novo-Redondo), (Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti), and (La Mé × Deli) was compared to (Deli × Angola Novo-Redondo) selfed × La Mé using Student test. TBW mean values varied from 156.4±49.35 kg palm^{-1} yr^{-1} for (La Mé × Deli) to168.1±55.15 kg palm^{-1} yr^{-1} for (Deli × Angola Novo-Redondo) selfed × La Mé. Combinations involving (Deli × Angola Novo-Redondo) selfed have produced 15% more bunches than the controls (La Mé × Deli), on average. The Student test showed the superiority of (Deli × Angola Novo-Redondo) selfed-derived combinations for TBW and BN (Table 2). The high TBW observed was most probably due to their high BN. Darkwah et al (2020a) selected 7 *dura* accessions from Ghana for their high TBW contributed by high BN and ABW. Lubis et al. (1991) moved further and found that BN was a predominant factor in TBW and palm oil production. Recently, Isa et al. ((2009) also reported from their study of the variation in yield and yield components in Malaysian oil palm (*Elaeis guineensis* Jacq.) D × P planting materials under various planting density that the highest fresh fruit bunch (or TBW) obtained were attributed to high mean BN. The high ABW of (La Mé × Deli) and (Deli × Angola Novo-Redondo) derived-combinations did not compensate for the low BN. Furthermore, Isa et al. (2009) found positive correlation between TBW and BN (r = 0.69) and a negative correlation between BN and ABW (r = - 0.43) at a planting density of 148 palms ha^{-1} which was the closest to 143 palms ha^{-1} of the current study. Globally, the vertical growth rate of (Deli × Angola Novo-Redondo) selfed-derived combinations was comparable to those of the controls (La Mé × Deli) and (Deli × Angola Novo-Redondo) × La Mé combination. Growth rates, independently of the combinations type, were less than 50 cm yr^{-1} considered as slow growth rate for current planting materials.

Table 2. Comparison of (Deli × Angola Novo-Redondo) selfed × La Mé combinations to each of the (Deli × Angola Novo-Redondo) self × (La Mé × Sibiti), La Mé × (Deli × Angola Novo-Redondo), and (La Mé × Deli) combinations for bunch production and its components and vertical growth rate

Combinaisons	df	TBW (kg yr^{-1})		BN		ABW (kg)		VGR (cm yr^{-1})		
		Mean	*t*	Mean	*t*	Mean	*t*	df	Mean	*t*
(Deli × Angola Novo-Redondo) selfed × La Mé		168.1±55.15		10.61±4.11		16.62±3.84			48.5±6.6	
(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)	7972	163.3±60.88	2.69^{**}	9.97±4.00	4.86^{***}	17.10±4.35	3.75^{***}	1992	47.4±6.8	2.56^{**}
La Mé × (Deli × Angola Novo-Redondo)	7213	156.3±59.91	4.05^{***}	9.02±3.67	7.31^{***}	17.92±3.96	6.39^{***}	1802	47.7±6.8	1.08^{ns}
La Mé × Deli	7981	156.4±49.35	6.76^{***}	8.97±3.25	12.80^{***}	18.06±3.63	11.78^{***}	1995	48.3±6.1	0.57^{ns}

Note. Df: degree of freedom; TBW: total bunch weight; BN: bunch number; ABW: average bunch weight; VGR: vertical growth rate; *t*: value of Student statistic; **: value significant at 1%; ***: value significant at 1‰; ^{ns}: value not significant.

(Deli × Angola Novo-Redondo) selfed-derived combinations were close to the original combination La Mé × (Deli × Angola Novo-Redondo) and to the controls (Deli × La Mé) for F/B and O/M. They differ for M/F that led to a difference between combinations for oil extraction rate (Table 3). Bakoumé et al. (2010) found that self-pollination of *dura* considerably affects M/F, O/M, and subsequently OER. However, relatively high oil yield (OY) was obtained from (Deli × Angola Novo-Redondo) selfed-derived combinations with high TBW and BN given the positive correlations between BN and OY as well as between TBW and OY (r = 0.63 and r = 0.91, respectively) (Isa et al., 2009).

Table 3. Comparison of (Deli × Angola Novo-Redondo) selfed × La Mé combinations to each of the (Deli × Angola Novo-Redondo) self × (La Mé × Sibiti), La Mé × (Deli × Angola Novo-Redondo), and (La Mé × Deli) combinations for bunch characteristics

Combinaisons	df	F/B (%)		M/F (%)		O/M (%)		OER (%)	
		Mean	*t*	Mean	*t*	Mean	*t*	Mean	*t*
(Deli × Angola Novo-Redondo) selfed × La Mé		62.36±6.92		74.26±5.70		59.28±8.13		27.27± 5.37	
(Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti)	804	64.12±7.15	2.46^{**}	71.12±4.53	5.49^{***}	61.96±7.03	3.27^{***}	28.41±4.84	2.10^{*}
La Mé × (Deli × Angola Novo-Redondo)	726	65.83±5.78	2.74^{**}	76.63±4.99	2.28^{*}	60.48±7.03	0.81^{ns}	31.56±5.46	4.29^{***}
La Mé × Deli	781	62.09±5.31	0.35^{ns}	77.85±5.40	5.55^{***}	59.15±9.03	0.13^{ns}	29.63±6.75	3.74^{***}

Note. df: degree of freedom; F/B: fruit to bunch ratio; M/F: mesocarp to fruit ratio; O/M: oil to mesocarp ratio; OER: oil extraction rate; *t*: value of Student statistic; *: value significant at 5%; **: value significant at 1%; ***: value significant at 1‰; ^{ns}: value not significant.

3.2 Progenies Performances for Bunch Production and Its Components and Vertical Growth Rate

The total bunch weight of [(Deli × Angola Novo-Redondo) selfed × La Mé] progenies varied from 164.15 kg $palm^{-1}$ yr^{-1} (22.16 t ha^{-1}) to 177.15 kg $palm^{-1}$ yr^{-1} (23.92 t ha^{-1}). The mean TBW (168.43 kg $palm^{-1}$ yr^{-1}) was by 4%

greater than the mean TBW of [(Deli × Angola Novo-Redondo) selfed × (Sibiti × La Mé)] progenies and 8% higher than each of the (Deli × La Mé) and [La Mé × (Deli × Angola Novo-Redondo)] progenies' means (155.72 kg palm^{-1} yr^{-1} and 156.07 kg palm^{-1} yr^{-1}, respectively). The ANOVA revealed differences between male parents as well as between female parents including (Deli × Angola Novo-Redondo) selfed genitors for bunch production and its components and vertical growth rate as well (Table 4). Furthermore, very significant male parent × female parent interaction was detected with the exception of vertical growth rate. The ANOVA also revealed differences among male parents and among female parents for bunch characteristics except for mesocarp to fruit ratio (Table 5). However, the male parent × female parent interaction was not significant for all the bunch characteristics. The different genetic backgrounds of the genitors crossed led to the difference between male parents and between female parents. La Mé origin, Sibiti × La Mé combination were most probably genetically dissimilar. Selfing of (Deli × Angola Novo-Redondo) hydrid genitor (LM 5448 T) had generated different allele combinations during the formation of the F_2 oil palm populations used in the (Deli × Angola Novo-Redondo) selfed × La Mé and (Deli × Angola Novo-Redondo) selfed × (La Mé × Sibiti) crosses.

Table 4. Analysis of variance of total bunch weight and its production components and vertical growth rate

Source of variation	df	TBW		BN		ABW		Vertical Growth Rate		
		MS	F	MS	F	MS	F	df	MS	F
Repetition	5	58 441. 24	19.59***	113.22	7.92***	97.10	7.55***	5	10 925.94	12.84***
Parent male	13	19 993.95	6.70***	1104.50	77.27***	1458.62	113.36***	12	12 299.36	14.46***
Parent female	15	15 453.52	5.18***	232.83	16.29***	293.70	22.83***	14	9 475.27	11.14***
Male × Female	195	13 431.33	4.50**	153.11	10.71***	221.84	17.24***	168	1618.59	1.90^{ns}
Residual error	9351	2 982.95		14.29		12.87		2227	850.65	

Note. df: degree of freedom; TBW: total bunch weight; BN: bunch number; ABW: average bunch weight; MS: mean square; F: Fisher value calculated; *: value significant at 5%; **: value significant at 1%; ***: value significant at 1‰; ^{ns}: value not significant.

Table 5. Analysis of variance of bunch characteristics

Source of variation	df	F/B		M/F		O/M		OER		
		MS	F	MS	F	MS	F	df	MS	F
Repetition	5	86.74	2.19^{ns}	52.22	2.27*	387.79	0.86^{ns}	5	73.94	2.76*
Male parent	12	369.43	9.34***	710.79	30.96***	413.50	0.91^{ns}	12	218.41	8.15***
Female parent	13	249.29	6.30***	113.60	4.95***	437.38	0.96^{ns}	14	131.47	4.90***
Male × Female	156	68.24	1.73^{ns}	27.54	1.20^{ns}	311.24	0.69^{ns}	168	48.83	1.82^{ns}
Residual error	775	39.54		22.96		453.36		2 227	26.81	

Note. df: degree of freedom; F/B: fruit to bunch; M/F: mesocarp to fruit; O/M: oil to mesocarp; OER: oil extraction rate; MS: mean square; F: Fisher value calculated; *: value significant at 5%; **: value significant at 1%; ***: value significant at 1‰; ^{ns}: value not significant.

The DMRT presented groups of means of TBW, BN, ABW and vertical growth rate overlapping each other. The results indicated that (Deli × Angola Novo-Redondo) selfed-derived progenies were comparable to the controls, of the current commercial planting materials (Table 6). Coefficients of variation of TBW, oil yield and vertical growth rate were low. They varied from 3 % for TBW to 8% for oil yield further supporting progeny homogeneity. The 21 (Deli × Angola Novo-Redondo) selfed-derived progenies were comparable to the 3 (La Mé × Deli) control progenies for oil yield (6.22 t ha^{-1} versus 6.17 t ha^{-1}), and comparable vertical growth rate with the current commercial material (48.45 cm yr^{-1} versus 48.41 cm yr^{-1}). However, they recorded 8% more TBW than the 3 (La Mé × Deli) control progenies (167.50 kg palm^{-1} yr^{-1} versus 155.72 kg palm^{-1} yr^{-1}). Similarity for oil yields derived from the low M/F of (Deli × Angola Novo-Redondo) selfed-derived progenies despite their high TBW. The low M/F probably resulted from the inbreeding depression usually due to self-pollination in oil palm. Bakoumé et al. (2010) reported that inbreeding depression reduced bunch characteristics including M/F of (DA 3 D × DA 5 D) selfed-derived progenies. Besides, low M/F implied low OER.

Table 6. Comparison of mean values of fresh bunch production components at maturity and vertical growth rate

Bunch production at maturity									Vertical Growth Rate		
TBW			BN			ABW (kg)					
Progeny No.	Mean (kg palm^{-1} yr^{-1})	Grouping	Progeny No.	Mean	Grouping	Progeny No.	Mean (kg palm^{-1})	Grouping	Progeny No.	Mean (cm yr^{-1})	Grouping
16	177.15	a	25	13.89	a	12	19.30	a	14	53.16	a
10	174.95	ab	24	13.45	a	10	18.82	ab	23	52.16	ab
22	174.51	ab	19	11.29	b	4	18.78	ab	9	50.88	abc
9	173.99	ab	9	11.17	bc	2	18.58	abc	1	50.12	bcd
23	173.43	ab	21	11.05	bcd	13	18.18	bc	13	50.04	bcd
19	172.23	ab	20	10.97	bcde	3	18.02	bcd	8	49.80	bcd
20	171.11	ab	23	10.93	bcde	11	17.78	cde	10	49.68	**bcde**
5	169.03	abc	8	10.85	bcde	16	17.78	cde	20	49.48	bcdef
6	168.31	abc	22	10.85	bcde	5	17.66	cdef	7	48.84	cdefg
8	168.31	abc	15	10.33	bcdef	17	17.18	defg	11	48.72	cdefg
7	167.55	abcd	14	10.29	bcdefg	7	17.14	defg	12	48.60	cdefg
14	165.87	abcd	6	10.25	bcdefg	18	16.98	efgh	15	48.48	cdefg
24	165.35	abcd	16	10.17	cdefgh	6	16.74	fgh	3	48.04	defg
15	164.83	abcd	1	10.13	cdefgh	1	16.58	gh	24	47.84	defg
18	164.63	abcd	7	10.09	cdefgh	14	16.58	gh	2	47.56	defg
25	164.15	abcd	18	9.97	defgh	9	16.54	gh	4	47.56	defg
11	163.71	abcd	5	9.89	efgh	22	16.50	gh	16	47.48	defg
13	163.59	abcd	17	9.57	fghi	23	16.50	gh	22	47.32	defg
17	163.55	abcd	10	9.41	fghi	15	16.38	gh	5	47.28	defg
1	162.95	bcd	11	9.41	fghi	8	16.14	ghi	17	46.92	efg
21	162.51	bcd	13	9.21	ghij	19	16.14	ghi	21	46.68	fgh
3	156.07	cde	3	9.13	hij	20	16.06	hi	6	46.64	fgh
2	154.19	de	2	8.61	ijk	21	15.34	i	18	46.36	gh
4	150.03	e	4	8.37	jk	24	13.26	j	25	44.20	h
12	148.75	e	12	7.97	k	25	12.54	j	19	44.16	h

Note. TBW: total bunch weight; BN: bunch number; ABW: average bunch weight; Progeny with the same letter are not significantly different.

Fusarium indices (FI) of all the (Deli × Angola Novo-Redondo) selfed-derived progenies were relatively low (41-84) indicating that they were tolerant (or resistant) to Fusarium wilt. In fact, progenies with FI < 100 are qualified tolerant to the disease. FI of (La Mé × Deli) control progenies were equal to 96 or 97 (Table not presented). Genitors descendants from (Deli × Angola Novo-Redondo) selfed that is LM 5448 T selfed might have predominantly contributed to the tolerance to Fusarium wilt expressed by their hybrid progenies. In fact, (Deli × Angola Novo-Redondo)'s LM 5448 T was selected in a recent study for its tolerance to Fusarium wilt (FI = 82) in addition to its high bunch and oil yields (Adon et al., 2021).

The main aims of oil palm breeding in Africa including Côte d'Ivoire are to maximize palm oil (and kernel) yield, to reduce vertical growth to extend the plant's economic life, and to explore new sources of tolerance to Fusarium wilt (Bakoumé et al., 2016). In a recent study aiming to select elites genotypes within natural oil palm accessions collected in Ghana, Darkwah et al. (2020b) confirmed the high heritability of TBW (h^2 = 0.52), a feature that indicated the possibility to get it (heritability) expressed in subsequent generations. Three progenies (LM 22723, LM 22835, LM 23169) out of the 8 that ranked first for oil yield were derived from crosses involving (Deli × Angola Novo-Redondo) selfed. They possessed relatively high TBW and BN ((11% and 22% more than the controls, respectively) (Table 7). The trend was observed for oil yield. According to Isa et al. (2009), oil yield is mostly dependent on TBW and BN. Darkwah et al. (2020b), a Ghanaian Oil Palm Research Institute (OPRI) team, supported the interest of breeding programs in *dura* parents of relatively high number of bunches for further improvement of this character in the *tenera*. The team carried out an evaluation of the genetic variability of TBW and BN among other agronomic and morphological traits of natural *dura* accessions for the selection of elite ones to introduce in the advanced *dura* stocks. The 3 progenies' vertical growth rate values represented 2% and 8% rise over the trial mean and (La Mé × Deli) control progenies' mean, respectively. Darkwah et al. (2020b) selected 5 genotypes whose mean VGR represented 7% increase over the controls' mean. Furthermore, the 3 progenies selected were tolerant to Fusarium wilt (FI = 32-79). Therefore, the 3 progenies viz LM 22723, LM 22835, and LM 23169 should be added to the commercial seed production programme. Vertical growth rate constituted a minor constraint because shorter descendants of (Deli × Angola Novo-Redondo) selfed would be selected for use in the seed production.

Table 7. Bunch production, bunch characteristics and vertical growth rate of the best (Deli × Angola Novo-Redondo) selfed-derived progenies

Progeny	Cross type	Oil (t ha^{-1})	TBW (kg palm^{-1} yr^{-1})	BN	ABW (kg)	F/B (%)	M/F (%)	O/M (%)	OER (%)	VGR (cm yr^{-1})	FI
LM 22835	**LM 13516 D** × LM 5005 T	7.17	177.15	10.16	17.78	61	79	60	30	47.48	79
LM 22723	LM 5475 D × **LM 13511 T**	6.58	173.99	11.17	16.54	64	71	58	28	50.88	56
LM 23169	LM 5468 D × **LM 13511 T**	6.36	168.31	10.85	17.78	64	72	60	28	49.80	32
Mean		6.70	173.15	10.73	17.37	63	74	59	29	49.80	56
Trial mean		6.23	165.25	10.29	16.86	63	74	61	28	48.32	56
(La Mé × Deli) controls' mean		6.17	155.72	8.80	14.91	62	75	59	29	45.83	97

Note. Oil: oil yield; TBW: total bunch weight; BN: bunch number; ABW: average bunch weight; F/B: fruit to bunch; M/F: mesocarp to fruit; O/M: oil to mesocarp; OER: oil extraction rate; VGR; vertical growth rate; FI: Fusarium index.

3.3 Breeding Values of (Deli × Angola Novo-Redondo) Selfed Genitors of Progenies Intended to Seed Production

The breeding value of a genitor is the average value of all the progenies from the genitor concerned (Corley & Tinker, 2003). Two (2) genitors from (Deli × Angola Novo-Redondo) selfed which were parents of the 3 progenies selected including 1 *dura* (LM 13516 D) and 1 *tenera* (LM 13511 T). The 2 genitors' breeding values for bunch production, bunch characteristics, oil yield, and vertical growth rate were presented in Table 8. Their mean oil yield was 6.74 t ha^{-1} contributed by 23.22 t ha^{-1} of bunches, 63% fruit to mesocarp, and 29% O/M. Breeding values of the two genitors were considered satisfactory for the present study. Corley and Tinker (2003) also defined a breeding value of a parent as a difference between the average value of all the progenies from the genitor concerned and the overall mean for the trial. The breeding value calculated using the preceding expression were 5.75 kg palm^{-1} yr^{-1} and 7.75 kg palm^{-1} yr^{-1} for LM 13511 T and LM 13516 D, respectively for TBW. The rest of the breeding values of the 2 genitors, all parameters put together were comprised between -2% for F/B and 1.68 cm yr^{-1} for VGR, independently of the genitor (Table not shown) indicating that the individual performances were too close to the trial means and could be well considered relatively high. In fact, the trial performed significantly better for bunch production, oil yield than the (La Mé × Deli) control progenies which were representatives of the best planting materials of the second selection cycle. The breeding values obtained would be used to predict the performances of progenies derived from crosses where they would be involved. According to Corley and Tinker (2003), the expected performances of progenies to be reproduced will be simply the mean values of the two parents. In addition, Sparnaaij & van der Vossen (1980) recommended that in breeding for oil yield in oil palm, breeding values should be exploited by crossing parents with contrasting yield components. Therefore, it would be imperative to determine the breeding values of the 2 genitors' partners prior to the preparation of the seed production crossing chart.

Table 8. Genetic values of genitors for production of (Deli × Angola Novo-Redondo) selfed × La Mé commercial seeds

Genitor	Oil (t ha^{-1})	TBW (kg palm^{-1} yr^{-1})	BN	ABW (kg)	F/B (%)	M/F (%)	O/M (%)	OER (%)	VGR (cm yr^{-1})
LM 13516 D	7.01	173	10	18	61	79	60	30	48
LM 13511 T	6.46	171	11	16	64	72	59	28	50
Mean	6.74	172	11	17	63	76	60	29	49

Note. Oil: oil yield; TBW: total bunch weight; BN: bunch number; ABW: average bunch weight; F/B: fruit to bunch; M/F: mesocarp to fruit; O/M: oil to mesocarp; OER: oil extraction rate; VGR: vertical growth rate.

4. Conclusion

The Mé Oil Palm Research station has successfully introduced additional blood (Angola Novo-Redondo blood) into to the Deli origin, the unique of group A of RRS until now. It has revealed the good performances of (Deli × Angola Novo-Redondo) selfed × La Mé progenies for oil yield due to their high TBW and BN over (La Mé × Deli) control progenies; best planting materials of the second cycle of RRS carried out in Côte d'Ivoire. The study has provided oil palm growers with 3 (Deli × Angola Novo-Redondo) selfed × La Mé commercial progenies with additional gene for tolerance to Fusarium wilt and high bunch production and oil yield through the introduction of the Angola Novo-Redondo germplasm. The new progenies are relatively superior to the current planting materials derived from the second selection cycle. Based on the breeding values obtained from the progenies' parents, seed production should put emphasis on crossing individuals with contrasting bunch and oil parameters for improved yields. Furthermore, continuous production of LM 13516 D, LM 15311 T descendants for commercial seeds production should be taken a second look to prevent inbreeding depression in intra-group hybrids.

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Abbreviations

DA 10 D: 10^{th} genitor of *dura* type selected at Dabou; EH GP3: 3^{rd} progeny trial established at Ehania (Côte d'Ivoire); LM: La Mé (Côte d'Ivoire); LM 2 T: 2^{nd} genitor of *tenera* type selected in La Mé (Côte d'Ivoire); D: *dura* palm; T: *tenera* palm; P: *pisifera* palm.

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