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POTENTIAL OIL PALM GENETIC MATERIALS DERIVED FROM INTROGRESSION OF GERMPLASM (MPOB-NIGERIA, MPOB-ZAIRE AND MPOB-CAMEROON ACCESSIONS) TO ADVANCED (AVROS) BREEDING POPULATION

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ABSTRACT

The narrow genetic base of current oil palm planting materials is the main obstacle in oil palm breeding and population improvements. However, genetic variability can be widened through introgression of advanced materials with selected oil palm germplasm. Thus, tenera *performance was evaluated from 14* tenera *x* pisifera *involving MPOB-Nigeria (MPOB-NGA), MPOB-Cameroon (MPOB-CMR) and MPOB-Zaire (MPOB-ZRE) crosses with* Algemene Vereniging van Rubberplanters ter Oostkust van Sumatra *(AVROS) progenies. Analysis of variance between groups showed significant differences in fresh fruit bunch (FFB) yield and its components, bunch quality components and most of the vegetative traits studied. Strong and positive correlations of FFB and oil to bunch (O/B) with oil yield (OY) suggested that oil yield can be improved by increasing FFB yield or O/B. Broad-sense heritability estimates varied from a low of 20.56% (FFB yield) to a high of 100% (shell to fruit ratio). Both PK 1858 (MPOB-ZRE x AVROS) and PK 1867 (MPOB-NGA x AVROS) progenies have been identified as potential sources of* pisifera *for selection due to their promising results in most of the desired traits.*

Keywords: germplasm advanced breeding population, introgression.

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INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is the largest produced and traded vegetable oil in the global oils and fats market. It has the lowest production costs of all vegetable oils and production has been estimated to reach 240 million tonnes by 2050 (Corley, 2009). As the second largest producer and exporter of palm oil, Malaysia has a huge role to play in fulfilling the increasing global need for vegetable oils and fats. In 2018, Malaysia contributed about 33% or 16.49 million tonnes of global palm oil exports (Kushairi, 2019). The global demand for edible vegetable oils has grown in recent decades and palm oil production has expanded rapidly to meet that demand. The Malaysian oil palm industry is supported by strategic policies as well as research and development activities by the Malaysian Palm Oil Board (MPOB) in developing high yielding planting materials. However, introduction of new exotic germplasm is necessary to widen the genetic pool of oil palm for further improvements. This realisation inspired MPOB to explore new oil palm genetic materials from its centre of origin in Africa (Hardon, 1974; Rajanaidu, 1994).

In 1973, the first prospection was conducted in

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Nigeria for MPOB-Nigeria (MPOB-NGA) collection (Rajanaidu *et al.*, 2008). The MPOB-Cameroon (MPOB-CMR) and MPOB-Zaire (MPOB-ZRE) oil palm germplasm was jointly collected with Unilever in 1984. These three earliest germplasm collections have been field planted at the MPOB Research Station, Kluang, Johor and have been extensively evaluated for yield, bunch quality traits, fatty acid composition, vegetative measurement and physiological parameters. The MPOB-NGA germplasm provided several interesting traits for breeding, particularly dwarfness, high iodine value and high kernel content (Rajanaidu *et al.*, 2000). High oleic acid was also a trait of this germplasm (Isa *et al.*, 2006). Elite MPOB-NGA materials of high oil yield, high iodine value (>60) and low stature were distributed to members of the industry for progeny testing and introgression into the current breeding materials to initiate new breeding lines for commercial seed production. MPOB has discovered the potential of oil palm collections to develop planting materials via selecting the outstanding MPOB-NGA *dura* and *pisifera* palms to increase the level of genetic variability in current Deli *dura* and *tenera/pisifera* (Rajanaidu *et al.*, 1996).

MPOB-CMR and MPOB-ZRE were among the germplasm collections which produced oils with high vitamin E (Kushairi *et al.*, 2004). Selected palms from both MPOB-CMR and MPOB-ZRE populations have also shown partial resistance to *Ganoderma* in nursery screening experiments (Idris *et al.*, 2005). MPOB-CMR and MPOB-ZRE germplasm collections also possessed more than 20% crude protein in the kernel (Noh *et al.*, 2014). In addition, MPOB-CMR genetic material was listed as an MPOB germplasm with low lipase and high bunch index (BI) traits, the latter an essential character for the selection of high yielding materials (Maizura *et al.*, 2008; Fadila *et al.*, 2016).

The AVROS has been widely distributed as the source of *pisifera* parent by major seed producers worldwide. It is noted for its high oil yield and vigorous growth-conferring attributes. In addition, they exhibit high mesocarp to fruit (M/F), oil to bunch (O/B) ratios and trunk height increment (HTi) (Lee and Yeow, 1985; Rajanaidu *et al.*, 1986; Rao *et al.*, 1999; Noh *et al.*, 2012). Therefore, the aim of this study was to determine the performance of *teneras* from the *tenera* x *pisifera* (TxP) crosses, involving MPOB-NGA, MPOB-CMR and MPOB-ZRE introgressed into AVROS. *Pisifera* palms would also be identified from the outstanding progenies for progeny testing with advanced breeding populations.

MATERIALS AND METHODS

A total of 14 progenies derived from TxP crosses of 4 MPOB-NGA x AVROS, 7 MPOB-CMR x AVROS and 3 MPOB-ZRE x AVROS were planted in a triangular planting system at 9 m apart in a Randomised Completely Block Design (RCBD) with 16 palms per plot (progeny) with two replications (*Table 1*). The progenies were planted in Trial 0.351 at the MPOB Research Station, Keratong in 1996. The site in Keratong is characterised by the Serdang soil series and average annual rainfall recorded here is below 2000 mm.

Data Collection

The fresh fruit bunch (FFB) yield data was recorded for each individual palm in both replications at an interval of three rounds per month. FFB yield is the sum of bunch weight (BWT) while average bunch weight (ABW) is the quotient between FFB and bunch number (BNO). BWT and BNO are recorded for each palm per harvesting round, starting from 36 months after field planting for seven consecutive years (2003-2009). Bunch analysis is conducted to estimate the oil and kernel content of bunches, so that oil yields can be calculated (Corley and Tinker, 2016). The bunch analysis method developed by Blaak *et al.* (1963) and modified by Rao *et al.* (1983) was used to determine oil extraction and fruit quality components, such as mesocarp to fruit (% M/F), shell to fruit (% S/F), oil to dry mesocarp (% O/DM), fruit to bunch (% F/B), oil to bunch (O/B), kernel to bunch (% K/B), kernel to fruit (% K/F), oil yield (OY) and total economic product (TEP). Three to five bunches were sampled from each palm from 2003-2009. To avoid seasonal variation, ripe bunches with one to 10 loose fruits were randomly sampled at intervals of at least three months from the previous sampling palm (Rao, 1987). One round of vegetative measurement was conducted in 2004, which is eight years after field planting as proposed by Corley and Breure (1981). Palm height was measured from the ground level to the base of frond number 41. Height increment was calculated using the formula: height increment/year = (height at year t) / (t - 2), where t is the age of the palm (Breure and Powell, 1987). Morphological traits such as frond production (FP), petiole cross section (PCS), rachis length (RL), leaflet length (LL), leaflet number (LN), height increment (HTI), leaflet area (LA), leaflet area index (LAI) diameter (DIA) were also recorded following methods established by Breure and Powell, (1987).

Statistical Analysis

The data on bunch yield, FFB, ABW and BNO, bunch quality characters and vegetative measurement was analysed using Statistical Analytical System (SAS version 9.2). The analysis of variance (ANOVA) and correlations for all traits

TABLE 1. LIST OF (TxP) *Tenera* PROGENIES IN TRIAL 0.351 AT MPOB RESEARCH STATION, KERATONG

No.	Materials	Progeny	Female parent (A)	Male parent (B)	A	B	Pedigree B
1	NGA x AVROS	PK 1595	0.151/330	0.182/357	NGA 17.02	MS 2182	0.79/11 x 0.79/221
2	NGA x AVROS	PK 1768	0.151/638	0.182/357	NGA 11.18	MS 2182	0.79/11 x 0.79/221
3	NGA x AVROS	PK 1867	0.149/11745	0.174/304	NGA 16.02	MS 1258	0.79/196 x 0.79/116
4	NGA x AVROS	PK 2005	0.149/11526	0.174/211	NGA 12.01	MS 1436	0.79/374 x 0.79/27
5	CMR x AVROS	PK 1776	0.218/1336	0.174/282	CMR 19.02	MS 1410	0.79/45 x 0.79/286
6	CMR x AVROS	PK 1885	0.219/844	0.174/211	CMR 19.02	MS 2184	0.79/231 x 0.79/281
7	CMR x AVROS	PK 1904	0.219/299	0.182/25	CMR 19.02	MS 2184	0.79/231 x 0.79/281
8	CMR x AVROS	PK 1917	0.219/299	0.174/211	CMR 19.02	MS 1436	0.79/374 x 0.79/27
9	CMR x AVROS	PK 1922	0.218/1336	0.174/211	CMR 19.02	MS 1436	0.79/374 x0.79/27
10	CMR x AVROS	PK 1963	0.218/1006	0.174/211	CMR 29.01	MS 1436	0.79/374 x0.79/27
11	CMR x AVROS	PK 1971	0.219/299	0.174/282	CMR 19.02	MS 1410	0.79/45 x 0.79/286
12	ZRE x AVROS	PK 1815	0.211/341	0.182/410	CMR 30.01	MS 2188	0.79/372 x 0.79/583
13	ZRE x AVROS	PK 1858	0.211/341	0.174/955	CMR 30.01	MS 1436	0.79/374 x 0.79/27
14	ZRE x AVROS	PK 1923	0.221/739	0.174/955	CMR 30.01	MS 1436	0.79/374 x 0.79/27
15	SC (DxP)	PK 1589	0.175/912	0.200/812	MS 1421	MS 3138	0.95/6195x 0.79/6165

studied were calculated using SAS (*Table 2*). The Duncan New Multiple Range Test (DNMRT) was used for comparison between progeny means. Broad-sense heritability statistics were estimated for each character using variance components. The variance analysis for the estimation of broad-sense heritability was processed from the variance component procedure (PROC VARCOMP) of SAS version 9.2 using the formula:

$$h^2_B = \frac{\alpha^2 f}{\alpha^2 f + \alpha^2 wf}$$

where α^2f = variance between family, α^2wf = variance within family. In full-sib families, $2h^2_B$ equals broad sense heritability (Falconer and Mackay, 1996).

RESULTS AND DISCUSSION

Yield and Yield Components

Yield and its components for all groups of crosses comprising MPOB-NGA x AVROS, MPOB-ZRE x AVROS and MPOB-CMR x AVROS are shown in *Table 3*. Analysis of variance (ANOVA) between groups showed significant differences for FFB, BNO and ABW. A wide range in yield and its components was observed among these progenies, which may be important for oil palm breeding and selection. This high variability was also reported by Marhalil *et al.* (2013) on their study in genetic variability of yield and vegetative traits of MPOB-NGA *dura* x AVROS *pisifera*. Junaidah *et al.* (2011) also reported high performance variability in *teneras* derived from Deli *dura* and different *pisifera* sources.

TABLE 2. OUTLINE OF ANOVA AND VARIANCE COMPONENTS ESTIMATION

Source	*df*	Mean square	EMS
Replication (r)	r-1	MS1	$\sigma^2 w + n'\sigma^2_{rp} + n'p\sigma^2_r$
Progeny (p)	p-1	MS2	$\sigma^2 w + n'\sigma^2_{rp} + n'r\sigma^2_p$
Replication x progeny (r x p)	(r-1)(p-1)	MS3	$\sigma^2 w + n'\sigma^2_{rp}$
Error (w)	rp (n′-1)	MS4	$\sigma^2 w$

Note: n′ - harmonic mean for palms, r - number of replication, p - number of progeny or genotype; df - degrees of freedom.

TABLE 3. ANOVA OF *Tenera* PROGENIES FOR YIELD AND YIELD COMPONENTS

Source of variance	*df*	FFB (kg palm^{-1} yr^{-1})	BNO (bunches palm^{-1} yr^{-1})	ABW (kg bunches^{-1})
Between groups	2	4 314.83**	22.39*	14.29**
Within groups	178	1 088.75	7.35	11.74

Note: *, **, indicate significant at P ≤ 0.05, P ≤ 0.01, respectively; FFB - fresh fruit bunch; BNO - bunch number; ABW - average bunch weight.

Further analysis indicated that both MPOB-NGA x AVROS and MPOB-ZRE x AVROS crosses exhibited statistically significant differences in their BNO and ABW, while MPOB-CMR x AVROS demonstrated significant difference in their FFB yields (*Table 4*). Among the three crosses, MPOB-ZRE x AVROS registered the highest FFB yield (P<0.05) (*Table 5*). On the other hand, FFB and ABW production from both MPOB-NGA x AVROS and MPOB-CMR x AVROS were not significantly different from MPOB-ZRE x AVROS. MPOB-CMR x AVROS also produced a lower BNO (P<0.05) than MPOB-NGA x AVROS and MPOB-ZRE. These results were in line with the findings of Rajanaidu *et al.* (2000), whereby the population means of FFB yield and its components for MPOB-ZRE was slightly higher than MPOB-CMR.

Among the progenies, PK 1963 from MPOB-CMR x AVROS produced the highest FFB yield of 189.59 kg palm^{-1} yr^{-1}, which was slightly higher than the best progeny from MPOB-ZRE x AVROS (181.16 kg palm^{-1} yr^{-1}). However, the lowest FFB yield was also recorded from MPOB-CMR x AVROS by PK 1885 which produced only 139.26 kg palm^{-1} yr^{-1} of FFB.

PK 1768 from MPOB-NGA x AVROS produced a low BNO of 8.80 bunches palm^{-1} yr^{-1} but recorded a significantly higher ABW of 19.42 kg bunch^{-1}. Among the MPOB-ZRE x AVROS progenies, PK 1858 produced the highest ABW of 13.16 bunches palm^{-1} yr^{-1}. The low BNO with high ABW observed for MPOB-NGA crosses was also observed for introgressed MPOB-NGA *dura* x Deli *dura* (Noh *et al.*, 2014). In contrast, Isa *et al.* (2008) suggested that MPOB-NGA materials were categorised as high BNO and low ABW.

Bunch Quality Components

Significant difference was observed for all bunch quality component traits between the three groups of crosses (*Table 6*). However, when compared between the families within each cross, statistically significant difference was only observed in OY for all three crosses (*Table 7*). For MPOB-NGA x AVROS cross, statistically significant difference was observed between families for M/F, S/F, O/B and TEP while significant difference in M/F, K/F, S/F, K/B, and KY between families was observed in the MPOB-CMR x AVROS cross. MPOB-ZRE x AVROS exhibited significant difference only for the O/DM trait. The significant difference for these traits indicates high genetic variation for these characters. High genetic variability has also been observed in bunch quality traits in Deli *dura* x AVROS *pisifera* (Noh *et al.*, 2010).

Further analysis showed that MPOB-NGA x AVROS demonstrated the highest means in traits M/F and O/B, but with significantly lower S/F, K/B and K/Y. On the other hand, MPOB-ZRE x AVROS produced excellent values for F/B, KY with a high TEP of 40.34 kg palm^{-1} yr^{-1} (*Table 8*). PK 1867

TABLE 4. ANOVA OF MPOB-NGA x AVROS, MPOB-CMR x AVROS AND MPOB-ZRE x AVROS *Tenera* PROGENIES FOR YIELD AND YIELD COMPONENTS

Materials	Source of variance	*df*	FFB	BNO	ABW
MPOB-NGA x AVROS	Between family	3	674.01^{ns}	27.54**	95.09**
	Within family	57	1 300.11	5.96	7.80
MPOB-CMR x AVROS	Between family	6	3 642.16**	8.81^{ns}	7.52^{ns}
	Within family	79	856.88	7.03	10.96
MPOB-ZRE x AVROS	Between family	2	50.20^{ns}	27.17*	48.23*
	Within family	31	903.94	7.23	11.36

Note: *, **, and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively; FFB - fresh fruit bunch; BNO - bunch number; ABW - average bunch weight.

TABLE 5. MEAN PERFORMANCE OF *Tenera* PROGENIES FOR YIELD AND ITS COMPONENTS

Material	Progeny code	Pedigree	Mean for year 2003-2009		
			FFB (kg palm^{-1} yr^{-1})	BNO (bunches palm^{-1} yr^{-1})	ABW (kg bunches^{-1})
MPOB-NGA x AVROS	PK 1595	0.151/330 x 0.182/357	154.81^{bc}	12.01^{ba}	13.32^{d}
	PK 1768	0.151/638 x 0.182/357	170.24^{bac}	8.80^{d}	19.42^{a}
	PK 1867	0.149/11745 x 0.174/304	164.54^{bac}	10.25^{bdc}	16.15^{bdc}
	PK 2005	0.149/11526 x 0.174/211	155.98^{bc}	11.77^{ba}	13.83^{d}
		Mean	**162.44^{b}**	**10.54^{ba}**	**15.91^{a}**
MPOB-CMR x AVROS	PK 1776	0.218/1336 x 0.174/282	162.95^{bac}	10.80^{bdac}	15.94^{bdc}
	PK 1885	0.219/844 x 0.174/211	139.26^{c}	9.12^{dc}	15.58^{bdc}
	PK 1904	0.219/299 x 0.182/25	164.81^{bac}	9.71^{bdc}	17.55^{ba}
	PK 1917	0.219/299 x 0.174/211	164.64^{bac}	9.53^{bdc}	17.38^{ba}
	PK 1922	0.218/1336 x 0.174/211	143.30^{c}	9.23^{dc}	17.00^{bac}
	PK 1963	0.218/1006 x 0.174/211	189.59^{a}	11.40^{bac}	17.01^{bac}
	PK 1971	0.219/299 x 0.174/282	156.99^{bc}	10.07^{bdc}	16.10^{bdc}
		Mean	**160.39^{b}**	**9.89^{b}**	**16.78^{a}**
MPOB-ZRE x AVROS	PK 1815	0.211/341 x 0.182/410	177.07^{ba}	10.38^{bdc}	17.58^{ba}
	PK 1858	0.211/341 x 0.174/955	181.16^{ba}	13.16^{a}	14.06^{dc}
	PK 1923	0.221/739 x 0.174/955	178.92^{ba}	10.38^{bdc}	17.99^{ba}
		Mean	**178.79^{a}**	**11.20^{a}**	**16.65^{a}**
SC (DxP)	PK 1589	0.175/912 x 0.200/812	142.45	8.09	17.91
Grand mean			**167.21**	**10.54**	**16.45**

Note: FFB - fresh fruit bunch; BNO - bunch number; ABW - average bunch weight; Means with different small letter(s) in the same column are significantly different ($P < 0.05$) from Duncan New Multiple Range Test (DNMRT).

TABLE 6. ANOVA OF *Tenera* PROGENIES FOR BUNCH QUALITY COMPONENTS

Source of variance	*df*	M/F (%)	K/F (%)	S/F (%)	O/DM (%)	F/B (%)	O/B (%)	K/B (%)	OY (kg palm^{-1} yr^{-1})	KY (kg palm^{-1} yr^{-1})	TEP (kg palm^{-1} yr^{-1})
Between group	2	907.46**	129.60**	386.03**	22.40**	354.48**	85.59**	63.11**	185.09*	195.07**	224.61*
Within group	178	29.05	4.84	13.87	5.78	40.63	11.00	2.71	60.48	8.51	76.44

Note: *, **, and ns indicate significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; M/F - mesocarp to fruit ratio; K/F - kernel to fruit ratio; S/F - shell to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield; TEP - total economic product.

from MPOB-NGA x AVROS marked the lowest S/F and K/F and consequently exhibited the highest M/F among the progenies. Conversely, PK 1885 from MPOB-CMR x AVROS with the highest value of S/F and a K/F, showed the lowest M/F at 68.21%. Shell and kernel in oil palm may therefore influence mesocarp content (Noh *et al.*, 2010).

The F/B parameter is an estimate of the fruit set in an oil palm bunch. High amount of F/B is essential for high O/B. The O/B values is derived from F/B, M/F and O/M measurements (Corley and Tinker, 2016). PK 1867 progeny from MPOB-NGA x AVROS exhibited the highest O/B, which may be attributed to its high M/F, F/B and O/DM mean values. When high M/F, K/B and F/B are coupled with high O/B and fresh fruit bunch (FFB), yields would likely be increased substantially (Kushairi *et al.*, 1999).

The TEP was derived from the sum of OY and 60% of KY. Therefore, a high TEP value is contributed by bunches with a high content of mesocarp and kernel, suggesting the importance for maintaining a high F/B. From this study, PK 1858 (MPOB-ZRE x AVROS) showed the highest OY and TEP, that was likely contributed by the high FFB yield. At

TABLE 7. ANOVA OF MPOB-NGA x AVROS, MPOB-CMR x AVROS AND MPOB-ZRE x AVROS *Tenera* PROGENIES FOR BUNCH QUALITY COMPONENTS

			Mean square (2005-2013)									
Materials	Source of variance	*df*	M/F (%)	K/F (%)	S/F (%)	O/DM (%)	F/B (%)	O/B (%)	K/B (%)	OY (kg palm^{-1} yr^{-1})	KY (kg palm^{-1} yr^{-1})	TEP (kg palm^{-1} yr^{-1})
MPOB-NGA x AVROS	Between family	3	309.92**	4.50^{ns}	272.87**	47.27*	64.55^{ns}	122.58**	1.88^{ns}	329.73**	8.85^{ns}	366.25**
	Within family	57	14.92	3.17	6.41	4.69	33.43	9.12	1.68	51.83	5.54	65.75
MPOB-CMR x AVROS	Between family	6	129.51**	19.35**	55.43**	8.85^{ns}	76.80^{ns}	5.84^{ns}	14.13**	136.82**	22.07*	155.37^{ns}
	Within family	79	22.02	5.53	14.63	4.80	47.13	9.53	2.84	57.12	9.36	74.62
MPOB-ZRE x AVROS	Between family	2	12.06^{ns}	7.18^{ns}	3.07^{ns}	26.94**	22.91^{ns}	16.98^{ns}	4.73^{ns}	147.12*	4.78^{ns}	123.61^{ns}
	Within family	31	24.85	3.20	8.81	4.30	29.14	8.03	1.98	38.47	9.18	54.39

Note: *, **, and ns indicate significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; M/F - mesocarp to fruit ratio; S/F - shell to fruit ratio; K/F - kernel to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield; TEP - total economic product.

the other extreme, PK 1595 from MPOB-NGA x AVROS recorded the lowest TEP and lowest OY. On the other hand, progeny PK 1923 from MPOB-ZRE x AVROS ranked the highest in terms of KY with 12.76 kg palm^{-1} yr^{-1} or 1.8 t ha^{-1} yr^{-1}, far above the trial mean of 10.33 kg palm^{-1} yr^{-1}. The lowest KY was recorded from PK 1595 from MPOB-NGA x AVROS.

Vegetative Traits

Highly significant differences were observed between crosses for all vegetative traits, except for LL, LW and HTi (*Table 9*). Significant differences in only FP and DIA traits were observed between families for all three crosses (*Table 10*). MPOB-NGA x AVROS and MPOB-CMR x AVROS crosses displayed significant differences between their progenies for all traits, indicating variations in these characters. On the other hand, MPOB-ZRE x AVROS, no significant difference was observed between progenies for all traits, except FP and DIA, suggesting minimal variation in most of the vegetative traits between progenies of this cross.

MPOB-NGA x AVROS displayed the highest petiole cross section (PCS), rachis length (RL), leaflet length (LL), leaflet number (LN), leaflet area (LA), leaf area index (LAI) and DIA (*Table 11*). MPOB-CMR x AVROS produced the smallest petiole cross section, height increment and trunk diameter but had the longest leaflet width. Meanwhile, MPOB-ZRE x AVROS produced the highest average frond production of 27.41 frond palm^{-1} yr^{-1} with a significantly shorter rachis length but displayed the lowest leaf area index and leaf number.

Besides FFB and bunch quality, other desirable vegetative and growth traits also contribute to yield performance (Teo *et al.*, 2004). The numbers of fronds produced (FP trait) would determine the limit to bunch production since bunches develop at the frond axils of the palm (Noh *et al.*, 2012). In this study, PK 1858 from MPOB-ZRE x AVROS was identified as the progeny which produced the highest FP and therefore also produced the highest BNO of 13.06 bunches palm^{-1} yr^{-1}. The lowest FP was produced by PK 1867 from MPOB-NGA x AVROS with BNO of only 10.25 bunches palm^{-1} yr^{-1}. Overall, the PCS ranged from 23.39 to 32.77 cm^2 for all three crosses. PK 1867 from MPOB-NGA x AVROS registered the highest PCS while PK 1885 from MPOB-CMR x AVROS had the lowest PCS.

Palms with short RL are favourable in breeding and selection as they may be used to increase planting density per hectare. Progeny PK 1858 from MPOB-MPOB-ZRE x AVROS exhibited the shortest RL (5.08 m) while PK 1867 from MPOB-NGA x AVROS had the longest RL of 6.14 m. The HTi trait is essential as it contributes to the economic life of an oil palm plantation. Progeny PK 1867 (MPOB-NGA x AVROS) and PK 1917 (MPOB-CMR x AVROS displayed the lowest HTi (0.30 m yr^{-1}). Low HTi may ease harvesting work.

Heratibility Estimaes

Broad-sense heritability estimates showed that h^2_B values for FFB and BNO were considered low (<30%), at 20.56% and 23.22% respectively, though ABW has a higher heritability estimate (*Table 12*).

TABLE 8. MEAN PERFORMANCE OF *Tenera* PROGENIES FOR BUNCH QUALITY COMPONENTS

			Mean (2005-2013)									
Materials	**Progeny code**	**Pedigree**	**M/F (%)**	**K/F (%)**	**S/F (%)**	**O/DM (%)**	**F/B (%)**	**O/B (%)**	**K/B (%)**	**OY (kg palm^{-1} yr^{-1})**	**KY (kg palm^{-1} yr^{-1})**	**TEP (kg palm^{-1} yr^{-1})**
MPOB-NGA x AVROS	PK 1595	0.151/330 x 0.182/357	72.05^{de}	10.26^{e}	17.69^{a}	74.22^{f}	57.06^{d}	18.97^{d}	5.87^{e}	24.88^{d}	7.68^{f}	29.49^{e}
	PK 1768	0.151/638 x 0.182/357	79.09^{ba}	10.79^{dec}	10.13^{fgh}	78.27^{a}	61.17^{bdac}	24.06^{ba}	6.60^{edc}	34.36^{ba}	9.40^{edfc}	40.00^{bac}
	PK 1867	0.149/11745 x 0.174/304	82.66^{a}	9.59^{e}	7.76^{h}	78.07^{ba}	64.13^{bac}	25.61^{a}	5.83^{e}	35.47^{a}	8.17^{ef}	40.37^{bac}
	PK 2005	0.149/11526 x 0.174/211	80.08^{ba}	9.90^{e}	10.02^{gh}	77.42^{bac}	61.46^{bdac}	24.27^{ba}	5.99^{ed}	31.14^{bdac}	7.52^{f}	35.65^{ebdac}
		Mean	**79.39^{a}**	**12.17^{a}**	**10.59^{b}**	**77.25^{a}**	**60.63^{b}**	**23.75^{a}**	**6.03^{b}**	**32.44^{ba}**	**8.25^{c}**	**37.37^{ba}**
MPOB-CMR x AVROS	PK 1776	0.218/1336 x 0.174/282	73.99^{dc}	13.11^{ba}	12.91^{edc}	76.06^{ebdfc}	59.88^{bdc}	21.66^{bdc}	7.81^{bac}	27.07^{dc}	9.91^{ebdfc}	33.02^{edc}
	PK 1885	0.219/844 x 0.174/211	68.21^{e}	13.94^{a}	17.85^{a}	77.01b^{dac}	61.92b^{dac}	20.47^{dc}	8.62^{ba}	24.94^{d}	10.57^{ebdac}	31.28^{ed}
	PK 1904	0.219/299 x 0.182/25	77.05^{bc}	10.93^{dec}	12.02^{feg}	78.35^{a}	58.10^{dc}	22.46^{bc}	6.26^{ed}	31.40^{bdac}	8.66^{edf}	36.59^{ebdac}
	PK 1917	0.219/299 x 0.174/211	71.31^{de}	12.97^{ba}	15.73^{ba}	76.35^{ebdac}	62.05^{bdac}	21.53^{bdc}	7.90^{bac}	30.78^{bdac}	11.25^{bdac}	37.53^{bdac}
	PK 1922	0.218/1336 x 0.174/211	70.84^{de}	13.02^{ba}	15.46^{bac}	76.26^{ebdac}	64.66^{ba}	21.70^{bdc}	8.88^{a}	28.41^{bdc}	11.47^{bac}	35.29^{ebdac}
	PK 1963	0.218/1006 x 0.174/211	73.37^{dc}	12.69^{bac}	13.94^{bedc}	77.07^{bdac}	61.42^{bdac}	22.30^{bc}	7.65^{bac}	35.00^{ba}	11.80^{bac}	42.07^{ba}
	PK 1971	0.219/299 x 0.174/282	77.08^{bc}	10.38^{de}	12.55^{fed}	75.97^{edfc}	56.56^{d}	21.89^{bc}	5.74^{e}	29.48^{bdac}	7.88^{f}	34.21^{ebdc}
		Mean	**72.70^{b}**	**12.67^{a}**	**14.63^{a}**	**76.85^{a}**	**61.05^{b}**	**21.70^{b}**	**7.68^{a}**	**29.78^{b}**	**10.44^{b}**	**36.05^{b}**
MPOB-ZRE x AVROS	PK 1815	0.211/341 x 0.182/410	71.76^{de}	12.24^{bdac}	16.00^{ba}	75.20^{edf}	66.74^{a}	21.73^{bdc}	8.14^{ba}	33.55^{bac}	12.58^{ba}	41.10^{ba}
	PK 1858	0.211/341 x 0.174/955	73.71^{dc}	11.29^{bdec}	15.00^{bdc}	77.75^{bac}	64.13^{bac}	22.93^{bac}	7.26^{bdc}	36.15^{a}	11.50^{bac}	43.05^{a}
	PK 1923	0.221/739 x 0.174/955	72.99^{dc}	12.69^{bac}	15.47^{bac}	74.72^{ef}	66.55^{a}	20.25^{dc}	8.64^{ba}	28.40^{bdc}	12.76^{a}	36.06^{ebdac}
		Mean	**72.66^{b}**	**10.03^{b}**	**15.56^{a}**	**75.82^{b}**	**65.92^{a}**	**21.69^{b}**	**8.02^{a}**	**32.95^{a}**	**12.31^{a}**	**40.34^{a}**
SC (DxP)	PK 1589	0.175/912 x 0.200/812	80.20	11.39	10.53	78.46	64.43	25.32	5.95	36.43	8.54	41.56
Grand mean			**74.92**	**11.77**	**13.59**	**76.31**	**62.53**	**22.38**	**7.24**	**31.72**	**10.33**	**37.92**

Note: *, **, and ns indicate significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; M/F - mesocarp to fruit ratio; S/F - shell to fruit ratio; K/F - kernel to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield; TEP - total economic product. Means with different letter(s) in the same column are significantly different at $P \leq 0.05$ with Duncan New Multiple Range Test (DNMRT).

TABLE 9. ANOVA OF *Tenera* PROGENIES FOR VEGETATIVE CHARACTERS

Source of variance	df	FP (frond palm^{-1} yr^{-1})	PCS (cm^2)	RL (m)	LL (cm)	LW (cm)	LN (no.)	HTi (m yr^{-1})	LA (m^2)	LAI	DIA (m)
Between group	2	36.55**	137.60**	5.29**	128.13^{ns}	0.64^{ns}	1 313.01**	0.006^{ns}	19.05**	6.68**	0.02**
Within group	178	7.51	29.89	0.20	61.00	0.36	91.81	0.004	2.97	1.04	0.004

Note: *, ** and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not-significant, respectively. FP - frond production; PCS - petiole cross-section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTi - palm height increment; LA - leaflet area; LAI - leaf area index; DIA - trunk diameter.

TABLE 10. ANOVA OF NGA x AVROS, CMR x AVROS AND ZRE x AVROS *Tenera* PROGENIES FOR VEGETATIVE CHARACTERS

			Mean square (2005-2013)										
Materials	Source of variance	df	FP (frond palm^{-1} yr^{-1})	PCS (cm^2)	RL (m)	LL (cm)	LW (cm)	LN (no.)	HTi (m yr^{-1})	LA (m^2)	LAI	DIA (m)
MPOB-NGA x AVROS	Between family	3	29.43**	14 7071**	1.42**	574.76**	2.40**	613.23**	0.02**	33.90**	11.88**	0.03**
	Within family	57	6.35	35.21	0.17	66.82	0.34	65.08	0.003	2.70	0.94	0.004
MPOB-CMR x AVROS	Between family	6	9.65**	144.29**	0.87**	108.19**	1.74**	272.70**	0.01*	8.97**	3.14**	0.02**
	Within family	79	7.14	18.90	0.15	38.89	0.23	85.21	0.03	1.99	0.70	0.002
MPOB-ZRE x AVROS	Between family	2	25.02*	3.07^{ns}	0.22^{ns}	1.81^{ns}	0.28^{ns}	36.45^{ns}	0.003^{ns}	1.02^{ns}	0.36^{ns}	0.01**
	Within family	31	6.91	22.10	0.14	51.65	0.26	75.87	0.002	1.93	0.68	0.003

Note: *, **, and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not-significant, respectively; FP - frond production; PCS - petiole cross-section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTi - palm height increment; LA - leaflet area; LAI - leaf area index; DIA - trunk diameter.

Low heritability estimates for FFB yield and its components have also been reported for Deli *dura* × MPOB-NGA *pisifera* population (Arolu *et al.*, 2017; Noh *et al.*, 2014). Heritability of yield and its component traits is very low due to the sensitive nature of the traits to environmental factors (Corley and Tinker, 2016). In bunch quality components, the broad-sense heritability estimates ranged from low to high (*Table 13*). The lowest was for F/B followed by TEP and OY. On the other hand, high heritability estimates (>50%) were obtained for S/F with 100%, then M/F (97.77%), K/B and K/F, indicating that these characters were highly heritable than FFB yield and its components. The results were in accordance to Hardon *et al.* (1985) as high heritability generally resulted from fruit characters such as M/F, S/F and K/F. Also, heritability estimates for vegetative traits varied from low (27.53%) to high (81.48%) (*Table 14*). Traits with high heritability estimates are generally more amenable for future breeding and selection (Noh *et al.*, 2014). The highest h^2_B was scored by RL (81.48%) followed by LA and LAI. High heritability values of above 50% were also observed for LN, LW and DIA, indicating weak influence of the environment on the expression of these traits. This is in line with the findings of Arolu *et al.* (2017) for Deli *dura* x Nigerian *pisifera* population, implying that these traits may be used as the basis for selection of high yielding and compact palms.

Correlation Analysis

Analysis of correlation among the yield traits indicated that FFB and BNO showed a strong positive correlation (r=0.58, P≤0.01) while the correlation coefficient for FFB and ABW was 0.21 (P≤0.01). This suggested that any positive increase in BNO and ABW will accelerate the improvement in FFB yield (*Table 15*). In contrast, the strong negative correlation (r = -0.63, P≤0.01) between BNO and ABW suggested that selection for genotypes with high BNO would produce relatively lower

TABLE 11. MEAN PERFORMANCE OF *Tenera* PROGENIES FOR VEGETATIVE MEASUREMENT

			Mean (2005-2013)									
Materials	**Progeny code**	**Pedigree**	**FP (frond palm^{-1} yr^{-1})**	**PCS (cm^2)**	**RL (m)**	**LL (cm)**	**LW (cm)**	**LN (no.)**	**HTi (m yr^{-1})**	**LA (m^2)**	**LAI**	**DIA (m)**
MPOB-NGA x AVROS	PK 1595	0.151/330 x 0.182/357	26.42^{bc}	25.62^{dec}	5.54^{fde}	86.74^{d}	5.22^{e}	164.17^{ecd}	0.31^{ed}	8.55^{d}	5.06^{d}	0.66^{ba}
	PK 1768	0.151/638 x 0.182/357	27.77^{ba}	29.10^{bac}	5.58^{fdec}	94.96^{bac}	6.05^{ba}	165.92^{ecd}	0.39^{ba}	10.87^{bac}	6.44^{bac}	0.68^{a}
	PK 1867	0.149/11745 x 0.174/304	24.73^{c}	32.77^{a}	6.14^{a}	98.92^{ba}	5.41^{dec}	175.19^{ba}	0.37^{bac}	11.87^{a}	7.03^{a}	0.62^{bdc}
	PK 2005	0.149/11526 x 0.174/211	25.20^{bc}	30.89^{ba}	5.94^{bac}	87.27^{d}	5.50^{dec}	178.10^{a}	0.30^{e}	9.69^{dc}	5.74^{dc}	0.57^{ed}
		Mean	**25.79^{b}**	**30.27^{a}**	**5.87^{a}**	**93.77^{a}**	**5.76^{a}**	**171.52^{a}**	**0.35^{a}**	**10.65^{a}**	**6.30^{a}**	**0.63^{a}**
MPOB-CMR x AVROS	PK 1776	0.218/1336 x 0.174/282	27.50^{ba}	28.30^{bdac}	5.53^{fde}	99.24^{a}	5.60^{bdec}	160.38^{e}	0.40^{a}	9.78^{bdc}	5.79^{bdc}	0.66^{ba}
	PK 1885	0.219/844 x 0.174/211	27.79^{ba}	23.39^{e}	5.39^{feg}	93.14^{bdac}	6.00^{ba}	159.14^{e}	0.32^{edc}	8.9^{2d}	5.28^{d}	0.53^{e}
	PK 1904	0.219/299 x 0.182/25	27.07^{bac}	30.18^{bac}	6.09^{ba}	94.25^{bac}	5.28^{de}	169.87^{bc}	0.34^{bedc}	11.15^{ba}	6.60^{ba}	0.64^{bac}
	PK 1917	0.219/299 x 0.174/211	26.12^{bc}	28.27^{bdac}	5.99^{ba}	90.14^{dc}	6.08^{ba}	169.82^{bc}	0.30^{ed}	10.9^{bac}	6.45^{bac}	0.60^{dc}
	PK 1922	0.218/1336 x 0.174/211	25.62^{bc}	30.97^{ba}	5.97^{ba}	91.55^{dc}	6.25^{a}	169.00^{bcd}	0.34^{bedc}	10.73^{bac}	6.35^{bac}	0.63^{bac}
	PK 1963	0.218/1006 x 0.174/211	27.77^{ba}	23.93^{de}	5.75^{bdec}	89.36^{dc}	6.07^{ba}	165.23^{ecd}	0.34^{bedc}	9.72^{dc}	5.75^{dc}	0.60^{dc}
	PK 1971	0.219/299 x 0.174/282	27.50^{ba}	28.35^{bdac}	5.84^{bdac}	92.40^{bdc}	5.82^{bac}	161.33^{ed}	0.31^{ed}	9.80^{bdc}	5.80^{bdc}	0.60^{dc}
		Mean	**26.95^{a}**	**27.57^{b}**	**5.82^{a}**	**92.45^{ba}**	**5.84^{a}**	**165.8^{b}**	**0.33^{a}**	**10.24^{a}**	**6.06^{a}**	**0.60^{b}**
MPOB-ZRE x AVROS	PK 1815	0.211/341 x 0.182/410	27.20^{bac}	28.42^{bdac}	5.22^{fg}	90.71^{dc}	5.72^{bdc}	162.12^{ecd}	0.35^{bdc}	9.21^{d}	5.45^{d}	0.62^{bdc}
	PK 1858	0.211/341 x 0.174/955	29.10^{a}	27.44^{bdec}	5.08^{g}	90.13^{dc}	5.76^{bdac}	158.70^{e}	0.34^{bedc}	9.14^{d}	5.41^{d}	0.68^{a}
	PK 1923	0.221/739 x 0.174/955	25.89^{bc}	27.79^{bdec}	5.38^{fg}	89.98^{dc}	5.43^{dec}	161.33^{ed}	0.37^{bac}	9.73^{dc}	5.76^{dc}	0.63^{bac}
		Mean	**27.41^{a}**	**27.97^{b}**	**5.22^{b}**	**90.35^{b}**	**5.61^{a}**	**160.91^{c}**	**0.35^{a}**	**9.34^{b}**	**5.52^{b}**	**0.64^{a}**
SC (DxP)	PK 1589	0.175/912 x 0.200/812	26.63	33.18	6.03	94.69	6.05	170.31	0.4	11.11	6.58	0.63
Grand mean			**26.72**	**28.6**	**5.64**	**92.19**	**5.74**	**166.08**	**0.34**	**10.08**	**5.96**	**0.63**

Note: *, **, and ns indicate significant at $P \le 0.05$, $P \le 0.01$ and not significant, respectively; M/F - mesocarp to fruit ratio; S/F - shell to fruit ratio; K/F - kernel to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield; TEP - total economic product. Means with different letter(s) in the same column are significantly different at $P \le 0.05$ with Duncan New Multiple Range Test (DNMRT).

TABLE 12. MEAN SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES OF PROGENIES FOR YIELD AND YIELD COMPONENTS

Source of variance	*df*	FFB	BNO	ABW
Between family	13	2 508.08**	18.05**	35.03**
Within family	167	1 016.90	6.70	9.95
σ^{2f}		116.50	0.88	1.95
σ^{2wf}		1 016.90	6.70	9.95
Total		1 133.40	7.58	11.90
Heritability (%)		**20.56**	**23.22**	**32.77**

Note: *, **, and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant; respectively; FFB - fresh fruit bunch; BNO - bunch number; ABW - average bunch weight.

TABLE 13. MEANS SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES OF PROGENIES FOR BUNCH COMPONENTS

Source of variance	*df*	M/F	K/F	S/F	O/DM	F/B	O/B	K/B	OY	KY	TEP
Between family	13	272.76**	31.01*	148.41**	22.55**	108.40**	46.76**	17.39**	190.35**	43.44**	209.80**
Within family	167	20.6	4.30	7.86	4.67	39.11	9.11	2.29	51.86	8.02	67.84
σ^{2f}		19.70	2.09	10.98	1.40	5.41	2.94	1.18	10.82	2.77	11.09
σ^{2wf}		20.6	4.30	7.86	4.67	39.11	9.11	2.29	51.86	8.02	67.84
Total		40.3	6.38	18.84	6.07	44.52	12.05	3.47	62.68	10.79	78.93
Heritability (%)		**97.77**	**65.40**	**100**	**46.13**	**24.30**	**48.80**	**68.01**	**34.52**	**51.34**	**28.10**

Note: *, ** and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively; M/F - mesocarp to fruit ratio; K/F - kernel to fruit ratio; S/F - shell to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield and TEP - total economic product; Estimates of heritability > 100% were recorded as 100%.

TABLE 14. MEAN SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES OF PROGENIES FOR VEGETATIVE MEASUREMENT

Source of variance	*df*	FP	PCS	RL	LL	LW	LN	HTi	LA	LAI	DIA
Between family	13	20.72**	108.48**	1.57**	202.56**	1.49**	474.99**	0.01**	15.05**	5.27**	0.02**
Within family	167	6.83	25.06	0.16	50.79	0.27	76.6	0.003	2.22	0.78	0.003
σ^{2f}		1.09	6.52	0.11	11.86	0.10	31.12	0.001	1.00	0.35	0.001
σ^{2wf}		6.83	25.06	0.16	50.79	0.27	76.6	0.003	2.22	0.78	0.003
Total		7.92	31.58	0.27	62.65	0.37	107.72	0.004	3.22	1.13	0.004
Heritability (%)		**27.53**	**41.29**	**81.48**	**37.86**	**54.05**	**57.78**	**37.84**	**62.11**	**61.95**	**50.00**

Note: *, ** and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively; FP - frond production; PCS - petiole cross section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTi - height increment; LA - leaflet area; LAI - leaf area index; DIA - trunk diameter.

ABW. Kushairi *et al.* (1999) also reported a similar observation when FFB yield exhibited significant positive correlations with BNO and ABW in the populations studied. The high correlation coefficient for FFB yield and BNO suggested that the BNO component was the determinant for FFB yields. Therefore, selection of BNO may suffice for FFB yield improvement in oil palm.

For bunch quality components, positive correlations were observed between OY and FFB, BNO, ABW, M/F, O/DM (*Table 15*). In addition, OY showed strong positive correlations with TEP (r = 0.73), O/B (r = 0.60), KY (r = 0.52) and O/B (r = 0.60) traits. The results suggested that any

TABLE 15. CORRELATION AMONG TRAITS IN *Tenera* PROGENIES

	BNO	ABW	M/F	K/F	S/F	O/DM	F/B	O/B	K/B	O/Y	K/Y	TEP	FP	PCS	RL	LL	LW	LN	HTi	LA	LAI	DIAM
FFB	0.58**	0.21**	0.03^{ns}	0.02^{ns}	-0.05^{ns}	0.10^{ns}	0.004^{ns}	0.04^{ns}	0.005^{ns}	0.69**	0.52**	0.73**	0.07^{ns}	0.17*	-0.02^{ns}	0.08^{ns}	0.20**	0.09^{ns}	0.21**	0.18**	0.18**	0.16*
BNO		-0.63**	0.08^{ns}	-0.14*	-0.06^{ns}	0.02^{ns}	-0.14^{ns}	0.03^{ns}	-0.19**	0.39**	0.16*	0.38**	0.10^{ns}	-0.12^{ns}	-0.15*	-0.08^{ns}	-0.20**	-0.09^{ns}	0.07^{ns}	-0.19**	-0.19**	0.04^{ns}
ABW			-0.08^{ns}	0.21**	0.04ns	0.07ns	0.17*	-0.001^{ns}	0.25**	0.16*	0.30**	0.21**	-0.07^{ns}	0.30**	0.12^{ns}	0.19**	0.43**	0.18**	0.11^{ns}	0.40**	0.40**	0.13^{ns}
M/F				-0.84**	-0.94**	0.40**	-0.16*	0.57**	-0.77**	0.32**	-0.62**	0.15*	-0.12^{ns}	0.24**	0.24**	0.26**	0.15*	0.33**	0.16*	0.34**	0.34**	0.09^{ns}
K/F					0.66**	-0.26**	0.18**	-0.43**	0.90**	-0.23**	0.72**	-0.04^{ns}	0.09^{ns}	-0.17*	-0.12^{ns}	-0.17*	-0.05^{ns}	-0.27**	-0.05^{ns}	-0.22**	-0.21**	-0.14^{ns}
S/F						-0.44**	0.14^{ns}	-0.59**	0.62**	-0.34**	0.50**	-0.19**	0.14^{ns}	-0.25**	-0.28**	-0.27**	-0.16*	-0.33**	-0.20**	-0.35**	-0.35**	-0.05^{ns}
O/DM							-0.12^{ns}	0.49**	-0.28**	0.36**	-0.16*	0.28**	0.02^{ns}	0.13^{ns}	0.09^{ns}	0.23*	0.20**	0.14^{ns}	0.19**	0.27**	0.27**	0.04^{ns}
F/B								0.45**	0.57**	0.27**	0.44**	0.34**	-0.12^{ns}	0.08^{ns}	-0.08^{ns}	0.07^{ns}	0.09^{ns}	-0.04^{ns}	0.04^{ns}	0.07^{ns}	0.07^{ns}	0.01^{ns}
O/B									-0.18**	0.60**	-0.14*	0.50**	-0.13^{ns}	0.16*	0.12^{ns}	0.25**	0.12^{ns}	0.22**	0.18**	0.26**	0.26**	0.06^{ns}
K/B										-0.10^{ns}	0.78**	0.08^{ns}	0.02^{ns}	-0.10^{ns}	-0.14^{ns}	-0.11^{ns}	0.004^{ns}	-0.24**	-0.03^{ns}	-0.15*	-0.15*	-0.10^{ns}
O/Y											0.40**	0.98**	0.03^{ns}	0.18**	0.06^{ns}	0.14*	0.25**	0.21**	0.25**	0.28**	0.28**	0.11^{ns}
K/Y												0.58**	0.10^{ns}	-0.03^{ns}	-0.16*	-0.10^{ns}	0.11^{ns}	-0.16*	0.11^{ns}	-0.06^{ns}	-0.06^{ns}	-0.01^{ns}
TEP													0.05^{ns}	0.15*	0.02^{ns}	0.11^{ns}	0.25**	0.15*	0.25**	0.24**	0.24**	0.09^{ns}
FP														-0.29**	-0.36**	-0.09^{ns}	-0.16*	-0.38**	0.26**	-0.27**	0.27**	0.14*
PCS															0.49**	0.34**	0.44**	0.50**	0.17*	0.58**	0.58**	0.31**
RL																0.28**	0.35**	0.65**	0.05^{ns}	0.57**	0.57**	0.01^{ns}
LL																	0.13^{ns}	0.26**	0.15*	0.64**	0.64**	0.20**
LW																		0.38**	0.02^{ns}	0.77**	0.77**	0.17*
LN																			-0.02^{ns}	0.69**	0.69**	0.03^{ns}
HTi																				0.09^{ns}	0.09^{ns}	0.21**
LA																					1.00**	0.10**
LAI																						0.19**

Note: *, **, and ns indicate significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; FFB - fresh fruit bunch; BNO - bunch number; ABW - average bunch weight; M/F - mesocarp to fruit ratio; K/F - kernel to fruit ratio; S/F - shell to fruit ratio; O/DM - oil to dry mesocarp ratio; F/B - fruit to bunch ratio; O/B - oil to bunch ratio; K/B - kernel to bunch ratio; OY - oil yield; KY - kernel yield and TEP - total economic product; FP - frond production; PCS - petiole cross section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTi - height increment; LA - leaflet area; LAI - leaf area index; DIA - trunk diameter.

positive increase in these traits would increase the OY of a palm. The significant negative correlations of K/F (r = -0.84) and S/F (r = -0.94) with M/F is a supplementary source of variation for O/B. Both K/F and S/F contents of the fruit were affected mainly from their strong correlations with M/F. Increase in kernel size would increase the shell size and cause a reduction in the mesocarp content of a fruit. Thus, in order to be more effective in improving oil production, increase in M/F or a decrease in the kernel and shell should be emphasised on (Okeye *et al.*, 2009).

Positive but weak correlations were observed for vegetative traits PCS, LW, HTi, LAI and DIA with FFB yield (*Table 15*). This suggested that preferred vegetative charaters such as low HTi, PCS, DIA and RL would be a disadvantage as it might impair FFB production. Despite a positive correlation observed between HTi and FFB, selection for planting materials with high FFB but low height must continue (Isa *et al.*, 2005). Moreover, OY was positively correlated with PCS, LL, LW, LN, HTi, LA and LAI. HTi showed a significant positive correlation with FP, PCS, LL and DIA.

CONCLUSION

Generally, the three progenies exhibited wide variability and genetic diversity for selection. MPOB-ZRE x AVROS cross was excellent for yield traits FFB and BNO. It also exhibited highest values in bunch quality components traits such as S/F, F/B, KY and TEP and was promising in the vegetative traits RL, LL and LN. On the other hand, MPOB-NGA x AVROS performed well in several bunch quality traits such as for M/F, S/F, O/B and O/DM. The MPOB-CMR x AVROS cross performed better in the PCS, HTi and DIA vegetative traits. Heritability of yield and its components was very low. Therefore, family or progeny selection may be a more suitable approach to improve these traits. However, high heritability was observed in most of the bunch quality and vegetative traits, implying that these traits could be used for the selection of high yielding and compact palms. PK 1858 from MPOB-ZRE x AVROS may meet this purpose due to its high BNO, TEP, OY and FP, with lowest LN and RL. At the same time, PK 1867 from MPOB-NGA x AVROS also showed promising M/F, K/F, S/F, O/B values, which may contribute to high oil yield coupled with low PCS and HTi. The TxP crosses in this study was initated as a source of *pisifera* for commercial seed production. Therefore, the *pisifera* parent from PK 1858 and PK 1867 could be considered for progeny testing with advanced breeding populations such as Deli *dura* to reduce the dependence on AVROS as the main pollen source in current commercial DxP seed production.

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REFERENCES

Arolu, I W; Rafii, M Y; Marjuni, M; Hanafi, M M; Sulaiman, Z; Rahim, H A; Abidin, M I Z; Amiruddin, M D; Din, A K and Nookiah, R (2017). Breeding of high yielding and dwarf oil palm planting materials using Deli *dura* × Nigerian *pisifera* population. *Euphytica, 213(7)*: 154.

Blaak, G; Sparnaaij, L D and Menendez, T (1963). Breeding and inheritance in the oil palm (*Elaeis guineensis* Jacq.). Part II. Methods of bunch quality of analysis. *J.W. Afr. Inst. Oil Palm Res. 4*: 146-155.

Breure, C J and Powell, M S (1987). The one-shot method of establishing growth parameters in oil palm. *Proc. of the 1987 International Oil Palm Conference on Progress and Prospect*. PORIM, Kuala Lumpur. p. 203-209.

Corley, R H V and Breure, C J (1981). *Measurements in oil palm experiments*. Internal Report, Unilever Plantations Group, London. p. 21.

Corley, R H V (2009). How much palm oil do we need? *Environ. Sci. Policy, 12*: 134-139.

Corley, R H V and Tinker, P B (2016). *The Oil Palm. 5th Edition*. World Agricultural Series. Wiley Blackwell Publishers Ltd.

Fadila, A M; Norziha, A; Mohd Din, A; Rajanaidu, N and Kushairi, A (2016). Evaluation of bunch index in MPOB oil palm (*Elaeis guineensis* Jacq.) germplasm collection. *J. Oil Palm Res. Vol. 28*: 442-451.

Falconer, D S and Mackay, T F C (1996). Introduction to quantitative genetics genetics (4th Ed). *Trends in Genetics, 12(7)*: 280.

Hardon, J J; Rao, V and Rajanaidu, N (1985). A review of oil palm breeding. *Progress in Plant Breeding* (Russell, G E ed.). New York, Butterworth and Co. p. 139-163.

Hardon, J J (1974). The oil palm. *In: Handbook of plant introduction in tropical crops*, F.A.O Agricultural Studies 93, Rome.

Hardon, J J; Williams, C N and Watson, I (1969). Leaf area and yield in the oil palm in Malaya. *Experimental Agriculture, 5(1)*: 25-32.

Idris, A; Kushairi, A; Ismail, S and Ariffin, D (2005). Selection for partial resistance in oil palm to *Ganoderma* basal stem rot. *J. Oil Palm Res. Vol. 16*: 12-18.

Isa, Z A; Mohd Din, A; Maizura, I; Noh, A; Kushairi, A and Rajanaidu, N (2006). PS12: Breeding population for high oleic acid palm oil. *MPOB Information Series No. 313*.

Isa, Z A; Ong, K P; Norasyikin, I and Suboh, O (2008). Performance of MPOB-MPOB-Nigeria Population 12 at Kulim-An Update. *Proc. of the 3rd Seminar on Performance of PS1 and PS2 Materials and Elite Germplasm*. MPOB, Bangi. p. 139-149.

Junaidah, J; Rafii, M Y; Chin, C W and Saleh, G (2011). Performance of *tenera* oil palm population derived from crosses between Deli *dura* and *pisifera* from different sources on inland soils. *J. Oil Palm Res. Vol. 23(3)*: 1210-1221.

Kushairi, A; Rajanaidu, N; Jalani B S and Zakri, A H (1999). Agronomic performance and genetic variability of *dura* x *pisifera* progenies. *J. Oil Palm Res. Vol. 11(2)*: 1-24.

Kushairi, A; Rajanaidu, N; Jalani, B S and Mohd Isa, Z A (1999). PORIM Series 1- PORIM elite oil palm planting materials. *PORIM Information Series No. 100*.

Kushairi, A; Rajanaidu, N; Sundram, K and Maizura, I (2004). PS8: Vitamin E breeding population. *MPOB Information Series No. 222*.

Kushairi, A (2019). Palm oil economic review and outlook seminar 2019. Malaysian Oil Palm Industry Performance 2018 and Prospects for 2019. *Paper presented at the Palm Economic Review & Outlook (R&O) Seminar 2019*. Le Meridien, Putrajaya.

Lee, C H and Yeow, K H (1985). Progress in breeding and selection for seed production at HMPB Oil palm research station. *The Planter, 61*: 18-31.

Maizura, I; Kushairi, A; Mohd Din, A; Noh, A; Marhalil, M; Wong, Y T and Sambanthamurthi, R (2008). PS13: Breeding populations selected for low lipase. *MPOB Information Series No. 400*.

Marhalil, M; Rafi, M Y; Arolu, I W; Noh, A; Mohd Din, A; Kushairi, A; Norziha, A; Rajanaidu, N; Latif M A and Malek, M A (2013). Genetic variability in yield and vegetative traits in elite germplasm of MPOB-Nigerian *dura* × AVROS *pisifera* progenies. *J. Food Agric Environ. Vol. 11(2)*: 515-519.

Noh, A; Rafii, M Y; Mohd Din, A; Kushairi, A; Norziha, A; Rajanaidu, N; Latif, M A and Malek, M A (2014). Variability and performance evaluation of introgressed Nigerian *dura* x Deli *dura* oil palm progenies. *Genet. Mol. Res. 13(2)*: 2426-2437.

Noh, A; Rafii, M Y; Saleh, G; Kushairi, A and Latif, M A (2012). Genetic performance and general combining ability of oil palm Deli *dura* x AVROS *pisifera* tested on inland soils. *The Scientific World Journal*. http://dx.doi.org/10.1100/2012/792601 Article ID:792601.

Noh, A; Rafii, M Y; Saleh, G and Kushairi, A (2010). Genetic performance of 40 Deli *dura* x AVROS *pisifera* full-sib families. *J. Oil Palm Res. Vol. 22*: 781-795.

Okoye, M N; Okwuagwu C O and Uguru, M I (2009) Population Improvement for Fresh Fruit Bunch Yield and Yield Components in Oil Palm (*Elaeis guineensis* Jacq.). *American-Eurasian J. Scientific Research, 4(2)*: 59-63.

Rajanaidu, N; Kushairi, A; Mohd Din, A and Maizura, I (2008). A review on utilization and performance of MPOB PS series genetic materials. *Proc. of the 3rd Seminar on Performance of PS1 and PS2 Materials and Elite Germplasm*. MPOB, Bangi. p. 3-25.

Rajanaidu, N; Jalani, B S; Soh, A C; Tek, J; Musa, B; Chin, C W and Yong, Y Y (1996). Performance of second generation of PORIM Nigerian material evaluated in Malaysia. *Proc. of the 1996 PORIM International Palm Oil Congress: Competitiveness for the 21st Century - Agriculture Conference*. PORIM, Bangi. p. 32-45.

Rajanaidu, N; Kushairi, A; Rafii, M; Mohd Din, A; Maizura, I and Jalani, B S (2000). Oil palm breeding and genetic resources. *Advances in Oil Palm Research* (Yusof, B; Jalani, B S and Chan, K W eds.). MPOB, Bangi. p. 171-237

Rajanaidu, N; Tan, Y P; Ong, E C and Lee, C H (1986). The performance of inter-origin commercial D×P planting material. *Proc. of the International Workshop on Oil Palm Germplam and Utilization*. PORIM, Bangi. p. 155-161.

Rajanaidu, N (1994). MPOB Oil Palm Genebank: collection, evaluation, utilization and conservation of oil palm genetic resources. MPOB, Bangi. p. 1-18.

Rao,V (1987). Important traits in oil palm selection. *Proc. of the Colloquium on Breeding and Selection for Clonal Oil Palms*. PORIM, Bangi. p. 21-33.

Rao, V; Soh, A C; Corley, R H V and Lee, C H (1983). A critical re-examination of the method of bunch quality analysis in oil palm breeding. *PORIM Occasional Paper, 9*: 1-28.

Teo, K W; Rao, V; Chia, C C and Lim, C C (2004). Performance of some *pisiferas* of Binga, Ekona, URT and Angolan origins: part 2 - fruit bunch yields, vegetative growth and physiological trait. *J. Oil Palm Res. Vol. 16(1)*: 22-38.