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Genetic Variability and Performance of MPOB-Nigeria *Dura* x AVROS *Pisifera* Planting Materials

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ABSTRACT

A long-term evaluation on fourteen D x P progenies of introgressed MPOB-Nigeria *dura* x AVROS *pisifera* were laid down in a randomized complete block design in two replicates with 371 palms in 2002. The aim was to evaluate the performance of fresh fruit bunch yield, bunch quality and vegetative traits among progenies. Analysis of variance revealed highly significant difference for all traits, indicating the existence of substantial variability within these population. In all cases, the phenotypic coefficient of variance was higher than the genotypic coefficients. Broad-sense heritability values estimated ranged from 8.85% to 100% for all the traits studied. The fresh fruit bunch also was found to be positively and highly correlated with bunch number, average bunch weight, oil yield ratio and kernel yield ratio. PK 3248 and PK 3166 were preferred as potential parental lines in breeding programmes and to be included in introgression with advanced breeding populations such as Deli *dura*.

Key words: *advanced breeding population, germplasm, oil palm, introgression*

INTRODUCTION

The oil palm (*Elaeis guineensis*) is the most profitable and high-yielding oil crop compared to other vegetable oils. Palm oil production in 2020/2021 was roughly 72.27 million metric tonnes, while it was 73.23 million metric tonnes in 2019/2020 (Shahbandeh 2022). It is the world's most important export oil crop, providing a significant source of foreign cash for a number of nations, and its numerous applications have given rise to a slew of local businesses (Soh 2017). Apart from its significant contribution to edible food and fats, this versatile crop also plays an essential role in the non-food industry ranging from high-value oleochemicals to more fundamental biomass items such as paper and plywood (Suleiman *et al.* 2019). With China and India being the country's top export destinations, Malaysia and Indonesia presently account for approximately 85% of the world's total palm oil output (Rahman 2020).

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Deli, the backbone of the present breeding stock in Malaysia, originated from four *dura* palms planted in 1848 in the Bogor Botanical Gardens in Java, Indonesia (Rajanaidu *et al.* 1979). Sub-populations from selected Deli *dura*, i.e. Elmina, Ulu Remis (URD), Banting (BD) and Johore Labis (JLD), have been established and are mainly crossed with the Yangambi and AVROS pisiferas for the development of commercial planting materials (Kushairi *et al.* 1999). Deli *dura* has been used as the female parent for decades, primarily in commercial *dura* x *pisifera* (DxP) or tenera hybrid seed production programmes.

To expand the genetic pool of oil palm and further boost Deli *dura*'s small genetic base, the Malaysian Palm Oil Board (MPOB) had initiated exploration on new oil palm genetic materials from its origin in Africa (Hardon 1974; Rajanaidu 1994). MPOB, in cooperation with the Malaysian Agriculture Research and Development Institute (MARDI) and the Nigerian Institute for Oil Palm Research (NIFOR), held the first expedition to Nigeria in 1973 gathered 595 *dura* and 324 tenera materials, which were brought back to Malaysia (Rajanaidu 2017). The materials were planted and observed in ex-situ field MPOB genebank in 1975/76 for yield, bunch traits, fatty acid composition, physiological parameters and vegetative characteristics.

From the observation, the Nigerian germplasm had appealing characteristics such as dwarfism, high iodine value and high kernel (Rajanaidu *et al.* 2000), high oleic acid (Isa *et al.* 2005), high bunch index (Junaidah *et al.* 2004) and high vitamin E (Kushairi *et al.* 2004). The selected Nigerian elite palms have been exclusively used in MPOB breeding programmes, especially a group of palms coded as "Population 12", which is known for its dwarfism and high fresh fruit bunch (FFB) yields (Amiruddin *et al.* 2020). The aim of this study was therefore to determine the performance of the MPOB Nigeria *dura* x AVROS *pisifera* in terms of bunch yield, bunch quality components and vegetative characters and to estimate the genetic components and heritability of desired agronomic traits.

MATERIAL AND METHODS

Experimental Design

Fourteen MPOB-Nigeria *dura* x AVROS *pisifera* (DxP) oil palm progenies and a DxP Control from Deli *dura* x AVROS *pisifera* were planted in MPOB Research Station Kluang, Johor, Malaysia, in November 2002 (Table 1). They were planted in a triangular planting system of nine meters apart with a planting density of 148 palms/ha, in a randomized complete block design (RCBD) with 16 palms per progeny in two replicates.

Data Collection

Data on bunch yield, bunch quality components and vegetative characters was collected, according to standard methods for oil palm (Corley and Tinker 2016). After 36 months of field planting, bunch weight (BWT) and bunch number (BNO) were recorded at 15 days interval (equivalent to two harvesting rounds per month) for each palm in both replications for four consecutive years (2013 to 2016), according to the specifications in the Malaysian Standard MS157:2017 (2017). FFB yield is tabulated from the sum of BWT while average bunch weight (ABW) is the quotient between FFB and bunch number (BNO).

Bunch quality parameters were analysed for each palm (Blaak *et al.* 1963; Rao *et al.* 1983). Mesocarp to fruit (% M/F), kernel to fruit (% K/F), oil to bunch (O/B), kernel to bunch (% K/B), kernel

Table 1 Details on MPOB-Nigeria (NGA) x AVROS progenies

No.	Progeny Code	Palm IDs for Pedigree (NGA / AVROS)	Number of palms per progeny
1	PK2903	0.149x14676 /0.174x678	13
2	PK2992	0.149x14133 /0.174x872	12
3	PK2996	0.149x6235 /0.174x480	8
4	PK3010	0.149x3077 /0.174x655	21
5	PK3063	0.149x14376 /0.174x655	22
6	PK3070	0.151x814 /0.174x655	22
7	PK3119	0.149x14376 /0.174x656	13
8	PK3150	0.149x14376 /0.174x480	9
9	PK3166	0.151x814 /0.174x655	17
10	PK3187	0.149x10702 /0.174x655	16
11	PK3248	0.149x14676 /0.174x888	13
12	PK3273	0.150x498 /0.174x678	14
13	PK3290	0.149x7009 /0.174x886	10
14	PK3295	0.150x5218 /0.174x888	31
15	DxP Control	0.212/270 x 0.159/149	30

yield (kg/p/yr KY) and oil yield (kg/p/yr OY) were calculated to determine the bunch quality component. For this analysis, three to five fruit bunches are sampled per palm whereby ripe bunches of one to 10 loose fruits are randomly sampled. Sampling is carried out between periods of at least three months from the previous palm sampling interval to minimise seasonal variation (Rao 1987).

Morphological features such as frond production (FP), petiole cross section (PCS), rachis length (RL), leaflet length (LL), leaflet number (LN), leaflet width (LW), height increment (HTI), leaflet area (LA) and leaflet area index (LAI) were measured on frond number 17 based on Breure and Powell (1988). The data was analysed using SAS version 9.2. ANOVA, variance components and heritability estimates were carried out using intra class coefficient correlation (tg) as suggested by Falconer and Mackay (1996). In full sib family, total genetic variance to phenotypic variance is equal to $2t_g$ using this formula:

$$t_g = \sigma 2 \frac{\sigma 2}{\sigma 2w + \sigma 2gr + \sigma e} \quad (1)$$

where, α_g = variance progeny, α_{gr} = variance progeny x replication, α_e = variance environment.

Phenotypic and genotypic variances were calculated using formulas adopted from Johnson *et al.* (1955):

$$PCV = \frac{\overline{\sigma p}}{x} \times 100 \quad (2)$$

$$GCV = \frac{\sigma g}{x} \times 100 \quad (3)$$

where, PCV = phenotypic coefficient of variance, GCV= genotypic coefficient of variance, σp = phenotypic standard deviation, σg = genotypic standard deviation, x = mean. Comparison between progeny means was carried out with duncan's multiple range test.

RESULT AND DISCUSSION

Agro-Morphological Variabilities in Yield Traits.

Analysis of variance revealed that yield traits were highly significantly different ($P \leq 0.01$) among the progenies (Table 2). This demonstrated that substantial variability exists within the breeding population for all these traits. Highly significant results were also reported by Noh *et al.* (2010) on the genetic performance of Deli *dura* x AVROS pisifera. A similar trend was also observed by Junaidah *et al.* (2011) on the performance of tenera derived from Deli *dura* and different *pisifera* sources. This was further supported by Marhalil *et al.* (2013), who reported that MPOB-Nigeria *dura* x AVROS *pisifera* progenies were highly significant for these traits. In oil palm breeding and selection, possessing a wide variety in yield and its components among progenies is crucial as the presence of wide genetic variability may enhance breeding efficiency, resulting in better selection gain (Abdullah *et al.* 2011; Nor Azwani *et al.* 2020).

Further analysis showed that progeny PK3248 produced the highest FFB yield at 206.93 kg palm^{-1} year^{-1} while PK2992 produced the lowest FFB of only 136.87 kg palm^{-1} year^{-1} (Table 3). This wide range in FFB yield was likely due to their BNO production as PK3248 also produced the highest BNO (11.18 bunches^{-1} palm year^{-1}) and PK2992 produced the lowest BNO (6.60 bunches^{-1} palm year^{-1}) among the progenies. In case of ABW, PK3166 was found to be the highest at 25.38 kg^{-1} bunch while PK2903 had the lowest at 16.97 kg^{-1} bunch. A high ABW result was also found in PK3070 at 24.94 kg^{-1} bunch.

The size of the mesocarp and kernel is also an important criteria when evaluating oil palm fruit bunch quality. The progeny PK3295 displayed the highest mesocarp to fruit ratio with a mean of 82.21% which was higher than the D x P control, though it exhibited relatively low kernel content (measured by K/F, K/B and KY parameters). In contrast, PK3010 produced excellent kernel content as observed by its 18.24% K/F, 12.29% K/B and16.87% KY but produced a low 60.97% mesocarp to fruit ratio. This was not surprising as mesocarp content is known to be negatively associated with kernel content (Kushairi *et al.* 1999). Oil to bunch (O/B) is a crucial trait in oil palm breeding and selection. The selection for high O/B is one of the approaches to achieve a high extraction ratio in the early stages of palm growth. In this study, the O/B was highest in PK2992 at 25.95%. The highest oil-yielding progeny was PK3248, which was 59% higher than the D x P control. The high oil yield (OY) corresponded with high FFB and BNO in this progeny. PK3248's FFB was 16% higher than the D x P control while its bunch number production was 52% higher than the D x P control.

Agro-Morphological Variabilities in Vegetative Traits.

There were highly significant differences observed for all vegetative traits, implying high genetic variation exists in the traits studied (Table 4). Though frond production was not significantly different among the progenies (Table 5), PK3010 displayed the shortest rachis length (a mean of 4.99 m). Noh *et al.* (2010) reported that palms with short rachis length of less than 5m are potential planting materials for high density planting. The rachis length was comparable to the recently commercialised Clonal Palm Series 2 (CPS 2) (4.5 m) (Samsul *et al.* 2018). Moreover, palms with low height increment and short rachis length were desired as they may potentially lengthen the economic life of the palm and more nutrients can be channelled to FFB production instead of vegetative growth and maintenance.

Table 2 ANOVA results for yield traits

Source of Variance	df	FFB (kg palm^{-1} yr^{-1})	BNO (bunches palm^{-1} yr^{-1})	ABW (kg/bunch)	M/F (%)	K/F (%)	O/B (%)	K/B (%)	OY (kg/p/yr)	KY (kg/p/yr)
Replication (R)	1	5729.04^{ns}	52.58ns	90.20**	39.15^{ns}	3.73^{ns}	11.39^{ns}	44.50**	0.92^{ns}	96.10**
Progeny (P)	13	11960.41**	54.46**	269.95**	645.55**	155.99**	45.10**	85.22**	280.47**	173.97**
R x P	13	8107.81**	12.06^{ns}	37.37**	40.85**	9.47**	15.17^{ns}	8.10**	217.16**	34.71**
Within palms	371	3053.24	8.35	12.98	17.43	5.30	14.38	4.33	88.10	13.02
Progeny variance ($\sigma^2 g$)	-	157.97 (4.42)	1.57 (15.42)	8.35 (36.21)	43.17 (67.43)	9.09 (60.55)	2.34 (13.91)	4.30 (55.13)	7.60 (6.76)	8.89 (35.96)
R x P variance ($\sigma^2 rp$)	-	358.87 (10.05)	0.26 (2.58)	1.73 (7.50)	1.70 (2.66)	0.45 (3.00)	0.10 (0.59)	0.13 (1.67)	16.69 (14.85)	2.80 (11.33)
Within palms variance ($\sigma^2 w$)	-	3053.20 (85.53)	8.35 (82.00)	12.98 (56.29)	19.15 (29.91)	5.47 (36.44)	14.38 (85.49)	3.47 (44.48)	88.10 (78.39)	13.02 (52.67)
Total	-	3570.04	10.18	23.06	64.02	15.01	16.82	7.80	112.39	24.71

*, ** and ns indicate significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; df: degrees of freedom, values in parentheses are percentages of the corresponding values of the phenotypic variance, FFB = fresh fruit bunch; BNO = bunch number; ABW = average bunch weight. M/F = mesocarp to fruit ratio; K/F = kernel to fruit ratio; O/B = oil to bunch ratio; K/B = kernel to bunch ratio; OY = oil yield ratio; KY = kernel yield ratio.

Table 3 Mean performance in yield traits

No.	Progeny Code	FFB (kg palm^{-1} yr^{-1})	BNO (bunches palm^{-1} yr^{-1})	ABW (kg bunch^{-1})	M/F (%)	K/F (%)	O/B (%)	K/B (%)	OY (kg/p/yr)	KY (kg/p/yr)
1	PK2903	142.51^{dc}	8.17^{fde}	16.97^{e}	77.94^{bc}	9.54^{ih}	23.65^{bdac}	5.91^{fde}	29.08^{cbd}	6.71^{gh}
2	PK2992	136.87^{d}	6.60^{f}	19.91^{d}	79.69^{ba}	11.04^{fhg}	25.95^{a}	6.81^{cde}	29.98^{cbd}	7.50^{ghf}
3	PK2996	171.82^{bc}	7.05^{fe}	24.09^{ba}	74.95^{c}	11.63^{feg}	24.34^{bac}	7.04^{cd}	32.71^{cbd}	9.62^{gcfed}
4	PK3010	173.41^{bac}	9.35^{bdc}	18.55^{ed}	60.97^{e}	18.24^{a}	19.71^{e}	12.29^{a}	27.12^{cd}	16.87^{a}
5	PK3063	182.76^{ba}	9.68^{bdac}	18.79^{ed}	69.06^{d}	15.68^{b}	20.57^{ed}	9.26^{b}	31.71^{cbd}	13.71^{b}
6	PK3070	179.84^{ba}	7.26^{fe}	24.94^{a}	71.83^{d}	12.66^{fed}	22.94^{bdac}	6.99^{cd}	34.30^{cb}	10.27^{cfed}
7	PK3119	176.50^{ba}	9.25^{bdc}	19.36^{d}	76.26^{c}	11.63^{feg}	22.87^{ebdac}	5.18^{fe}	35.03^{cb}	8.03^{ghfe}
8	PK3150	185.19^{ba}	8.44^{dec}	22.42^{bc}	69.49^{d}	14.95^{cb}	22.52^{ebdc}	7.31^{cd}	34.13^{cb}	10.87^{ced}
9	PK3166	171.92^{bc}	6.81^{fe}	25.38^{a}	69.00^{d}	14.22^{cbd}	20.58^{ed}	7.99^{cb}	29.99^{cbd}	11.23^{cbd}
10	PK3187	195.77^{ba}	9.11^{bdc}	21.82^{c}	69.94^{d}	13.30^{ced}	21.76^{edc}	7.61^{cd}	33.44^{cbd}	11.72^{cb}
11	PK3248	206.93^{a}	11.18^{a}	19.01^{ed}	79.81^{ba}	9.00^{i}	25.47^{ba}	4.95^{f}	46.12^{a}	8.67^{ghfed}
12	PK3273	141.82^{dc}	8.93^{bdc}	14.88^{f}	76.55^{bc}	10.40^{ihg}	22.02^{edc}	5.35^{fe}	26.08^{d}	6.33^{h}
13	PK3290	203.98^{ba}	10.63^{ba}	19.32^{d}	76.32^{c}	9.06^{i}	22.34^{ebdc}	4.41^{f}	33.40^{cbd}	6.59^{h}
14	PK3295	187.19^{ba}	10.04^{bac}	18.80^{ed}	82.21^{a}	8.65^{i}	23.43^{bdac}	4.71^{f}	35.50^{b}	7.11^{gh}
	Mean	175.47	8.75	20.3	73.86	12.14	22.72	6.84	32.76	9.66
	DxP control	177.62	7.35	22.22	77.94	9.54	23.65	5.91	29.08	6.71

Means with different superscript letter(s) in the same column are significantly different at $P \leq 0.05$ with Duncan New Multiple Range Test (DNMRT). FFB = fresh fruit bunch; BNO = bunch number; ABW = average bunch weight; M/F = mesocarp to fruit ratio; K/F = kernel to fruit ratio; O/B = oil to bunch ratio; K/B= kernel to bunch ratio; OY = oil yield ratio; KY = kernel yield ratio.

Table 4 ANOVA results for vegetative measurement

Source of Variance	df	FP (frond palm^{-1} yr^{-1})	PCS (cm^2)	RL (m)	LL (cm)	LW (cm)	HI (m yr^{-1})	LA (m^2)	LAI
Replication (R)	1	32.48^{ns}	63.17^{ns}	1.64**	55.42^{ns}	0.25^{ns}	5.18^{ns}	12.81^{ns}	4.48^{ns}
Progeny (P)	13	61.77**	175.97**	1.97**	425.98**	1.79**	682.27**	14.51**	5.08**
R x P	13	11.68^{ns}	61.93**	0.20^{ns}	126.37**	0.17^{ns}	39.51^{ns}	3.98^{ns}	1.40^{ns}
Within palms	371	5.78	27.58	0.16	42.02	0.18	29.24	2.02	0.71
Progeny variance (σ^2g)	-	1.73 (21.82)	3.78 (11.18)	0.065 (28.26)	10.28 (17.62)	0.06 (25.00)	23.18 (43.61)	0.38 (14.96)	0.13 (14.61)
R x P variance (σ^2rp)	-	0.42 (5.30)	2.44 (7.22)	0.00 (0.00)	6.00 (10.29)	0.00 (0.00)	0.73 (1.37)	0.14 (5.51)	0.05 (5.62)
Within palms variance (σ^2w)	-	5.78 (72.89)	27.58 (81.60)	0.163 (70.87)	42.02 (72.09)	0.18 (75.00)	29.24 (55.01)	2.02 (79.53)	0.71 (79.78)
Total		7.93	33.80	0.23	58.29	0.24	53.15	2.54	0.89

*, **, and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively. Values in parentheses are percentages of the corresponding phenotypic variances. FP = frond production; PCS = petiole cross section; RL= rachis length; LL= leaflet length; LW= leaflet width; HI= height index; LA = leaflet area; LAI = leaf area index.

Although PK3273 exhibited the lowest petiole cross-section (PCS) at 23.82 cm2 but this was not significantly different from PK3010's PCS. However, the shortest of the progenies were PK3273 and PK3290. Leaflet area index, an important index related to the growth and metabolism of the plant (Awal *et al.* 2010), was highest in PK3187 (6.28) though it was only slightly higher than the DxP control (6.17).

Genotypic and Phenotypic Coefficient of Variation and Heritability Estimates. Analysis on the coefficient of variation indicated that estimates of the phenotypic coefficient of variation (PCV) were higher than their corresponding genotypic coefficient of variation (GCV) (Table 6), similar to earlier reports (Noh *et al.* 2010; Sritharan *et al.* 2017). This suggested that environmental factors influenced their expression in all traits studied to a certain extent. GCV and PCV values of less than 10 were considered low, 10 to 20 were moderate, and values greater than 20 were classified as high (Deshmukh *et al.* 1986) The GCV for kernel to bunch (K/B) was highest (31.47%), suggesting a high genetic control of this character. Whereas leaflet length trait was likely to be highly influenced by the environment as it displayed the lowest GCV.

Heritability of traits is important in plant breeding. For this breeding cross, lowest heritability was observed for the yield FFB trait (h2B = 8.85%). Heritability values of >60% was classified as high, 30–60% as moderate, and <30% as low (Johnson *et al.* 1955). Various ranking orders for heritability has been reported for bunch yield traits, but BNO has commonly been reported as a highly heritable trait, followed by ABW and lastly, FFB (Hardon *et al.* 1985; Rafii *et al.* 2013).

Table 5 Mean performance in vegetative traits

No.	Progeny Code	Mean at year 2009							
		FP	PCS	RL	LL	LW	HI	LA	LAI
		(frond palm^{-1} yr^{-1})	(cm^2)	(m)	(cm)	(cm)	(m yr^{-1})	(m^2)	
1	PK2903	24.08^{fg}	29.92^{bac}	5.78^{b}	90.97^{cb}	5.11^{ed}	29.49^{e}	8.75^{dc}	5.18^{dc}
2	PK2992	25.04^{fe}	27.70^{bc}	6.12^{a}	84.33^{e}	5.17^{ecd}	32.69^{dce}	8.72^{dc}	5.16^{dc}
3	PK2996	27.71^{a}	30.54^{ba}	5.43^{ed}	89.75^{cbd}	5.07^{efd}	32.01^{de}	8.30^{d}	4.92^{d}
4	PK3010	28.13^{a}	24.05^{d}	4.99^{f}	91.26^{cb}	4.85^{fg}	41.09^{ba}	8.10^{d}	4.80^{d}
5	PK3063	25.13^{fe}	29.05^{bac}	5.65^{cbd}	90.77^{cb}	5.26^{bcd}	32.61^{dce}	9.39^{bc}	5.56^{bc}
6	PK3070	27.78^{a}	27.04^{c}	5.58^{cbd}	86.38^{ed}	5.47^{ba}	38.81^{b}	9.33^{bc}	5.52^{bc}
7	PK3119	25.45^{fde}	27.82^{bc}	5.70^{cb}	84.36^{e}	5.36^{bc}	32.72^{dce}	8.60^{dc}	5.09^{dc}
8	PK3150	27.57^{a}	31.72^{a}	5.63^{cbd}	90.20^{cb}	5.03^{efd}	33.42^{dc}	8.66^{dc}	5.13^{dc}
9	PK3166	26.90^{bac}	31.62^{a}	5.55^{cbd}	92.68^{b}	5.69^{a}	42.66^{a}	10.03^{ba}	5.94^{ba}
10	PK3187	26.00^{bdec}	29.63^{bac}	5.67^{cbd}	98.86^{a}	5.41^{bc}	35.40^{c}	10.61^{a}	6.28^{a}
11	PK3248	26.73^{bdac}	29.44^{bac}	5.27^{e}	93.65^{b}	4.94^{efg}	35.31^{c}	8.40^{d}	4.97^{d}
12	PK3273	23.43^{g}	23.99^{d}	5.72^{db}	90.46^{cb}	5.02^{efd}	25.27^{f}	8.53^{dc}	5.05^{dc}
13	PK3290	27.27^{ba}	28.99^{bac}	5.28^{e}	90.75^{cb}	4.75^{g}	26.10^{f}	8.39^{d}	4.97^{d}
14	PK3295	25.78^{dec}	27.40^{bc}	5.49^{ced}	87.82^{ced}	5.50^{ba}	30.56^{de}	9.30^{bc}	5.50^{bc}
	Mean	26.21	28.49	5.56	90.16	5.19	33.44	8.93	5.29
	DxP Control	27.66	40.47	5.98	89.23	5.7	43.34	10.42	6.17

*, **, and ns indicate significant at P ≤ 0.05, P ≤ 0.01 and not significant, respectively; Values in parentheses are percentages of the corresponding phenotypic variances. FP = frond production; PCS = petiole cross section; RL= rachis length; LL= leaflet length; LW= leaflet width; HI= height index; LA = leaflet area; LAI = leaf area index.

Low heritability of the FFB trait suggested a major influence of the environment in the expression of this trait. A low heritability value for FFB was also displayed by a Nigerian *dura* x Deli *dura* cross (Noh *et al.* 2014) and Deli *dura* × Nigerian *pisifera* (Arolu *et al.* 2017). Heritability of bunch quality traits such as M/F, K/F, K/B were instead the highest (100%). High heritability of these bunch quality traits in oil palm have been reported previously (Constantin *et al.* 2017; Nor Azwani *et al.* 2020). High heritability values for oil palm height increment and rachis length observed in this study are in accordance with earlier reports (Noh *et al.* 2014; Arolu *et al.* 2017).

Correlation and Associations Coefficient among Traits.

FFB was found to be highly and positively correlated with BNO and OY, implying that a significant genetic relationship among these traits is present (Table 7). BNO was also highly correlated with OY, but was negatively correlated with ABW, K/F, K/B and RL. ABW displayed significant

Table 6 Genetic parameters for yield traits

Traits	Mean	Genotypic variance	Phenotypic variance	Genotypic coefficient of variance (%)	Phenotypic coefficient of variance (%)	Heritability (%)
FFB	175.47	157.97	3570.04	7.16	34.05	8.85
BNO	8.75	1.57	10.18	14.32	36.46	30.84
ABW	20.30	8.35	23.06	14.23	23.66	72.42
M/F	73.86	6.57	64.02	8.89	10.83	100.00
K/F	12.14	3.01	15.01	19.77	25.41	100.00
O/B	22.72	2.34	16.82	6.73	18.05	27.82
K/B	6.84	2.07	7.80	30.32	44.30	93.68
OY	32.76	7.60	112.39	8.42	32.36	13.52
KY	9.66	8.89	24.79	30.87	51.54	71.72
FP	26.21	1.73	7.93	5.02	10.74	43.63
PCS	28.49	3.78	33.80	6.82	20.41	22.37
RL	5.56	0.07	0.23	4.59	8.63	56.52
LL	90.16	10.28	58.29	3.56	8.47	35.27
LW	5.19	0.06	0.24	4.72	9.44	50.00
HI	33.44	23.18	53.15	14.40	21.80	87.22
LA	8.93	0.38	2.54	6.90	17.85	29.92
LAI	5.29	0.13	0.89	6.82	17.83	29.21

FFB = fresh fruit bunch; BNO = bunch number; ABW = average bunch weight; M/F = mesocarp to fruit ratio; K/F = kernel to fruit ratio; O/B = oil to bunch ratio; K/B= kernel to bunch ratio; OY = oil yield; KY = kernel yield; FP = frond production; PCS = petiole cross section; RL= rachis length; LL= leaflet length; LW = leaflet width; HI = height index; LA = leaflet area; LAI = leaf area index.

negative correlation with both M/F and O/B. The phenotypic associations among FFB, BNO and ABW suggested that high BNO with medium bunch weight should be targeted to attain high FFB yields. High correlations between FFB and BNO have been previously observed (Isa *et al.* 2005; Rafii *et al.* 2013). Although there was a clear positive association between FFB and palm height increment, the correlation was only moderate (r = 0.34), suggesting that selection based on high FFB may still result in progenies with high height increment. The height of the trunk is a major factor in determining an oil palm plantation's economic lifespan since tall palms are difficult to harvest. Furthermore, Isa *et al.* 2005 reported a strong and positive association in FFB-HT correlation, while Breure (1982) discovered a low environmental correlation but high genetic relationship between these traits. Even though there is a positive association between FFB yield and height increment, selection for high FFB yield remained to be the primary objective (Isa *et al.* 2005).

CONCLUSION

Generally, there is a wide variability and genetic diversity in the bunch quality and vegetative traits for further selection of these progenies from this study. Progeny PK3248 produced high fresh fruit bunch yield, bunch number and oil yield but heritability of these traits were

Table 7 Correlation among traits in the progenies

	BNO	ABW	M/F	K/F	O/B	K/B	OY	KY	FP	PCS	RL	LL	LW	HI	LA	LAI
FFB	0.82**	0.28**	0.05^{ns}	-0.11^{ns}	0.08^{ns}	-0.12^{ns}	0.71**	0.37**	0.32**	0.27**	-0.07^{ns}	0.22**	0.14*	0.34**	0.17**	0.17**
BNO		-0.27**	0.14**	-0.19**	0.06^{ns}	-0.19**	0.59**	0.22**	0.14*	0.06^{ns}	-0.14**	0.17**	-0.07^{ns}	0.06^{ns}	0.02^{ns}	0.02^{ns}
ABW			-0.16**	0.14**	-0.001^{ns}	0.10^{ns}	0.20**	0.26**	0.40**	0.40**	0.14*	0.06^{ns}	0.40**	0.50**	0.31**	0.31**
M/F				-0.91**	0.58**	-0.80**	0.37**	-0.67**	-0.15*	0.11^{ns}	0.21**	-0.15**	0.17**	-0.34**	0.07^{ns}	0.07^{ns}
K/F					-0.56**	0.86**	-0.39**	0.69**	0.09^{ns}	-0.14*	-0.18**	0.07^{ns}	-0.14**	0.33**	-0.08^{ns}	-0.08^{ns}
O/B						-0.39**	0.60**	-0.30**	0.08^{ns}	0.16**	0.09^{ns}	-0.04^{ns}	0.03^{ns}	-0.08^{ns}	-0.004^{ns}	-0.004^{ns}
K/B							-0.33**	0.80**	0.10^{ns}	-0.15**	-0.23**	0.05^{ns}	-0.18**	0.31**	-0.14**	-0.14**
OY								0.14*	0.31**	0.34**	0.01^{ns}	0.19**	0.16**	0.26**	0.20**	0.20**
KY									0.29**	0.08^{ns}	-0.20**	0.20**	-0.02^{ns}	0.48**	0.04^{ns}	0.04^{ns}
FP										0.04^{ns}	-0.42**	-0.01^{ns}	0.04^{ns}	0.56**	-0.02^{ns}	-0.02^{ns}
PCS											-0.46**	0.34**	0.47**	0.19**	0.53**	0.53**
RL												0.12^{ns}	0.33**	-0.20**	0.47**	0.47**
LL													-0.06^{ns}	0.09^{ns}	0.51**	0.51**
LW														0.26**	0.58**	0.58**
HI															0.16**	0.16**
LA																1.00**

*, **, 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; O/B = oil to bunch ratio; K/B= kernel to bunch ratio; OY = oil yield ratio; KY = kernel yield ratio; FP = frond production; PCS = petiole cross section; RL= rachis length; LL= leaflet length; LW= leaflet width; HI= height index; LA = leaflet area; LAI = leaf area index.

extremely low. Thus, PK3166 is preferred for selection as it displayed generally good average bunch weight and fresh fruit bunch yields which were higher than both the D x P control and the trial means. High heritability values for kernel traits (K/F, K/B and KY) and rachis length suggested that progeny PK3010 could be of special interest for selection as phenotypic expression of these traits in individual palms can be initiated by adopting simple selection methods. Therefore, the female parent for both progenies (palm IDs 0.151/814 and 0.150/5218) may be considered as potential parental lines in future breeding programmes and should be included in introgression programmes with advanced breeding populations such as Deli *dura*.

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