

GENETIC PERFORMANCE OF 3-WAY (MPOB-NIGERIA × DELI) *Dura* × *Pisifera* OIL PALM CROSSES

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ABSTRACT

The AVROS and Yangambi populations represent the primary paternal lineages utilised in global oil palm seed production and breeding programmes. This study assessed the progeny performance of two 3-way crosses, Cross I (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera* and Cross II (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera* with emphasis on bunch yield, bunch quality components and vegetative traits. All genotypes were cultivated using a Randomised Complete Block Design (RCBD) in 2011. Analysis of variance (ANOVA) revealed highly significant variations between genotypes for most traits of bunch yield, bunch quality components, and vegetative traits, indicating the impact of their genetic background on these variables. PKG115 from Cross II produced the highest fresh fruit bunches (FFB) at 264.46 kg palm⁻¹ yr⁻¹ and oil yield (OY) at 62.67 kg palm⁻¹ yr⁻¹, whereas PKG144 from Cross I obtained an exceptional oil to bunch (O/B) of 29.35%. The broad-sense heritability (h_b^2) for leaflet length (LL) was estimated at 61.17%, indicating greater genetic variance than the other traits. Due to its excellent FFB yields, high mesocarp to fruit ratio (M/F) and OY, with low shell to fruit ratio (S/F), PKG115 has been recognised as a potential parental material for upcoming oil palm breeding programmes.

Keywords: AVROS, oil yield, 3-way cross, Yangambi.

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INTRODUCTION

Palm oil dominates the global vegetable oil market, representing more than 60% of worldwide oil-bearing crop exports (Organisation for Economic Co-operation and Development [OECD] & Food and Agriculture Organization of the United Nations [FAO], 2022). In 2021, approximately one-third of the global oil and fat production (241.36 million tonnes) originated from major palm oil-producing countries: Indonesia

(42.00 million tonnes), Malaysia (18.15 million tonnes) and Thailand (3.38 million tonnes) (Oil World, 2021; U.S. Department of Agriculture, 2024). Considering the expanding world population and rising standards of living, the demand for palm oil is estimated to increase to at least 240 million tonnes by 2050 (Corley, 2009; Srisawasdi et al., 2023). Palm oil has been used in a variety of high-end manufacturing processes, especially in the chemical, pharmaceutical and food sectors. Additionally, it is frequently used as a primary raw material in biodiesel manufacturing due to its relatively cheaper cost compared to other oil crops (Mukherjee & Sovacool, 2014).

For several decades, the Deli *Dura* × AVROS *Pisifera* (D×P) hybrid has been the predominant commercial planting material in Malaysia and globally (Kushairi et al., 1999), although some seed producers also develop Deli *Dura* × Yangambi *Pisifera* hybrids (Kushairi et al., 2011).

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However, the development of these D×P planting materials in the global oil palm industry remains heavily dependent on a limited genetic pool. The Deli populations in Malaysia trace their origins to only four Bogor palms, while the AVROS and Yangambi *Pisifera*s were derived from the “Djongo” palms of the Eala Botanical Garden in Zaire (currently Democratic Republic of the Congo). The limited genetic base of the current planting materials poses a significant challenge for further yield improvements. To address this issue, the Malaysian Palm Oil Board (MPOB), together with members from the industry, has gathered 1,467 oil palm accessions from the wild populations since the 1970s. This was done to achieve substantial improvement of the oil palm’s genetic diversity. MPOB currently owns the biggest collection of oil palm germplasm in the world (Martin et al., 2022; Okwuagwu et al., 2011; Rajanaidu, 1994). The collection of *Elaeis guineensis* and *E. oleifera* germplasm was brought into Malaysia for cultivation and evaluation at the MPOB Research Station Kluang. Results of continued germplasm evaluation have been implemented into the ongoing process of improving the breeding stock (Rajanaidu et al., 2000; Yaakub et al., 2023) and developing superior D×P planting materials (Arolu et al., 2017; Fadila et al., 2024).

Genes from new germplasm sources were introgressed into the existing Deli and AVROS populations to improve the breeding stock. Noh et al. (2014) reported significant genetic variability among 12 introgressed Nigeria *Dura* × Deli *Dura* oil palm progenies, highlighting adequate potential for further breeding and selection. The progenies had demonstrated exceptional performance, producing high fresh fruit bunches (FFB) yields of up to 212 kg palm⁻¹ yr⁻¹ and oil to bunch (O/B) of up to 19%. Similarly, progenies from MPOB-Zaire *Tenera* × AVROS *Pisifera* and MPOB-Nigeria *Tenera* × AVROS *Pisifera* demonstrated strong potential as new *Pisifera* pollen sources for commercial D×P seed production. The top-performing progenies from these crosses achieved high oil yields (OY) of 36.15 and 35.47 kg palm⁻¹ yr⁻¹, respectively (Nor Azwani et al., 2020).

These introgressed progenies served as the foundation for initiating 3-way and 4-way crosses at MPOB, with the goal of leveraging heterosis, where hybrids outperform their parents. Consequently, the primary objective of this study was to evaluate 18 3-way *Dura* (D×D) × *Pisifera* (P) progenies, derived from two 3-way crosses: Cross I (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera* and Cross II (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera* with emphasis on yield, bunch quality and vegetative characteristics. The parental lines of superior progenies can be utilised in the development of commercial D×P seed production

and breeding programmes to mitigate the yield stagnation observed in the oil palm sector over the past two decades.

MATERIALS AND METHODS

Planting Materials

Eight genotypes (progenies) from Cross I, and 10 from Cross II were planted in a triangular planting arrangement, spaced 9 m apart, utilising a Randomised Complete Block Design (RCBD) (Table 1). The *Pisifera* was an AVROS descendant of BM119 from the Oil Palm Research Station, Banting, Selangor, Malaysia, while the Yangambi was from FELDA Agricultural Services Sdn. Bhd. (FASSB). The genotypes were planted in Trial 0.529 at MPOB Research Station Hulu Paka, Terengganu, Malaysia, in 2011. The mean annual rainfall from 2016–2021 was 3,458.33 mm yr⁻¹, ranging from 2,934.00–3,811.00 mm yr⁻¹. Fertiliser was provided every three months for each palm, at a rate of 3 kg palm⁻¹ yr⁻¹. Each genotype is represented by four replications.

Data Collection

The yield performance of each genotype was recorded for each palm at intervals of two rounds each month. The FFB yield is the sum of bunch weight, whereas the average bunch weight (ABW) is the ratio of FFB to bunch number (BNO). Each palm weight and number were recorded at every harvesting cycle, from 36 months after field planting, and data for four consecutive years (2017–2020) were used for analysis. To evaluate the oil extraction and bunch quality components, the bunch analysis method established by Blaak et al. (1963) and modified by Rao et al. (1983) was implemented. Three to five bunches were sampled from each palm from 2016 to 2021. Ripe bunches with one to 10 loose fruits were randomly collected at least three months after the previous palm to eliminate seasonal change (Rao, 1987). One round of vegetative measurement was applied in 2019, at eight years following field planting, as suggested by Corley and Breure (1981).

Statistical Analysis

The data on bunch yield, bunch quality components, and vegetative characters were analysed using the Statistical Analytical System (SAS version 9.4). The analysis of variance (ANOVA) for all traits was conducted. The means of the data obtained were subjected to analysis of variance using a general linear model (PROC GLM) due to some missing and uneven distribution of

TABLE 1. LIST OF *Tenera* (D×P) GENOTYPES

No.	Cross-type	Genotype code	MPOB-Nigeria × Deli <i>Dura</i> code	Female parent (A)	Male parent (B)	Pedigree
1	Cross I	PKG116	D1	0.318/1,165	0.395/419	0.318/1,165 × 0.395/419
2		PKG124	D2	0.318/1,052	0.395/419	0.318/1,052 × 0.395/419
3		PKG136	D3	0.318/4	0.395/384	0.318/4 × 0.395/384
4		PKG144	D3	0.318/4	0.395/419	0.318/4 × 0.395/419
5		PKG153	D4	0.318/572	0.395/384	0.318/572 × 0.395/384
6		PKG163	D5	0.318/618	0.395/419	0.318/618 × 0.395/419
7		PKG169	D6	0.318/403	0.395/419	0.318/403 × 0.395/419
8		PKG164	D6	0.318/403	0.395/384	0.318/403 × 0.395/384
9	Cross II	PKG100	D7	0.318/583	0.395/176	0.318/583 × 0.395/176
10		PKG102	D1	0.318/1,165	0.395/148	0.318/1,165 × 0.395/148
11		PKG110	D2	0.318/1,052	0.395/176	0.318/1,052 × 0.395/176
12		PKG111	D1	0.318/1,165	0.395/176	0.318/1,165 × 0.395/176
13		PKG115	D8	0.318/2	0.395/148	0.318/2 × 0.395/148
14		PKG126	D9	0.318/1,018	0.395/176	0.318/1,018 × 0.395/176
15		PKG141	D3	0.318/4	0.395/176	0.318/4 × 0.395/176
16		PKG142	D8	0.318/2	0.395/176	0.318/2 × 0.395/176
17		PKG166	D6	0.318/403	0.395/176	0.318/403 × 0.395/176
18		PKG151	D10	0.318/673	0.395/148	0.318/673 × 0.395/148
19	SC	PK 5193		0.212/3	0.174/247	0.212/3 × 0.174/247

Note: Cross I - (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera*; Cross II - (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera*; SC - Standard cross Deli *Dura* × AVROS *Pisifera*.

the progeny's palms (Arolu et al., 2016). Duncan's new multiple range test (DMRT) was used for the comparison between the genotype means while the least significant difference (LSD) analysis was used to compare the means between crosses. Broad-sense heritability (h_b^2) statistics were estimated for each character, using variance components. The variance analysis for the estimation of h_b^2 was processed from the variance component procedure (PROC VARCOMP) using the formula in Equation (1):

$$h_b^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2} \quad (1)$$

where, σ_g^2 is the genotype variance and σ_e^2 is the error variance. The 18 three-way *Dura* (D×D) × *Pisifera* (P) genotypes were used to calculate the h_b^2 from the $2h_b^2$ (Falconer & Mackay, 1996).

RESULTS AND DISCUSSION

Agro-morphological Variabilities in Bunch Yield

The ANOVA revealed no significant differences in the FFB, BNO and ABW between the two crosses (Table 2), while there were significant

differences in FFB and ABW ($p < 0.01$) among the genotypes, but not in BNO. For bunch yield traits, the coefficient of variation (CV) for FFB was the highest for both cross-type (25.57%) and genotype (23.58%). In contrast, the CV values for ABW were the lowest, which were 19.52% (cross-type) and 17.32% (genotype). The observed variability in the genotypes was related to the nature of these traits as the yield and yield component traits are quantitatively regulated by polygenes (Ithnin et al., 2021). A wide genetic variation among genotypes is critical for oil palm breeding and selection because it could enhance breeding efficiency and selection gains (Nor Azwani et al., 2020).

Among genotypes, PK115 from Cross II recorded the highest FFB mean yield (264.46 kg palm⁻¹ yr⁻¹), followed by PKG136 from Cross I (204.13 kg palm⁻¹ yr⁻¹), with yields 69.31% and 30.69% higher than the standard cross (SC), respectively (Table 3). The outstanding FFB yield is not surprising as the MPOB-Nigeria genotype had successfully produced over 200 kg palm⁻¹ yr⁻¹ through its use as a *Pisifera* parent crossed with Deli *Dura* in the PS1.1 planting material (Mohd Din et al., 2023). PKG115's high FFB yields is likely associated to its high ABW of 15.57 kg bunch⁻¹ while PKG126 from Cross II exhibited the lowest

FFB yield (159.23 kg palm⁻¹ yr⁻¹), attributed to its low ABW (11.21 kg bunch⁻¹) despite having a moderate BNO (14.21 bunches palm⁻¹ yr⁻¹). These results are in contrast with the observations by Arolu et al. (2016) and Myint et al. (2019), where the BNO of their genotypes was suggested to affect their FFB yields. Although a high BNO is necessary for a high

FFB, the most important component for an even higher yield is the ABW (Kushairi et al., 2001). The significance of ABW in determining FFB yields was possibly due to an earlier selection pressure for high BNO, which resulted in the consistently high BNO of varied ABW displayed in the current planting materials.

TABLE 2. ANOVA RESULTS FOR BUNCH YIELD COMPONENTS BASED ON THE CROSS-TYPES AND GENOTYPES

Source of variance	df	FFB	BNO	ABW
Cross-type	1	2,277.96 ^{ns}	8.89 ^{ns}	0.16 ^{ns}
Error	214	2,331.83	10.93	6.56
Total	215	501,290.11	2,347.63	1,403.56
CV (%)		25.57	22.66	19.52
Genotype	17	6,393.81 ^{**}	15.81 ^{ns}	22.48 ^{**}
Error	198	1,982.81	10.50	5.16
Total	215	501,290.11	2,347.63	1,403.56
CV (%)		23.58	22.21	17.32

Note: ** and ns - significant at $P \leq 0.01$ and not significant, respectively; df - degrees of freedom; FFB - fresh fruit bunches; BNO - bunch number; ABW - average bunch weight; CV - coefficient of variation.

TABLE 3. COMPARISON OF THE BUNCH YIELD COMPONENTS MEANS AMONG CROSSES AND GENOTYPES

No.	Cross-type	Genotype code	FFB (kg palm ⁻¹ yr ⁻¹)	BNO (No. palm ⁻¹ yr ⁻¹)	ABW (kg bunch ⁻¹)
1	Cross I	PKG116	179.52 ^{ab}	13.83	13.04 ^{b-f}
2		PKG124	167.35 ^{ab}	14.17	11.95 ^{d^{ef}}
3		PKG136	204.13 ^b	15.31	13.75 ^{a-e}
4		PKG144	199.27 ^{ab}	16.27	12.38 ^{def}
5		PKG153	171.58 ^{ab}	13.08	13.40 ^{b-f}
6		PKG163	191.08 ^{ab}	14.92	12.85 ^{c-f}
7		PKG169	176.52 ^{ab}	14.56	12.27 ^{def}
8		PKG164	192.29 ^{ab}	12.77	15.04 ^{ab}
Cross I mean			185.22	14.36	13.09
9	Cross II	PKG100	198.88 ^{ab}	15.19	13.24 ^{b-f}
10		PKG102	190.06 ^{ab}	14.19	14.12 ^{a-d}
11		PKG110	188.17 ^{ab}	16.02	12.10 ^{def}
12		PKG111	162.38 ^{ab}	14.10	11.56 ^{ef}
13		PKG115	264.46^a	16.73	15.57^a
14		PKG126	159.23^{ab}	14.21	11.21^f
15		PKG141	182.33 ^{ab}	15.69	11.69 ^{ef}
16		PKG142	197.15 ^{ab}	13.35	14.91 ^{abc}
17		PKG166	177.77 ^{ab}	15.10	11.88 ^{ef}
18		PKG151	197.13 ^{ab}	13.15	15.13 ^{ab}
Cross II mean			191.75	14.77	13.14
19	SC	PK5193	156.20	9.74	15.68
Cross mean			188.85	14.59	13.12
LSD 0.05 (Cross I vs. Cross II)			13.03	0.89	0.69
			ns	ns	ns

Note: Cross I - (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera*; Cross II - (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera*; SC- Standard cross Deli *Dura* × AVROS *Pisifera*. FFB - fresh fruit bunches; BNO - bunch number; ABW - average bunch weight. Means with the same superscript letters are not significantly different at $p \leq 0.05$ based on Duncan's new multiple range test (DMRT). Figures in bold within the mean column are minimum and maximum values.

Agro-morphological Variabilities in Bunch Quality Component Traits

There were no significant differences in all of the bunch quality component traits observed between the cross-types, except for the O/B ratio (Table 4). However, a comparison among genotypes revealed that all bunch quality component traits were highly significant, except for fruit to bunch ratio (F/B), which was significant. The kernel yield (KY) had the highest CV values of 41.52% for cross-type and 39.76% for genotype, demonstrating substantial variation. On the other hand, traits like oil to dry matter (O/DM) and mesocarp to fruit (M/F) showed much lower variability, suggesting these traits are more stable across the crosses and genotypes. The genetic variation in oil palm populations is useful for conservation and breeding programmes to develop new improved varieties with desirable traits. These results correspond with Nor Azwani et al. (2022), who reported high genetic variability in bunch quality traits in MPOB-Nigeria *Dura* × AVROS *Pisifera* genotypes.

In addition, the LSD test indicated that Cross I produced a better O/B ratio than Cross II, with half of the genotypes exceeding an O/B of 28% (Table 5). The results revealed that PKG144 from Cross I achieved the highest O/B of 29.35%, which is 5.54% higher than the SC. The excellent O/B may be attributed to the AVROS, which are recognised for their high oil-to-bunch ratios (Amiruddin et al., 2020; Lee & Yeow, 1985). The results obtained were comparable to PS1.1 materials, which produce an O/B of about 28% (Mohd Din et al., 2023). Besides displaying the highest O/B, PKG144 also produced the highest M/F although it exhibited the lowest kernel to fruit (K/F), kernel to bunch (K/B), and shell to fruit (S/F). On the other hand, PKG126 produced the highest K/B and thickest S/F among the Cross II

genotypes, with corresponding lowest M/F, O/DM, and O/B values. Both mesocarp and shell traits have an impact on all oil palm breeding and selection programmes (Swaray et al., 2020). The selection process usually prioritises a high M/F ratio instead of an S/F ratio to produce high yielding planting materials.

The oil component in these O/DM, O/B and OY traits refers to the mesocarp oil. Thus, the oil output for each bunch is significantly affected by the fruit's mesocarp composition, which leads to oil yield production (Corley & Tinker, 2016; Gawankar et al., 2022). PKG115 from Cross II recorded the highest oil yield (OY), making it highly valuable for oil production. Furthermore, its high M/F and F/B ratios added to its productivity. About 95% of OY is from the mesocarp (M/F), which determines the O/B and consequently affects the OY (Corley, 2003; Gawankar et al., 2022). Since the OY is a composite character, it is highly dependent on other components such as FFB, M/F, S/F and O/B. From these findings, the OY observed from PKG115 was likely attributed to its high FFB yield and M/F.

Agro-morphological Variabilities in Vegetative Characters

Significant differences in the vegetative traits were observed only for the petiole cross-section (PCS), leaflet length (LL), and leaf width (LW) between the cross-type (Table 6). In addition, there was a significant influence of the genotype on all vegetative characters, suggesting variation among the genotypes. The PCS exhibited the highest CV of 23.15% among cross-types and 22.64% among genotypes, whereas the leaf number (LN) trait recorded the lowest CV of 6.92% among cross-types and 6.34% among genotypes. Arolu et al. (2017) also observed a substantial influence of the

TABLE 4. ANOVA RESULT FOR BUNCH QUALITY COMPONENTS BASED ON CROSS-TYPES AND GENOTYPES

Source of variance	df	M/F	K/F	S/F	O/DM	F/B	O/B	K/B	OY	KY
Cross-type	1	0.31 ^{ns}	5.13 ^{ns}	2.91 ^{ns}	4.88 ^{ns}	0.50 ^{ns}	84.90*	2.82 ^{ns}	80.60 ^{ns}	13.89 ^{ns}
Error	214	22.40	5.04	8.50	4.67	24.82	11.25	2.63	149.73	9.90
Total	215	4,793.53	1,082.91	1,821.64	1,004.10	5,312.70	2,492.68	566.16	3,2123.78	2,133.35
CV (%)		5.75	28.73	29.32	2.72	7.83	12.44	34.92	27.63	41.52
Genotype	17	76.85**	16.49**	29.21**	12.46**	42.46*	29.21**	8.53**	462.29**	19.73**
Error	198	17.61	4.05	6.69	4.00	23.19	10.08	2.13	122.55	9.08
Total	215	4,793.53	1,082.91	1,821.64	1,004.10	5,312.70	2,492.68	566.16	32,123.78	2,133.35
CV (%)		5.10	25.77	26.01	2.52	7.57	11.78	31.39	25.00	39.76

Note: *, **, and ns - significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; df - degrees of freedom; 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; CV - coefficient of variation.

TABLE 5. COMPARISON OF BUNCH QUALITY COMPONENT MEANS AMONG CROSS-TYPES AND GENOTYPES

No.	Cross-type	Genotype code	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)
1	Cross I	PKG116	79.16 ^{fg}	9.63 ^{ab}	11.21 ^{abc}	79.00 ^{abc}	65.75 ^a	26.87 ^{abc}	5.94 ^a	41.28 ^{b-e}	9.02 ^{abc}
2		PKG124	82.13 ^{b-f}	7.87 ^{b-f}	10.01 ^{b-e}	80.70 ^a	64.37 ^{ab}	28.46 ^{ab}	4.62 ^{a-e}	45.14 ^{bcd}	7.33 ^{a-d}
3		PKG136	84.08 ^{a-e}	6.47 ⁱ	9.45 ^{c-f}	79.19 ^{abc}	62.93 ^{ab}	27.84 ^{ab}	3.84 ^{de}	47.63 ^{bcd}	6.50 ^{bcd}
4		PKG144	86.43 ^a	6.41 ^f	7.16 ^f	80.54 ^a	62.25 ^{ab}	29.35 ^a	3.55 ^e	51.02 ^b	6.28 ^{bcd}
5		PKG153	81.56 ^{c-f}	7.53 ^{c-f}	10.91 ^{abc}	79.80 ^{ab}	66.36 ^a	28.32 ^{ab}	4.61 ^{a-e}	42.61 ^{b-e}	6.90 ^{a-d}
6		PKG163	80.59 ^{efg}	8.21 ^{a-f}	11.21 ^{abc}	77.67 ^{cd}	62.68 ^{ab}	25.51 ^{bc}	4.89 ^{a-e}	41.37 ^{b-e}	8.13 ^{a-d}
7		PKG169	85.05 ^{abc}	6.56 ^{ef}	8.40 ^{def}	80.19 ^a	63.28 ^{ab}	28.10 ^{ab}	3.62 ^e	45.43 ^{bcd}	5.84 ^{cd}
8		PKG164	79.32 ^{f-g}	8.44 ^{ae}	12.24 ^{ab}	80.48 ^a	61.93 ^{ab}	26.88 ^{abc}	5.08 ^{a-d}	45.28 ^{bcd}	8.37 ^{a-d}
Cross I mean			82.29	7.64	10.07	79.70	63.69	27.67 ^A	4.52	44.97	7.30
9	Cross II	PKG100	81.37 ^{c-f}	7.73 ^{c-f}	10.91 ^{abc}	79.47 ^{abc}	59.87 ^b	24.55 ^{cd}	4.41 ^{b-e}	39.62 ^{cde}	7.09 ^{a-d}
10		PKG102	82.13 ^{b-f}	8.65 ^{abc}	9.23 ^{c-f}	80.03 ^{ab}	64.05 ^{ab}	27.66 ^{ab}	5.12 ^{a-d}	44.34 ^{bcd}	8.18 ^{a-d}
11		PKG110	80.98 ^{d-g}	8.43 ^{a-e}	10.59 ^{a-d}	80.15 ^{ab}	66.10 ^a	27.97 ^{ab}	5.27 ^{abc}	49.13 ^{abc}	9.21 ^{ab}
12		PKG111	80.67 ^{efg}	8.50 ^{a-d}	10.83 ^{a-d}	79.93 ^{ab}	65.39 ^a	26.98 ^{abc}	5.39 ^{ab}	37.41 ^{de}	7.56 ^{a-d}
13		PKG115	85.93 ^{ab}	6.48 ^f	7.59 ^{ef}	79.70 ^{ab}	63.00 ^{ab}	26.85 ^{abc}	3.73 ^{de}	62.67 ^a	8.81 ^{abc}
14		PKG126	77.43 ^s	9.66 ^{ab}	12.91 ^a	76.91 ^d	64.37 ^{ab}	22.56 ^d	5.96 ^a	33.11 ^e	9.08 ^{abc}
15		PKG141	84.87 ^{a-d}	6.99 ^{c-f}	8.14 ^{ef}	80.09 ^{ab}	59.95 ^b	26.95 ^{abc}	3.77 ^{de}	40.32 ^{b-e}	5.67 ^d
16		PKG142	84.56 ^{a-e}	6.56 ^{ef}	8.88 ^{c-f}	78.24 ^{bcd}	64.65 ^a	26.28 ^{abc}	3.98 ^{cde}	43.05 ^{b-e}	6.58 ^{bcd}
17		PKG166	83.64 ^{a-e}	6.71 ^{def}	9.65 ^{cde}	80.08 ^{ab}	63.48 ^{ab}	27.41 ^{abc}	3.91 ^{cde}	42.86 ^{b-e}	6.14 ^{cd}
18		PKG151	80.55 ^{efg}	9.78 ^a	9.67 ^{cde}	79.33 ^{abc}	65.11 ^a	26.83 ^{abc}	5.95 ^a	44.89 ^{bcd}	9.77 ^a
Cross II mean			82.21	7.95	9.84	79.39	63.60	26.40 ^B	4.75	43.74	7.81
19	SC	PK5193	82.79	7.86	9.35	79.41	64.2	27.81	4.77	35.65	5.92
Cross mean			82.25	7.81	9.94	79.53	63.64	26.96	4.65	44.29	7.58
LSD 0.05 (Cross I vs. Cross II)			1.28	0.61	0.79	0.59	1.34	0.91	0.44	3.30	0.85
			ns	ns	ns	ns	*	ns	ns	ns	ns

Note: Cross I - (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera*; Cross II - (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera*; SC - Standard cross Deli *Dura* × AVROS *Pisifera*; 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. Means with the same small letter are not significantly different at $p \leq 0.05$ based on Duncan's new multiple range test (DMRT). Figures in bold within the mean column are minimum and maximum values.

TABLE 6. ANOVA RESULT FOR VEGETATIVE TRAITS BASED ON CROSS-TYPES AND GENOTYPES

Source of variance	df	FP	PCS	RL	LL	LW	LN	HTI	LA	LAI	DIA
Cross-Type	1	16.38 ^{ns}	232.55*	0.44 ^{ns}	958.14**	1.47*	25.06 ^{ns}	0.02 ^{ns}	1.91 ^{ns}	0.67 ^{ns}	0.01 ^{ns}
Error	214	5.18	55.32	0.25	99.38	0.33	141.34	0.01	3.04	1.06	0.01
Total	215	1,124.37	12,070.22	54.73	22,225.61	72.84	30,270.87	1.28	651.98	228.47	1.16
CV (%)		8.97	23.15	8.75	10.93	10.50	6.92	19.22	17.70	17.70	11.44
Genotype	17	14.98**	94.04*	0.99**	458.29**	0.85**	397.84**	0.01**	8.23**	2.88**	0.01**
Error	198	4.39	52.89	0.19	72.90	0.29	118.73	0.01	2.59	0.91	0.00
Total	215	1,124.37	12,070.22	54.73	22,225.61	72.84	30,270.87	1.28	651.98	228.47	1.16
CV (%)		8.26	22.64	7.59	9.36	9.87	6.34	18.50	16.33	16.33	10.92

Note: *, **, and ns - significant at $P \leq 0.05$, $P \leq 0.01$ and not significant, respectively; df - degrees of freedom, FP - frond production; PCS - petiole cross section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTI - height increment; LA - leaf area; LAI - leaf area index; DIA - trunk diameter.

high genetic variability on the vegetative traits in their D×P progenies. According to Swaray et al. (2020), vegetative traits should also be considered in selecting better performing materials.

The LSD results suggested that Cross I performed slightly higher in LL, while Cross II produced better in PCS and LW when compared to Cross I (Table 7). PKG163 from Cross I displayed the largest leaf length (LL) of 102.87 cm, while PKG110 of Cross II recorded the shortest LL of 81.19 cm. Broader leaves may indicate a better photosynthesis potential, as wider leaves typically capture more sunlight. PKG110 had the widest leaves (6.27 cm), whereas PKG163 had the narrowest (5.19 cm). Additionally, selecting palms with smaller PCS and shorter rachis length (RL) is advantageous, as it enables increased planting density each hectare and better land utilisation. PKG111 from Cross II was observed to have the lowest PCS at 25.61 cm² combined with low RL at 5.45 m, which were 19.31% and 5.22% lower than the SC, respectively. Breeding for compactness is one of the main objectives in the oil palm industry, where height increment (HTI) and rachis length (RL) are crucial traits. These traits may enhance production and profitability for each hectare on the currently limited land (Norziha et al., 2020). For the genotypes in this study, HTI varied from 0.32 m yr⁻¹ (PKG153) to 0.45 m yr⁻¹ (PKG110), compared to the dwarfed PS1.1 materials, which display a height increment of 0.20–0.45 m yr⁻¹ (Mohd Din et al., 2023). Frond production, which plays a key role in photosynthesis and yield improvements, ranged from 23.75 fronds yr⁻¹ (PKG 116) to 27.25 fronds yr⁻¹ (PKG166).

The highest number of leaves (LN) was observed in PKG144, with an average of 181.50 leaves, which could contribute to an overall higher photosynthetic capacity. In contrast, PKG111 recorded the lowest number of leaves (161.08 leaves). For leaf area (LA), the results ranged from

8.51 m² (PKG111) to 11.54 m² (PKG151). PKG151 also gained the highest value in leaf area index (LAI, 6.83), suggesting it possesses a more efficient canopy area for light interception and nutrient use.

Heritability Estimates

Heritability estimates ranged from very low (<30%), to medium (30%–60%), to high (over 60%) (Johnson et al., 1955). Broad-sense heritability estimates for bunch yields revealed that h_b^2 values varied from low (for BNO) to moderate (for FFB and ABW) (Table 8). This could be due to the wide genetic variability among the genotypes studied, affecting the genetic contribution to these traits. Sritharan et al. (2017) reported moderate (30.20%) to high (82.50%) h_b^2 in two-way and multi-way crosses of D×P oil palm progenies. On the other hand, the h_b^2 for yield and its components were low in the Deli *Dura* × MPOB-NGA *Pisifera* population (Arolu et al., 2017). Low h_b^2 is due to the high environmental sensitivity of these yield traits (Corley & Tinker, 2016). Poor female inflorescence production, water stress, climate change, or inadequate fertiliser input in oil palm may reduce productivity. In this study, low to medium range h_b^2 values were obtained for bunch quality components, with the highest heritability estimate obtained for S/F (43.87%) while the lowest was for F/B (12.98%). High h_b^2 had been reported for bunch quality components such as mesocarp and oil content (Kushairi & Rajanaidu, 2000). For vegetative traits, the highest broad-sense heritability estimate was observed for LL (61.17%), suggesting higher genetic variation in this trait than the other traits. The observations in this study suggested that the expression of most traits was greatly influenced by environmental factors.

TABLE 7. COMPARISON OF VEGETATIVE TRAITS MEANS AMONG CROSS-TYPES AND GENOTYPES

No.	Cross-type	Genotype code	FP (frond yr ⁻¹)	PCS (cm ²)	RL (m)	LL (cm)	LW (cm)	LN (No.)	HTI (m yr ⁻¹)	LA (m ²)	LAI	DIA (m)
1	Cross I	PKG116	23.75 ^g	33.39 ^a	5.66 ^{def}	92.23 ^{-f}	5.43 ^{bcd}	166.75 ^{cde}	0.40 ^{abc}	9.52 ^{b-e}	5.63 ^{b-e}	0.62 ^{abc}
2		PKG124	24.92 ^{d-g}	30.46 ^{abc}	5.48 ^{ef}	88.49 ^{d-i}	5.25 ^{cd}	168.25 ^{b-e}	0.37 ^{cd}	9.03 ^{cde}	5.34 ^{cde}	0.59 ^c
3		PKG136	26.25 ^{a-d}	34.13 ^a	5.70 ^{b-f}	93.05 ^{b-e}	5.46 ^{bcd}	171.50 ^{-d}	0.40 ^{a-d}	9.91 ^{b-e}	5.87 ^{b-e}	0.66 ^{ab}
4		PKG144	26.25 ^{a-d}	32.41 ^{ab}	5.67 ^{-f}	92.10 ^{-f}	5.29 ^{bcd}	178.50 ^{ab}	0.44 ^{abc}	9.87 ^{b-e}	5.85 ^{b-e}	0.62 ^{abc}
5		PKG153	24.08 ^g	32.74 ^{ab}	6.07 ^{ab}	94.42 ^{bcd}	5.39 ^{bcd}	164.50 ^{de}	0.32 ^d	9.51 ^{b-e}	5.63 ^{b-e}	0.66 ^{ab}
6		PKG163	25.08 ^{c-g}	35.12 ^a	6.07 ^{abc}	102.87 ^a	5.19 ^d	172.58 ^{-d}	0.38 ^{bcd}	10.66 ^{ab}	6.31 ^{ab}	0.64 ^{abc}
7		PKG169	25.92 ^{a-f}	34.08 ^a	5.88 ^{a-e}	94.03 ^{bcd}	5.46 ^{bcd}	172.58 ^{-d}	0.37 ^{cd}	10.10 ^{a-d}	5.98 ^{a-d}	0.66 ^{ab}
8		PKG164	24.25 ^{d-g}	33.96 ^a	5.94 ^{a-d}	91.55 ^{-c-g}	5.79 ^b	181.50 ^a	0.45 ^{ab}	11.00 ^{ab}	6.52 ^{ab}	0.60 ^{bc}
Cross I mean			25.06	33.28 ^A	5.81	93.59 ^A	5.41 ^B	172.26	0.39	9.95	5.89	0.63
9	Cross II	PKG100	24.42 ^{d-g}	29.63 ^{abc}	5.60 ^{def}	84.16 ^{ghi}	5.57 ^{bcd}	164.58 ^{de}	0.41 ^{abc}	8.80 ^{de}	5.21 ^{de}	0.58 ^c
10		PKG102	27.17 ^{ab}	30.73 ^{abc}	6.10 ^{ab}	92.73 ^{cde}	5.19 ^d	176.58 ^{abc}	0.41 ^{abc}	9.74 ^{b-e}	5.76 ^{b-e}	0.69 ^a
11		PKG110	27.00 ^{abc}	33.93 ^a	5.57 ^{def}	81.19 ⁱ	6.27 ^a	175.67 ^{abc}	0.45 ^a	10.24 ^{a-d}	5.06 ^{a-d}	0.64 ^{abc}
12		PKG111	25.50 ^{a-g}	25.61 ^c	5.45 ^f	84.36 ^{f-i}	5.50 ^{bcd}	161.08 ^e	0.44 ^{abc}	8.51 ^e	5.04 ^e	0.64 ^{abc}
13		PKG115	24.58 ^{d-g}	36.09 ^a	6.08 ^{ab}	99.36 ^{abc}	5.22 ^d	175.00 ^{-d}	0.41 ^{abc}	10.41 ^{abc}	5.16 ^{abc}	0.69 ^a
14		PKG126	26.17 ^{a-e}	26.19 ^{bc}	5.30 ^f	85.31 ^{f-i}	5.66 ^{bcd}	165.17 ^{de}	0.41 ^{abc}	9.08 ^{cde}	5.37 ^{cde}	0.66 ^{ab}
15		PKG141	25.25 ^{b-g}	31.78 ^{abc}	5.46 ^f	89.52 ^{d-h}	5.40 ^{bcd}	172.50 ^{-d}	0.41 ^{abc}	9.51 ^{b-e}	5.63 ^{b-e}	0.62 ^{abc}
16		PKG142	24.17 ^{ef-g}	34.28 ^a	5.90 ^{a-d}	93.84 ^{bcd}	5.77 ^{bcd}	174.92 ^{-d}	0.39 ^{a-d}	10.83 ^{ab}	6.42 ^{ab}	0.64 ^{abc}
17		PKG166	27.25 ^a	31.73 ^{abc}	5.46 ^f	82.27 ^{hi}	5.53 ^{bcd}	171.00 ^{-e}	0.38 ^{bcd}	8.95 ^{cde}	5.30 ^{cde}	0.66 ^{ab}
18		PKG151	24.67 ^{d-g}	32.55 ^{ab}	6.28 ^a	100.82 ^{ab}	5.63 ^{bcd}	179.25 ^a	0.38 ^{bcd}	11.54 ^a	6.83 ^a	0.66 ^{ab}
Cross II mean			25.62	31.20 ^B	5.72	89.35 ^B	5.57 ^A	171.58	0.41	9.76	5.78	0.65
19	SC	PK5193	24.73	31.74	5.75	88.12	5.68	178.07	0.43	10.28	6.09	0.59
Cross Mean			25.37	32.12	5.76	91.24	5.50	171.88	0.40	9.85	5.83	0.64
LSD 0.05 (Cross I vs. Cross II)			0.61 ns	2.00 *	0.14 ns	2.69 *	0.16 *	3.21 ns	0.02 ns	0.47 ns	0.28 ns	0.02 ns

Note: Cross I - (MPOB-Nigeria × Deli) *Dura* × AVROS *Pisifera*; Cross II - (MPOB-Nigeria × Deli) *Dura* × Yangambi *Pisifera*; SC - Standard cross Deli *Dura* × AVROS *Pisifera*; FP - frond production; PCS - petiole cross-section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTI - height increment; LA - leaf area; LAI - leaf area index; DIA - trunk diameter. Means with the same small letter are not significantly different at $p \leq 0.05$ based on Duncan's new multiple range test (DMRT). Figures in bold within the mean column are minimum and maximum values.

TABLE 8. VARIANCE COMPONENTS AND HERITABILITY ESTIMATES

Category	Traits	σ_g^2	σ_e^2	Total	Heritability (%)
Yield	FFB	367.58	1,982.80	2,350.38	31.28
	BNO	0.44	10.50	10.94	8.04
	ABW	1.44	5.16	6.60	43.64
Bunch quality	M/F	4.94	17.61	22.55	43.81
	K/F	1.04	4.05	5.09	40.86
	S/F	1.88	6.69	8.57	43.87
	O/DM	0.70	4.00	4.70	29.79
	F/B	1.61	23.19	24.80	12.98
	O/B	1.59	10.08	11.67	27.25
	K/B	0.53	2.13	2.66	39.85
	OY	28.31	122.55	150.86	37.53
	KY	0.89	9.08	9.97	17.85
Vegetative	FP	0.88	4.39	5.27	33.40
	PCS	3.43	52.89	56.32	12.18
	RL	0.07	0.19	0.26	53.85
	LL	32.12	72.90	105.02	61.17
	LW	0.05	0.29	0.34	29.41
	LN	23.26	118.73	141.99	32.76
	HTI	0.00	0.01	0.01	0.00
	LA	0.47	2.59	3.06	30.72
	LAI	0.16	0.91	1.07	29.91
	DIA	0.00	0.00	0.00	0.00

Note: σ_g^2 - variance of genotype; σ_e^2 - variance of error; FFB - fresh fruit bunches; 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; FP - frond production; PCS - petiole cross-section; RL - rachis length; LL - leaflet length; LW - leaflet width; LN - leaflet number; HTI - height increment; LA - leaf area; LAI - leaf area index; DIA - trunk diameter.

CONCLUSION

Generally, the genotype factor was highly significant for all traits, suggesting adequate genetic variation for effective selection within this breeding population. The broad-sense heritability estimates were low for most of the traits, suggesting a greater influence on these traits by the environment. PKG115 from Cross II has been identified to possess a good combination of traits, such as its high FFB yields of 264.46 kg palm⁻¹ yr⁻¹ or 39.14 t ha⁻¹. The high yield was combined with promising bunch quality components such as high M/F and OY, and a low S/F. From the *Dura* side, the Nigerian germplasm could also incorporate other interesting traits for future breeding programmes, apart from its good FFB yield. The female (0.318/2 of MPOB-NGA × Deli *Dura*) and male (0.395/148 of Yangambi *Pisifera*) parents of PKG115 can be used in the development of commercial D×P seed production and breeding programmes as the mother palm and pollen source, which may help to address the yield stagnation observed in the oil palm sector in recent decades.

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