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Yield and Bunch Quality Component Comparison between Two-Way Crosses and Multi-Way Crosses of DxP Oil Palm Progenies

(Perbandingan antara Kacuk Dua Hala dengan Kacuk Pelbagai Hala bagi Hasil dan Komponen Tandan dalam Progeni DxP Kelapa Sawit)

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ABSTRACT

Breeding for hybrid DxP oil palm in many commercial seed producers has recently switched from simple two-way crosses to complicated multi-way crosses with the hope of increasing hybrid vigour and thus higher yield potential. The objective of this study was to evaluate the yield potential of the multi-way (MW) crosses as compared to conventional two way (TW) crosses in United Plantations Berhad. A trial was set up in 2004 where 20 crosses of both multi-way and two-way combinations were field planted and evaluated for six years after maturity. Palms were assessed for yield traits and bunch components through bunch analysis. Fresh fruit bunch weight for both types of crosses was significantly different with MW crosses yielding 37.11 tonnes per ha per year as opposed to TW crosses with 36.40. MW crosses had 1.46 tonnes oil per ha per year advantage over TW. High coefficient of variation (CV%) was seen for selected traits such as bunch number (BNO), average bunch weight (ABW), kernel, shell and mesocarp to bunch (KB, SB and MB), oil to dry and oil to wet mesocarp (ODM and OWM), as well as mean fruit weight (MFW). ANOVA showed that replicate (REP), year (Y) and progeny (ID) were significantly different (p≤0.01) for BNO and fresh fruit bunch (FFB) in both crosses but not significant for REP in ABW of TW. REP was not significant for all the traits except ODM whereas ID was significant for all the traits in both TW and MW. Phenotypic and genotypic coefficients of variance (PCV and GCV) were low (<10%) for all the traits in both types of crosses with MW crosses showing higher PCV and GCV in most cases. Heritability for ABW, FFB, KB, oil to bunch (OB), SB and MFW were higher in MW crosses but lower for BNO, fruit to bunch (FB), MB, ODM and OWM compared to TW crosses.

Keywords: Breeding; multi-way; oil palm; two-way; yield

ABSTRAK

Pembiakan hibrid DxP minyak sawit oleh kebanyakan pengeluar benih komersial baru-baru ini telah beralih daripada jenis kacuk dua hala kepada kacuk pelbagai hala dengan harapan meningkatkan kecergasan hibrid dan seterusnya meningkatkan hasil. Objektif kajian ini adalah untuk menilai potensi hasil daripada kacuk pelbagai hala (MW) berbanding kacuk konvensional dua hala (TW) di United Plantations Berhad. Kajian telah dijalankan pada tahun 2004 dengan 20 kacuk pelbagai hala dan dua hala ditanam dan dinilai untuk enam tahun selepas matang. Pokok telah dinilai untuk ciri hasil dan komponen tandan melalui analisis tandan. Berat tandan untuk kedua-dua jenis kacuk berbeza secara signifikan dengan kacuk MW menghasilkan 37.11 tan metrik sehektar setahun berbanding dengan TW dengan 36.40. Kacuk MW mempunyai kelebihan minyak 1.46 tan metrik sehektar setahun berbanding TW. Pekali variasi (CV%) tinggi diperhatikan untuk ciri bilangan tandan (BNO), purata berat tandan (ABW), kernel, kulit dan mesokarpa dalam tandan (KB, SB dan MB), minyak kering dan minyak dalam mesokarpa basah (ODM dan OWM) serta berat biji lerai (MFW). ANOVA menunjukkan bahawa replikasi (REP), tahun (Y) dan progeni (ID) berbeza secara signifikan (p≤0.01) untuk BNO dan berat buah segar (FFB) dalam kedua-dua jenis kacuk tetapi tidak signifikan dalam REP untuk ABW dalam TW. REP didapati tidak signifikan untuk semua ciri kecuali ODM sedangkan ID adalah signifikan untuk semua ciri dalam TW dan MW. Pekali varians fenotip dan genotip (PCV dan GCV) adalah rendah (<10%) untuk semua ciri dalam kedua-dua jenis kacuk dengan MW menunjukkan PCV dan GCV yang lebih tinggi dalam kebanyakan kes. Keterwarisan untuk ABW, BTS, KB, minyak dalam tandan (OB), SB dan MFW adalah lebih tinggi dalam MW tetapi lebih rendah untuk BNO, buah-buahan dalam tandan (FB), MB, ODM dan OWM berbanding kacuk TW.

Kata kunci: Dua-hala; hasil; kelapa sawit; pelbagai-hala; pembiakan

INTRODUCTION

Since the advent of science based agriculture, the primary focus has been towards increasing yield through integration of cultural, agronomic practices and enhanced genetics. Plant breeding, a major wing in agricultural research, has been proven to be sound in many instances. World average cereal yields had seen an increase from 1.35 to 3.51 tonnes per ha from 1961 to 2009. Total cereal production was increased by 183% from 877 million to 2489 million tonnes with only 9% expansion in land use (Prohens 2011). In the high Andes of Peru, a 50% yield increase was realized with the planting of stronger and healthier varieties of barley producing an average harvest of 1.2 tonnes per ha (IAEA 2015). In the United States, maize breeders exploiting hybrid vigour since 1939 succeeded in improving commercial grain yield from 1.3 tonnes per ha in 1939 to 7.8 tonnes per ha in 2005, translating to an increase of 500% in 66 years (7.6% per year) (Lee & Tracy 2009).

Breeding for most hybrid crops (annual and perennial) can be explained by two general schemes widely used by researchers, the Modified Recurrent Selection (MRS) and the Reciprocal Recurrent Scheme (RRS). Each of these schemes comes with their own advantages. The MRS focuses attention on establishing crosses with high General Combining Ability (GCA) whereas the RRS enables the selection for Specific Combining Ability (SCA) (Rajanaidu et al. 2013). GCA is defined as the average performance of a line in hybrid combination whereas SCA refers to certain combinations in the population with better or worse performance than the average (Sprague & Tatum 1942).

Following realization of its yield potential and profitability, research in oil palm agronomy and breeding gained impetus leading to expanded commercialization in the early 1900s. For the initial phases of expansion in land areas, fruits from high yielding *dura* (thick shelled) palms were collected, germinated and planted. Variability in yield and vegetative parameters led to selection of individual palms for the creation of specific control pollinated crosses and thus commencing oil palm breeding. In 1941, a milestone was reached to revolutionize the oil palm industry. The discovery of the shell thickness inheritance by Beirnaert and Vanderweyen (1941), switched commercial plantings from *dura* to *tenera* (thin shelled variety) and led to an estimated 30% oil yield gain. Following this, much attention was focused on *dura* x *tenera* (DxT) and *dura* x *pisifera* (DxP) crosses for commercial planting after the acquisition of various *pisifera* materials through collaborative works with research organizations such as Institut de recherche pour les huiles et oléagineux (IRHO), Nigerian Institute for Oil Palm Research (NIFOR) and Institut national pour les études agronomiques du Congo belge (INEAC). It was at this point in time that research departments throughout Malaysia launched aggressive and elaborate breeding schemes aimed at increasing yield. Most companies in Malaysia have at present been planted with second, third and in some cases fourth generations with continuous improvement in planting material. As of year 2015, a total of 5.3 million ha were planted with oil palm in Malaysia producing 19.96 million tonnes of crude palm oil averaging to 3.78 tonnes oil per ha (MPOB 2016).

United Plantations Berhad (UP) is a public listed company with 11 plantations in Peninsular Malaysia covering 38,903 ha comprising 92% oil palm and 8% coconut. United Plantations Research Department (UPRD), located in Jendarata Estate, is an integral component of the group. With over 50 years of research experience, the department's core activities include the production of high yielding oil palm, coconut and banana planting material, and applied research as well as advisory services. UPB's group yield averaged at 5.25 tonnes oil per ha over 45,095 ha in 2015.

Conventionally, DxP crosses in UPB were created with highly in-bred pure lines of a single lineage in both the *dura* and *pisifera* materials to maximize on heterosis forming the standard two way (TW) cross. This proved highly successful in early years with commercial yield touching six tonnes oil per ha and the materials planted showing high uniformity. Breeding for conventional TW crosses continued up to the early 1990s until new conundrums were thrown at breeders. The oil palm industry was faced with ganoderma (a soil-borne fungal pathogen) and stagnating yields. Being one of the oldest commercial plantations in Malaysia, most fields in their second generation of planting were severely infested with ganoderma, leading to a 30% loss in stand by the 20th year after planting. In its plight to push yield barriers and possibly solve the ganoderma problems, UPB ventured into the possibility of multi-way (MW) crosses. Breeding programs were altered to combine different bloodlines both in the *dura* and *pisifera* families through elaborate introgressive breeding programmes. New mixed blood *dura* and *pisifera* are continuously progeny tested to evaluate yield components as well as disease tolerance or resistance.

Dura improvement programme in UPB traces back to the 1920s where the first collection was obtained from Marihat Baris Estate of Indonesia which was derived from the avenue palms in Medan (Indonesia) originating from the famous four Bogor Palms. These UPB Deli collections were expanded with the addition of *duras* from Elmina, Klanang Baru (Banting), Ulu Remis and Johor Labis through participation with the DOA organized Cooperative Breeding Scheme (CBS) in the late 1950s to the early 1960s. Consecutively, Dabou Deli crosses from IRHO were procured and planted in 1970. These bloodlines were maintained as BPRO (breeding populations of restricted origin) to maximize on uniformity. Thereafter, with the foresight for ganoderma tolerance, inter-origin crosses amongst *duras* were preferred. Concomitantly, yields increased with greater heterosis between the pure lines, culminating in UPB's mixed blood *duras*. In recent years, Angolan *duras* as well as other Nigerian based *duras* identified for novel traits were acquired from MPOB. Since the introduction of the first *dura* planting material at UPB in 1918, *dura* populations have gone through eight generations of selection and improvement.

The earliest *pisifera* population used in UPB for commercial DxP evaluation in the early 1960s on the other hand is speculated to be of Calabar origin. This population is now recognized as the Jendarata TT. Further, UPB acquired INEAC, Serdang and Highlands materials which are conjectured to be through the CBS programme. A major impact in *pisifera* improvement was the addition of Yangambi, LaMe and Yocoboue Teneras in the 1970s from IRHO. One of the first records of mixed blood *pisiferas* is the crossing of AVROS pollen received from OPRS Banting into the Jendarata TT. Success in progeny testing of these JenTT/AVROS led to the development of an elaborate breeding programme in which mixed blood *pisifera* lines were developed and the progeny was tested. Breeding for materials with high IV and dwarf characteristics led to the procurement of Nigerian populations from MPOB. Currently, *pisiferas* used in the commercial seed production are primarily of mixed blood lines of three to four origins and pure lines of Yangambi which has been improved over three generations.

DxP testing, commonly referred to as progeny testing, is a key step in oil palm breeding enabling the identification of top yielding families. Subsequent statistical analysis thereafter helps identify parents for GCA or SCA based on the performance of the single parent in multiple crosses. In the past, major parameters used as selection criteria in progeny evaluations were fresh fruit bunch (FFB) weight and ratio of oil to bunch (OB). Selection for large bunch weight was replaced with high bunch number due to logistical problems in harvesting and loading as well as inefficient mill processing. Unforeseen to the breeders, increased bunch number corresponds to high sex ratio which can become problematic with regards to pollination efficiencies. Presently, several parameters are included in the selection of progeny parents. Amongst them are FFB yields, OB, sex ratio (through male flower count), disease tolerance, oil quality and desired vegetative traits (low height increment and frond length). At UPB, over 1400 progenies of different parent sources have been evaluated since 1970.

This paper evaluates the performance of MW progenies as compared to TW progenies. Mixed bloodlines forming MW crosses are primarily combinations of Deli, Nigerian, NIFOR, Yangambi, Yocoboue and LaMe origins whereas pure-lines forming TW crosses are of Deli and Yangambi or NIFOR origins. Three yield components (average bunch weight (ABW), bunch number (BNO) and FFB) as well as eight bunch components (fruit to bunch (FB), kernel to bunch (KB), OB, shell to bunch (SB), mesocarp to bunch (MB), oil to dry mesocarp (ODM), oil to wet mesocarp (OWM) and mean fruit weight (MFW)) were analysed.

Materials and Methods

EXPERIMENTAL DESIGN

A trial was set up and planted in July 2004 at Jendarata Estate, United Plantations. 10 MW progenies (comprising three, four and five way crosses) and 10 TW crosses were planted in a Randomized Complete Block Design (RCBD) with four replicates. Details of crosses are listed in appendix. Plot size was 20 palms plot $^{-1}$ and spaced at 29 feet in equilateral triangle to form a planting density of 148 palms ha^{-1}. Soil type in planted area was Jawa series, an acid sulphate soil commonly found in Jendarata Estate. Maintenance of palms in the trial was as UPB standard estate practice.

DATA COLLECTION

Following maturity at the 32nd month, palms were evaluated for a six year period (2007 to 2012). Yield measurements were carried out at every harvest to record bunch weight and bunch number. Bunches were collected and subjected to bunch analysis for assessment of bunch components (approximately 100 bunches were analysed per progeny over the evaluation period). Biannual censuses were conducted to monitor palm health as well as other unique phenotypical traits. Palms which were diseased or dead were completely removed from evaluation and not used in calculations of progeny means.

DATA ANALYSIS

All the collected data of yield and bunch components from bunch analysis was subjected to statistical analysis using Statistical Analysis Software (SAS ver. 9.1). Univariate analysis was used to compute progeny means, standard error and coefficient of variance. ANOVA/GLM was run using progeny means by replicate to obtain variance components. Phenotypic and genotypic variances were estimated using formulas suggested by Burton and de Vane (1953):

$$\sigma_g^2 = \frac{\left(MS_g - MS_e\right)}{r}$$

$$\sigma_p^2 = \sigma_g^2 + \sigma_e^2$$

$$\sigma_e^2 = \mathrm{MS_e}$$

σ_g^2 = genotypic variance, σ_p^2 = phenotypic variance, σ_e^2 = environmental variance, MS_g – mean square due to genotypes, MS_e – error mean square, r = number of replications.

Phenotypic and genotypic coefficient of variance was estimated using formulas adopted by Johnson et al. (1955):

$$\mathrm{PCV} = \left[\frac{\sigma_p}{\bar{x}}\right] \times 100$$

$$\mathrm{GCV} = \left[\frac{\sigma_g}{\bar{x}}\right] \times 100.$$

PCV = phenotypic coefficient of variance, GCV = genotypic coefficient of variance, σ_p = phenotypic standard deviation, σ_g = genotypic standard deviation, $\bar{x}$ = mean.

Broad sense heritability (h^2) for traits was calculated using the formula by Allard (1960).

$$h^2 = \left[\frac{\sigma_g^2}{\sigma_p^2}\right] \times 100$$

Year was not used as an effect for yield traits as it consistently gave significant difference. This was not because of the year effect itself but due to increasing yield production trends. Variances were instead calculated using means of progenies in each rep averaged over six years of recording. Estimations for variances and heritability for bunch components may not be accurate due to unbalanced analysis in each replicate for progenies. Means of replicates averaged over years were used in calculation. Figures in results are only estimates generated using GLM to run ANOVA.

RESULTS AND DISCUSSION

Yield and bunch component performance summarized by variety (MW and TW) showed higher FFB in MW (Table 1). Though TW had higher BNO, the increase in ABW by 1.77 kg led to a 4.5 kg FFB gain per palm per year for MW leading to an increase of 0.71 tonnes FFB per ha per year. FFB yields in MW for individual crosses averaged over six years ranged from 34.50 to 39.40 tonnes per ha whereas TW ranged from 34.63 to 37.81 tonnes per ha. FFB yields, however, were not significantly different in the varieties. Higher CV% for BNO and ABW in individual crosses of the MW is most likely due to higher segregation of mixed bloodlines when compared to TW which was more homozygous.

Increase in OB by 4.02% can be attributed mostly to the improved FB in MW as compared to TW with values of 68.80% and 59.63% respectively (Tables 2 and 3). As FB is an integral component in the calculation of OB, any increase in FB is directly correlated to an increase in OB. Although highly influenced by environment (pollination), FB is heritable to a certain extent.

OER% estimated from O/B for MW and TW were 27.58% and 24.12%, respectively, translating to an increase of 14% through increased combinations of bloodlines (Table 4). OER% when combined with FFB yields per ha translated to average oil yields of 10.24 and 8.78 tonnes oil per ha per year in MW and TW equivalent to an oil yield gain of 1.46 tonnes per ha.

Analysis of variance for yield traits carried out using means of REP for each year showed high significant differences for year in both varieties (Table 5). This was most likely not caused by environmental factors but instead due to the influence of yield production trend (increasing from the first to sixth year), further strengthened by significant year by ID differences in most traits. Significant differences were also seen in genotype (ID) for both MW and TW indicating the presence of high variability between crosses (Table 6). Significant replicate differences were present for all traits except ABW in TW. Differences seen in replicates show the significant environmental influence on the performance of varieties. CV% for all traits were in general higher in the MW compared to TW owing to higher segregation and less uniformity.

TABLE 1. Mean, standard error and CV% for yield traits in both MW and TW crosses by ID

Type	Id	FFB (kg/palm/year)		BNO (per palm/year)		ABW (kg/palm/year)	
		Mean ± SEM	CV%	Mean ± SEM	CV%	Mean ± SEM	CV%
Multi way	MW1	247.93±2.39	24.33	25.62±0.32	31.45	10.66±0.16	38.65
	MW2	266.19±2.38	20.01	25.41±0.40	35.55	11.84±0.31	39.09
	MW3	248.19±2.40	24.54	22.64±0.31	34.54	12.35±0.20	41.02
	MW4	233.09±2.42	23.01	27.12±0.37	29.94	9.52±0.17	39.27
	MW5	246.99±2.09	20.21	26.21±0.34	30.95	10.44±0.17	37.99
	MW6	250.44±2.67	24.06	20.84±0.34	36.26	13.65±0.24	40.41
	MW7	257.43±2.46	21.19	26.00±0.10	33.95	11.21±0.21	41.08
	MW8	248.89±2.31	21.51	24.87±0.35	32.51	10.98±0.16	34.48
	MW9	251.44±2.61	21.07	27.06±0.36	26.94	10.01±0.16	33.38
	MW10	256.97±2.77	21.52	25.70±0.42	32.83	11.18±0.22	39.29
Two way	TW1	240.29±2.63	24.81	24.12±0.37	35.07	11.26±0.21	42.76
	TW2	245.67±2.33	22.27	28.40±0.31	25.22	9.33±0.15	36.48
	TW3	255.50±2.65	23.55	27.83±0.33	27.13	9.86±0.15	35.25
	TW4	244.98±2.62	23.86	28.71±0.34	26.42	9.20±0.15	36.94
	TW5	233.96±2.41	21.78	27.18±0.32	27.66	9.33±0.14	35.55
	TW6	253.53±2.41	22.07	28.20±0.31	25.92	9.69±0.15	35.06
	TW7	245.66±2.74	22.91	29.29±0.39	27.33	9.10±0.16	35.89
	TW8	248.27±2.79	23.29	30.88±0.32	21.18	8.43±0.18	32.39
	TW9	247.30±2.48	21.28	25.57±0.32	24.6	9.64±0.16	34.99
	TW10	244.38±2.92	23.55	28.48±0.38	26.13	9.24±0.17	35.38

TABLE 2. Mean, standard error and CV% for bunch components in both MW and TW crosses by ID

Type	Id	FB		KB		OB		SB	
		Mean ± SEM	CV%	Mean ± SEM	CV%	Mean ± SEM	CV%	Mean ± SEM	CV%
Multi way	MW1	64.73±0.49	7.91	4.48±0.14	32.88	31.06±0.24	8.03	4.92±0.17	35.99
	MW2	64.67±0.43	7.92	3.65±0.11	34.74	31.35±0.20	7.69	4.18±0.11	29.79
	MW3	65.70±0.55	8.92	4.42±0.14	34.34	31.99±0.24	8.14	4.90±0.17	36.63
	MW4	67.35±0.53	7.27	4.10±0.12	26.44	33.46±0.27	7.43	4.80±0.13	24.60
	MW5	68.16±0.42	7.18	5.07±0.10	23.57	31.66±0.20	7.29	6.48±0.11	19.05
	MW6	64.60±0.49	7.83	4.08±0.13	32.59	31.68±0.22	7.27	4.40±0.13	31.83
	MW7	66.18±0.50	7.42	4.10±0.12	23.40	30.97±0.20	6.49	6.39±0.13	20.43
	MW8	64.84±0.40	8.14	3.40±0.10	37.11	32.05±0.21	8.51	3.76±0.11	37.93
	MW9	65.53±0.57	8.19	4.53±0.12	24.83	31.81±0.25	7.41	5.05±0.13	24.84
	MW10	66.77±0.50	8.13	4.58±0.11	25.50	32.28±0.22	7.55	4.89±0.12	26.40
Two way	TW1	61.36±0.55	8.75	4.63±0.12	26.52	28.27±0.27	9.22	5.17±0.15	28.07
	TW2	59.64±0.57	10.98	4.91±0.13	29.58	27.93±0.25	9.98	5.21±0.15	31.79
	TW3	56.06±0.55	9.68	4.90±0.11	23.69	27.28±0.23	8.73	5.03±0.13	26.15
	TW4	60.84±0.54	9.12	5.05±0.14	28.51	27.95±0.23	8.55	5.61±0.14	25.93
	TW5	62.92±0.52	8.61	4.87±0.15	32.89	28.82±0.23	8.28	6.09±0.17	28.55
	TW6	59.12±0.49	10.3	4.81±0.10	26.22	27.53±0.21	9.38	5.07±0.11	28.42
	TW7	55.58±0.44	10.24	3.94±0.08	26.97	27.17±0.19	9.07	4.57±0.11	30.88
	TW8	59.49±0.73	11.15	5.17±0.17	29.04	27.73±0.29	9.50	5.66±0.20	31.58
	TW9	60.56±0.63	9.70	5.11±0.12	21.80	27.67±0.29	9.63	5.72±0.16	25.36
	TW10	61.12±0.66	9.33	4.69±0.13	24.28	27.95±0.29	8.97	5.54±0.16	24.36

Type	Id	MB		ODM		OWM		MFW	
		Mean ± SEM	CV%	Mean ± SEM	CV%	Mean ± SEM	CV%	Mean ± SEM	CV%
Multi way	MW1	55.33±0.45	8.6	80.57±0.14	1.89	56.22±0.23	4.39	15.27±0.31	21.31
	MW2	56.83±0.37	7.76	80.22±0.13	1.86	55.22±0.20	4.21	13.44±0.21	18.84
	MW3	56.38±0.46	8.63	80.70±0.13	1.67	56.81±0.22	4.05	13.77±0.26	20.35
	MW4	58.45±0.46	7.37	80.33±0.21	2.47	57.30±0.25	4.14	15.41±0.30	18.32
	MW5	56.61±0.34	6.99	80.82±0.12	1.73	55.96±0.20	4.21	16.02±0.27	19.41
	MW6	56.12±0.42	7.86	80.45±0.14	1.80	56.53±0.24	4.39	13.10±0.26	21.00
	MW7	54.69±0.45	8.07	80.44±0.15	1.82	56.77±0.27	4.72	14.94±0.36	23.79
	MW8	57.68±0.36	8.14	79.89±0.11	1.86	55.59±0.17	4.06	13.06±0.21	20.91
	MW9	55.95±0.47	7.93	80.96±0.14	1.59	56.92±0.23	3.77	17.33±0.32	17.30
	MW10	57.30±0.43	8.31	80.61±0.12	1.66	56.30±0.23	4.49	12.88±0.25	21.54
Two way	TW1	51.56±0.46	8.75	80.25±0.15	1.87	54.86±0.25	4.47	13.98±0.30	20.87
	TW2	49.31±0.44	10.25	80.29±0.13	1.81	56.70±0.22	4.37	17.08±0.25	16.83
	TW3	49.14±0.45	9.66	80.07±0.11	1.41	55.61±0.20	3.77	16.66±0.26	16.49
	TW4	50.19±0.45	9.30	79.75±0.15	1.90	55.78±0.25	4.55	15.72±0.30	19.85
	TW5	51.96±0.42	8.36	79.84±0.14	1.77	55.52±0.24	4.55	14.00±0.31	23.46
	TW6	49.32±0.38	9.72	80.43±0.09	1.44	55.88±0.18	4.10	16.67±0.28	20.92
	TW7	47.07±0.35	9.56	80.64±0.11	1.70	57.78±0.16	3.57	15.04±0.21	18.20
	TW8	48.67±0.53	9.84	80.45±0.14	1.59	57.03±0.24	3.77	15.65±0.29	17.09
	TW9	49.73±0.55	10.31	79.44±0.16	1.85	55.72±0.25	4.13	15.04±0.31	19.44
	TW10	50.90±0.52	8.79	79.95±0.13	1.57	54.93±0.22	3.47	17.34±0.40	20.09

TABLE 3. Average of mean, standard error and CV% for yield traits and bunch components in both MW and TW crosses

Character	Type			
	Multi way		Two way	
	Mean±SED	CV%	Mean±SED	CV%
FFB	250.43±0.78	22.51	245.93±0.83	23.06
BNO	25.05±0.12	33.40	27.99±0.11	27.28
ABW	11.22±0.06	40.33	9.45±0.05	37.39
FB	68.80±0.16	8.10	59.63±0.19	10.40
KB	4.29±0.04	32.37	4.75±0.04	28.37
OB	31.80±0.07	7.88	27.78±0.08	9.27
SB	4.91±0.05	33.56	5.29±0.05	29.58
MB	4.29±0.04	32.37	4.75±0.04	28.37
ODM	80.46±0.04	1.87	80.17±0.04	1.74
OWM	56.25±0.07	4.37	56.11±0.07	4.38
MFW	14.37±0.09	22.46	15.73±0.10	20.52

TABLE 4. FFB yield per ha estimated OER% and estimated oil yield per ha for MW and TW crosses

Type	Id	FFB/HA/YEAR (tonnes)	OER%	OIL/HA/YEAR (tonnes)
Multi way	MW1	36.69	26.92	9.88
	MW2	39.40	27.17	10.70
	MW3	36.73	27.72	10.18
	MW4	34.50	29.00	10.00
	MW5	36.55	27.44	10.03
	MW6	37.07	27.45	10.18
	MW7	38.10	26.84	10.23
	MW8	36.84	27.77	10.23
	MW9	37.21	27.57	10.26
	MW10	38.03	27.97	10.64
Average		37.11	27.58	10.24
Two way	TW1	35.56	24.50	8.71
	TW2	36.36	24.20	8.80
	TW3	37.81	23.64	8.94
	TW4	36.26	24.22	8.78
	TW5	34.63	24.98	8.65
	TW6	37.52	23.86	8.95
	TW7	36.36	23.55	8.56
	TW8	36.74	24.03	8.83
	TW9	36.60	23.98	8.78
	TW10	36.17	24.22	8.76
Average		36.40	24.12	8.78

Genotypic and phenotypic coefficients of variation were calculated using means of progenies within REPs averaged over years for both yield traits and bunch components (Table 7). Initial ANOVA by year showed high year influence for all traits studied. Averages over years were used instead to study only the replicate effect to enable easier computation of GCV and PCV. In all cases, PCV was higher than GCV indicating environmental factors influencing their expression to varying extents. GCV and PCV values below 10 were considered low, 10 to 20 considered moderate and above 20 considered high (Deshmukh et al. 1986). Narrow differences between PCV and GCV implied a relative resistance to environmental alteration (Okoye et al. 2009). With regards to this, GCV and PCV traits for all yield components were low with the exception of ABW for MW which was moderate. ABW and FFB in TW showed wide differences between PCV and GCV indicating a larger environmental influence.

Heritability in broad sense is a measure of range between the GCV and PCV indicating the extent of resistance to environmental alterations (Table 7). A wide range of heritability was seen in computed results for yield traits and bunch components. BNO and ABW to a certain extent showed high heritability with a range from

TABLE 5. Combined analysis of variance for bunch number (BNO), average bunch weight (ABW), fresh fruit bunch per palm (FFB) and fresh fruit bunch per ha (FFBHA) in multi-way crosses and two-way crosses

Type	Source of variation	d.f.	Mean squares			
			BNO	ABW	FFB	FFBHA
Multi way	REP	3	36.818***	6.31***	777.09**	17.021**
	YEAR	5	1790.709***	629.307***	27637.628***	605.375***
	ID	9	127.061***	43.248***	1853.815***	40.606***
	YEAR*ID	45	4.508**	1.728***	406.793***	8.91***
	REP*ID	27	7.901***	2.524***	218.404ns	4.784ns
	REP*YEAR	15	8.284***	0.714**	568.000***	12.441***
	REP*YEAR*ID	135	2.104	0.255	168.444	3.69
	CV%	-	5.836	4.454	5.17	5.17
Two way	REP	3	15.227***	0.295ns	1284.771***	28.142***
	YEAR	5	1522.91***	414.258***	46385.958***	1016.038***
	ID	9	72.69***	13.205***	944.557***	20.69***
	YEAR*ID	45	2.416**	0.593***	222.803ns	4.88ns
	REP*ID	27	3.701***	1.278***	334.077**	7.318**
	REP*YEAR	15	10.000***	0.708***	490.479**	10.743**
	REP*YEAR*ID	135	1.353	0.155	155.583	3.408
	CV%	-	4.155	4.139	5.076	5.076

d.f. = degrees of freedom; ** and *** significant at p= 1% and 0.01%, respectively; ns=not significant

TABLE 6. Analysis of variance for bunch number (BNO), average bunch weight (ABW), fresh fruit bunch per palm (FFB) and fresh fruit bunch per ha (FFBHA) in multi-way crosses and two-way crosses using means of six years

Type	Source of variation	d.f.	Mean squares			
			BNO	ABW	FFB	FFBHA
Multi way	REP	3	6.175**	1.208ns	128.766*	2.820*
	ID	9	20.252***	6.603***	303.421***	6.646***
	ERROR	27	1.305	0.379	35.815	0.784
	CV%	-	4.579	5.461	2.386	2.386
Two way	REP	3	2.565*	0.041ns	209.331*	4.585*
	ID	9	11.851***	2.088***	151.072*	3.309*
	ERROR	27	0.597	0.206	55.266	1.211
	CV%	-	2.756	4.774	3.027	3.027

d.f. = degrees of freedom; *, ** and *** significant at p=5%, 1% and 0.01%, respectively; ns=not significant

TABLE 7. Genetic variability parameters for yield components

Traits	Type	Mean	GV	PV	GCV%	PCV%	h2
BNO	MW	25.859	4.737	6.042	8.417	9.506	78.401
	TW	27.995	2.814	3.411	5.992	6.597	82.498
ABW	MW	11.339	1.556	1.935	11.001	12.268	80.413
	TW	9.522	0.471	0.677	7.207	8.641	69.572
FFB	MW	251.046	66.902	102.717	3.258	4.037	65.132
	TW	245.748	23.952	79.218	1.992	3.622	30.236
FFBHA	MW	37.155	1.466	2.250	3.259	4.037	65.156
	TW	36.371	0.525	1.736	1.992	3.623	30.242

69.6 to 82.5. This may be due to the highly divergent genotypes studied (Okoye et al. 2009). Heritability in yield traits was lowest for FFB in TW with only 30.2 most likely due to the inclusion of ABW and BNO factors in the calculation of FFB.

Analysis of variance for bunch components were carried out using means of REP averaged over the six years of data collection as most traits studied were ratios of components and not absolute except for MFW (Table 8). Therefore, it can be assumed that overall influence of

TABLE 8. Analysis of variance for bunch components (FB, KB, OB, SB, MB, ODM, OWM and MFW) in multi-way crosses and two-way crosses using means of six years

Type	Source of variation	d.f.	Mean squares			
			FB	KB	OB	SB
Multi way	REP	3	4.279ns	0.186ns	0.003ns	0.139ns
	ID	9	5.609*	1.031***	3.746***	2.652***
	ERROR	27	2.201	0.17	0.565	0.186
	CV%	-	2.259	9.735	2.359	8.83
Two way	REP	3	1.277ns	0.130ns	0.343ns	0.104ns
	ID	9	20.985***	0.587**	1.618**	1.135***
	ERROR	27	2.496	0.123	0.365	0.188
	CV%	-	2.648	7.393	2.18	8.129

	Source of variation	d.f.	Mean squares			
			MB	ODM	OWM	MFW
Multi way	REP	3	1.902ns	0.483*	1.616ns	1.416ns
	ID	9	7.103**	0.752**	1.540*	8.639***
	ERROR	27	2.105	0.255	0.568	0.854
	CV%	-	2.566	0.628	1.336	6.279
Two way	REP	3	1.126ns	0.406*	0.679ns	0.657ns
	ID	9	12.237***	0.726**	4.159***	7.193***
	ERROR	27	1.332	0.124	0.44	0.877
	CV%	-	2.328	0.439	1.184	5.922

d.f. = degrees of freedom; *, ** and *** significant at *p*=5%, 1% and 0.01%, respectively; ns=not significant

TABLE 9. Genetic variability parameters for bunch components

Traits	Type	Mean	GV	PV	GCV%	PCV%	H2
FB	MW	65.668	0.852	3.053	1.406	2.661	27.907
	TW	59.666	4.622	7.118	3.603	4.472	64.935
KB	MW	4.239	0.215	0.385	10.945	14.642	55.873
	TW	4.751	0.116	0.239	7.169	10.290	48.536
OB	MW	31.865	0.795	1.360	2.799	3.660	58.464
	TW	27.720	0.313	0.678	2.019	2.971	46.185
SB	MW	4.883	0.617	0.803	16.080	18.346	76.822
	TW	5.330	0.237	0.425	9.129	12.228	55.739
MB	MW	56.546	1.250	3.355	1.977	3.239	37.248
	TW	49.585	2.726	4.058	3.330	4.063	67.178
ODM	MW	80.488	0.124	0.271	0.438	0.647	45.849
	TW	80.079	0.151	0.275	0.484	0.654	54.827
OWM	MW	56.413	0.243	0.811	0.874	1.596	29.963
	TW	56.003	0.930	1.370	1.722	2.090	67.877
MFW	MW	14.717	1.946	2.800	9.479	11.370	69.503
	TW	15.816	1.579	2.456	7.945	9.909	64.292

year (increase in bunch size) contributed minimally to changes in ratio. This was further strengthened when data was analysed by year but showed non-significant year differences. No significant replicate differences were seen in all traits except ODM showing high uniformity of traits amongst palms within a variety. Differences in ODM may have been caused by the narrow range of values where individual outliers are highly influential or ODM being the only trait studied having a significant environmental influence. Significant ID differences were seen for all traits showing variability amongst ID within each variety. CV% for all traits was in general low with values ranging from 0.439 for ODM in TW to 9.735 for KB in MW. CV% was higher for all traits except FB in MW compared to TW, indicating higher segregation and less uniformity in mixed blood lines.

GCV values for bunch components were low in all cases except for SB and KB for MW (Table 9). Similarly, PCV values were low with the exception of KB and SB in both types of crosses and MFW in MW. As in the case of yield traits, all PCV values were higher than GCV indicating effect of environment to variable degree. It is to be noted once again that estimations for variances used in the calculation of PCV and GCV for bunch components may not be accurate due to unbalanced analysis in each replicate for progenies. With regards to bunch components, heritability of traits ranged from 27.9 for FB in MW to 76.8 for SB in MW. When averaged for both types of crosses, MFW and SB exhibited the highest heritability with values of 66.9 and 66.3, respectively.

CONCLUSION

MW crosses showed a clear advantage over TW crosses in terms of yield and bunch parameters. There is a FFB gain of only 1.9% with MW crosses compared to TW crosses. However, oil productivity increased owing to higher extraction rates. The average oil yield per ha with TW crosses is 8.78 tonnes per ha per year whilst with MW crosses the productivity gain is 16.6% with mean oil yields of 10.24 tonnes per ha per year. Currently commercial plantings with MW crosses have registered an average of 32 tonnes FFB per ha per year with an oil yield of 7 tonnes per ha per year with less than 10 year old palms.

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