Journal of Oil Palm Research Vol. 32 (3) September 2020 p. 394-405
DOI: https://doi.org/10.21894/jopr.2020.0050

MPOB OIL PALM (*Elaeis guineensis* Jacq.) GERMPLASMS LINKED TO COMPACT TRAIT FOR HIGH DENSITY PLANTING

NORZIHA, A*; FADILA, A M*; MARHALIL, M*; ZULKIFLI, Y*; MOHD DIN, A*; RAJANAIDU, N*; ONG-ABDULLAH, M* and KUSHAIRI, A*

ABSTRACT

The compact trait in oil palm was evaluated amongst the 11 germplasms collected from Nigeria, Cameroon, Zaire (now known as the Democratic Republic of Congo), Tanzania, Madagascar, Angola, Senegal, Gambia, Sierra Leone, Guinea and Ghana. The evaluation was based on the shortness of the rachis and a low height increment (HTi). However, priority was given to selection for short rachis length (RL). The MPOB-Madagascar germplasm showed the shortest RL and was significantly different from other germplasms for dura *(RL = 3.22 m, HTi = 0.21 m yr^{-1}). As for* tenera*, the shortest RL was found in MPOB-Tanzania germplasm (RL = 4.44 m, HTi = 0.19 m yr^{-1}) but not significantly different from MPOB-Guinea (RL = 4.49 m, HTi = 0.39 m yr^{-1}). The coefficient of variation (CV) for both* dura *and* tenera *accessions were considerably low with most germplasm showing CV of less than 20%. The highest RL CV among* duras *was noted in MPOB-Madagascar germplasm (CV = 18.09%), while among* teneras*, high variation was observed in MPOB-Guinea germplasm (CV = 13.72%). Broad-sense heritability estimate of RL for MPOB-Madagascar was highest for* dura *(h^2B = 100%) while that for MPOB-Zaire was highest for* tenera *(h^2B = 100%). Phenotypic correlations were moderately positive between RL and HTi for most germplasms providing the possibility of developing compact palms suitable for higher density planting which consequently would result in increased oil palm yield per hectare. In summary, MPOB-Tanzania germplasm showed good potential for further introgression into advanced breeding populations for the generation of future compact planting materials.*

Keywords: oil palm, compact, germplasm.

Date received: 8 January 2019; **Sent for revision:** 8 January 2019; **Accepted:** 30 September 2019; **Available online:** 28 August 2020.

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is the most efficient oil bearing crop compared to other vegetable oils. With the limitation of arable land for planting, oil palm breeding is geared towards increasing yield per hectare of land (Phalan *et al*., 2016). Kushairi *et al*. (2018) reported that integrated pest and *Ganoderma* management, intensified mechanisation, advanced breeding and biotechnology as well as good agricultural practices help boost oil palm yields for both plantations and smallholdings. Oil palm germplasms that possess economically important characteristics are valuable resources for oil yield improvement. In realising this, *E. guineensis* germplasms were collected from Africa to broaden the genetic base of the current oil palm

* Malaysian Palm Oil Board,
6 Persiaran Institusi, Bandar Baru Bangi,
43000 Kajang, Selangor, Malaysia.
E-mail: norziha.abdullah@mpob.gov.my

breeding materials in Malaysia. The first effort was accomplished through the collection from Nigeria in 1973 and was evaluated at MPOB Research Station at Kluang, Johor, Malaysia (Rajanaidu, 1986). Besides Nigeria, prospection was broadened to include other countries in Africa such as Angola, Cameroon, Zaire (now known as the Democratic Republic of Congo), Ghana, Guinea, Gambia, Madagascar, Sierra Leone, Senegal and Tanzania (Rajanaidu and Rao, 1987; Rajanaidu *et al*., 2013). Extensive screenings are continuously being carried out on these materials in order to exploit their genetic potential in oil palm breeding programmes.

Evaluation of the Nigerian germplasm highlighted several interesting attributes such as dwarfism, high iodine value (IV) and high kernel content (Rajanaidu *et al*., 2000). High oleic acid breeding populations were also obtained from the Nigeria germplasm (Isa *et al*., 2006). Whilst, the Angola palms exhibited large fruit *dura* (Kushairi *et al*., 2003) which is similar to the Deli *dura*s. Besides that, Angola palms were found to have unique long stalks that can be used for improving harvesting efficiency (Noh *et al*., 2005). Angola germplasms have also exhibited wide variability in fatty acid composition (FAC) as compared to those in the existing DxP materials (Noh *et al*., 2002). There were palms from Nigeria and Madagascar exhibiting IV of more than 60, which is relatively higher than the current levels (<50) found in most oils (Kushairi *et al*., 1999). Apart from the Nigerian germplasm, high content of vitamin E was observed in genetic materials from Zaire, Tanzania, Angola, and Cameroon. It is obvious that this rich collection of germplasm is Malaysia's treasure trove and should be rapidly mined for potential genetic gains towards improving productivity and a sustainable future. This simultaneously provides Malaysia the competitive advantage despite the challenges faced by the industry.

One practical approach to improving oil palm yield is by increasing the number of productive oil palms per hectare. Oil palms are commercially planted with a density of 120-150 palms ha^{-1} (Woittiez *et al*., 2017). Jusoh *et al.* (2003) mentioned that the maximum income could be achieved from a planting density of 148 palms ha^{-1}, in contrast to the conventional practice of 136-148 palms ha^{-1}. Palat *et al*. (2012) stated that an effective strategy for yield maximisation is high-density planting followed by selective thinning at 8-9 years after planting. Compact palm leaves are 6.5 m which allow a very high density planting at 180-200 palms ha^{-1} compared to 7-8 m leaves of standard commercial planting (Barcelos *et al.*, 2015).

In line with this, MPOB has developed a clone, P126 that showed rachis length (RL) at an average of 4.4 m which is shorter than the standard RL normally recorded for most palms at 5-6 m. This short RL is ideal for high density planting and trials of P126 planted at 198 palms ha^{-1} as opposed to the conventional 148 palms ha^{-1} have been yielding positive results (Zamzuri, 2011). In addition to being compact, P126 has been found to produce medium-sized bunches which are favourable for harvesting (Samsul *et al*., 2018).

Many studies on the development of compact palms have been reported. Guzman and Peralta (2010) stated that six compact clones with excellent agronomic characteristics such as short leaves and stems, precocious and high yielding have been selected for commercial production. Standard *E. guineensis* lines such as Deli, Ghana and Nigeria crossed with COMPACT (*E. oleifera* x *E. guineensis*) palms showed 6.6-6.9 m long leaves and can be planted at a density of 170 palms ha^{-1} which is higher than the industry standard of 136-148 palms ha^{-1} (Corley and Tinker, 2003). Alvarado *et al*. (2010) mentioned that seeds of such hybrids are more affordable to smallholder farmers, who can get such genetic materials as a chance to boost production and make better use of scarce land resources as compared to clones.

Expansion of current plantation area to increase oil palm production is no longer a feasible option. The only alternative to increase productivity is by improving yield and profitability per hectare on existing land. Therefore, the introduction of exotic germplasm to increase genetic variability was an important strategy for the oil palm breeding programme. Based on the extensive screening of MPOB germplasm, breeding for shorter RL and lower height increment (HTi) will open up the possibility of developing compact palms which are suitable for higher density planting resulting in increased yield per hectare. The objective of this study is to screen and evaluate all MPOB oil palm (*Elaeis guineensis* Jacq.) germplasms with good potential for compactness with reasonable yields as breeding materials. The compact trait will be introgressed into advanced breeding populations to generate value-added commercial planting materials.

MATERIALS AND METHODS

Materials

The *dura*s and *tenera*s used in this evaluation were from eight breeding trials planted at the MPOB Research Station Kluang, Johor, Malaysia involving eight germplasm collections from Nigeria, Cameroon, Zaire, Tanzania, Angola, Sierra Leone, Guinea and Ghana. However, only *dura* palms were evaluated from three trials namely, Madagascar, Senegal and Gambia. These trials were initiated from 1976 to 2000 with various statistical designs and replications as shown in *Table 1*.

TABLE 1. GERMPLASM TRIALS USED FOR COMPACT TRAIT EVALUATION

No.	Germplasm	Trial No.	Date planted	Statistical design	No. of replications
1.	Nigeria	0.150	Apr 1976	6 cubic lattice	3
2.	Cameroon	0.218	Nov 1986	RCBD	2
3.	Zaire	0.226	Jan 1987	RCBD	3
4.	Tanzania	0.256	Aug 1990	RCBD	4
5.	Madagascar	0.240	Jul 1990	CRD	1
6.	Angola	0.311	Apr 1994	RCBD	3
7.	Senegal	0.352	Jun 1996	ICRD	2
8.	Gambia	0.398	May 2000	Progeny row	1
9.	Sierra Leone	0.355	Jun 1996	RCBD	2
10.	Guinea	0.353	Jun 1996	RCBD	2
11.	Ghana	0.397	Apr 2000	RCBD	4

Note: RCBD - randomised complete block design.
CRD - completely randomised design.
ICRD – incomplete randomised design.

TABLE 2. OUTLINE OF ANALYSIS OF VARIANCE (ANOVA) AND VARIANCE COMPONENTS ESTIMATION

Source	df	Mean square	EMS
Family (g)	g-1	MS1	$\sigma^2_w + n'\sigma^2_g$
Within family (w)	g (n'-1)	MS2	σ^2_w

Note: n'- harmonic mean for palms, g - number of family or genotype, df - degree of freedom and EMS - expected mean squares.

With: $\sigma^2_g = \dfrac{MS1 - MS2}{n'}$

$\sigma^2_w = MS2$

Yield Record

Bunch yield was recorded from 36 months after field planting onwards with two rounds per month by taking readings of bunch weight (BWT) and bunch number (BNO) of individual palms. Fresh fruit bunch (FFB) refers to the weight of bunches produced by a particular palm (BWT x BNO).

Vegetative Measurement

One complete round of vegetative measurement using the non-destructive method was carried out eight years after field planting (Corley and Breure, 1981). RL was measured from the first rudimentary leaf at the petiole to the tip of the rachis. Meanwhile, palm height was measured from ground level to the base of frond 41. HTi is the height at year *t* divided by *t*-2, where *t* is the number of years after field planting.

Data Analysis

RL and HTi values from each trial were analysed by using analysis of variance (ANOVA), while the comparison between the germplasm means used Fisher's Least Significant Difference (LSD) at 5% level of probability.

Heritability of RL and HTi for each germplasm collection was estimated using the ANOVA variance components method. Variance components were estimated from appropriate expectations of mean squares in *Table 2*. Based on the variance components data, heritability estimates are as follows:

Phenotypic variance $(\sigma^2_p) = \sigma^2_g + \sigma^2_w$

Heritability $(h^2) = \dfrac{\sigma^2_g}{\sigma^2_g + \sigma^2_w} \times 100$

Heritability $(h^2_B) = 2h^2$

Intra-class correlation was used to estimate variance components and heritability (Falconer and Mackay, 1996). In full sib families, broad-sense heritability is the ratio of the total genetic variance to phenotypic variance is equal to $2h^2$.

The relationship between RL, HTi and selected traits were determined by simple correlation using the SAS software version 9.4. Correlations between traits of interest are to determine whether selection for one trait will have an effect on another.

RESULTS AND DISCUSSION

ANOVA

Tables 3 and *4* show mean squares for RL of *dura*s and *tenera*s of each collection, respectively. As for *dura*s, the ANOVA showed highly significant difference between families in all germplasms except for Gambia. This finding indicates that significant amount of genetic variability between families exists for RL. As for *tenera*s, there was a highly significant difference in RL between families in all collections except for Sierra Leone and Guinea. Therefore, Sierra Leone and Guinea germplasms could not be selected as the source of male parents for compact palm. The broad-sense heritability for RL of *dura*s ranged from 19.32% (Tanzania) to 100.00% (Madagascar). The heritability estimates for RL of *tenera*s were low to high, with the highest heritability for RL being recorded in Zaire germplasm (100.00%).

Mean squares for HTi of *dura*s and *tenera*s of each collection are presented in *Tables 5* and *6*, respectively. The ANOVA showed highly significant difference for HTi between families in all germplasms except for Madagascar in *dura*s. As for *tenera*s, there were highly significant differences in HTi between families in all collections except for Guinea. The results showed that there were variations in family effects for HTi in all germplasms excluding Guinea. The broad-sense heritability for HTi of *dura*s ranged from 28.51% (Tanzania) to 93.39% (Guinea), whilst those of *tenera*s were medium to high, with the highest heritability for HTi being recorded in Zaire and Sierra Leone (100.00%). This significant genetic variability suggests that selection based on HTi will produce good response if their variability could be exploited in the population (Okoye *et al*., 2009).

The broad-sense heritabilities of RL and HTi for both *dura*s and *tenera*s were high indicating good genetic control over the traits. This was expected as Breure and Corley (1983) mentioned that heritability appears high in vegetative characters. Besides that, high heritabilities were observed because the palms were derived from wild groves where the palms were highly variable. Corley and Tinker (2003) stated that the selection is likely to be more successful when the major proportion of total variation is due to genetic factors (broad-sense heritability). Therefore, it will be an advantage to select compact materials among *dura*s in Madagascar and among *tenera*s in Zaire germplasms.

Germplasm Performance

The frequency distribution of RL among *dura*s and *tenera*s, respectively is shown in *Figure 1.* The frequencies were close to normal distribution with mean values of 4.87 m for *dura*s and 5.46 m for *tenera*s. Meanwhile, *Figure 2* shows the frequency distribution of HTi for *dura*s and *tenera*s, respectively. The frequencies were normally distributed with mean values of 0.34 m yr^{-1} for *duras* and 0.40 m yr^{-1} for *tenera*s. RL and HTi values of 11 051 *dura*s from 11 germplasms and 3372 *tenera*s from eight germplasms involved were analysed (*Tables 7* and *8*). The Madagascar germplasm showed the shortest RL and was significantly different from other germplasms for *dura* (RL = 3.22 m, HTi = 0.21 m yr^{-1}). For *tenera*, Tanzania and Guinea germplasms showed the shortest RL compared to other germplasms. The coefficient of variation (CV) for both *dura* and *tenera* accessions were considerably low with most germplasms showing CV less than 18% for RL. For HTi, the CV ranged from 14.49% (Madagascar) to 35.93% (Tanzania) for *dura*s. As for *tenera*s, the CV ranged from 13.72% (Guinea) to 35.34% (Ghana). The CV observed among the germplasms for these respective traits evaluated indicates low genetic diversity within germplasms. Okoye *et al.* (2018) reported that differences in CV among the populations could be described by genotype, environment, or genotype-environment interaction.

Based on scatter plots for combination of both characters (RL and HTi) (*Figure 3*), six germplasms (Zaire, Ghana, Cameroon, Tanzania, Guinea and Madagascar) were located below the grand mean. However, Madagascar germplasm was the most compact evaluated for *duras. Figure 4* shows the scatter plots for combination of both characters. However, only those with FFB yield at more than 100 kg $palm^{-1}$ yr^{-1} were included in the analyses. Based on the scatter plot, the Tanzania germplasm was the most compact evaluated for *dura*s with reasonable yield. As for *tenera*s, the compact trait was shown by Zaire, Ghana and Cameroon and the most compact trait being shown by Tanzania germplasm (*Figure 5*). Based on *Figure 6*, compact trait with good yield was shown by Tanzania germplasm.

Correlations

Simple correlation coefficients between RL and selected traits for bunch yield and vegetative characters for *dura*s and *tenera*s are shown in *Tables 9* and *10,* respectively. Correlation analysis was conducted to show how close the relationship between two variables. When such association exists, a change in the value of one trait directly affects the value of the other due to strong selection pressures in breeding (Simmonds, 1986). In general, correlation between RL and these selected traits showed the same trend as observed in both *dura*s and *tenera*s. RL correlated positively and significantly with FFB and average bunch weight (ABW). There were negative relationships between RL and BNO in most of the germplasms.

TABLE 3. MEAN SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES FOR RACHIS LENGTH OF *Dura*s

Source	df	NGA	df	CMR	df	ZAR	df	TZA	df	MDG	df	AGO	df	SEN	df	GAM	df	SLE	df	GUI	df	GHA
Family	145	1.8308**	89	1.5767**	55	0.8897**	50	0.9839**	10	0.5225**	29	4.9892**	29	0.6275**	31	0.1180ns	29	2.9526**	20	1.3101**	49	5.8964**
Within family	2 363	0.2732	1 263	0.1987	657	0.1668	1 962	0.1889	6	0.0357	710	0.2785	317	0.1298	151	0.1385	517	0.1805	369	0.1676	2388	0.2040
σ^2_f		0.0908		0.0918		0.0570		0.0202		0.3284		0.1913		0.0551		-		0.1521		0.0615		0.1170
σ^2_w		0.2732		0.1987		0.1668		0.1889		0.0357		0.2785		0.1298		-		0.1805		0.1676		0.2040
Total		0.3640		0.2905		0.2238		0.2091		0.3641		0.4698		0.1849		-		0.3326		0.2291		0.3210
Heritability (h^2_B)		49.89%		63.20%		50.94%		19.32%		100.00%		81.44%		59.60%		-		91.46%		53.69%		72.90%

Note: ** Significant at P≤0.01, otherwise non-significant (ns).
NGA - Nigeria, CMR - Cameroon, ZAR - Zaire, TZA - Tanzania, MDG - Madagascar, AGO - Angola, SEN - Senegal, GAM - Gambia, SLE - Sierra Leone, GUI - Guinea, GHA - Ghana.
df - degree of freedom.

TABLE 4. MEAN SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES FOR RACHIS LENGTH OF *Tenera*s

Source	df	NGA	df	CMR	df	ZAR	df	TZA	df	AGO	df	SLE	df	GUI	df	GHA
Family	145	1.3512**	57	1.0680**	12	0.9898**	50	0.3473**	24	1.3825**	10	0.5691ns	10	0.5589ns	35	0.6211**
Within family	1 889	0.2408	266	0.1989	32	0.2162	515	0.1881	160	0.2859	15	0.3174	9	0.1812	131	0.2392
σ^2_f		0.0798		0.1583		0.2566		0.0146		0.1501		-		-		0.0859
σ^2_w		0.2408		0.1898		0.2162		0.1881		0.2859		-		-		0.2392
Total		0.3206		0.3481		0.4728		0.2027		0.4360		-		-		0.3251
Heritability (h^2_B)		49.78%		90.95%		100.00%		14.41%		68.85%		-		-		52.85%

Note: ** Significant at P≤0.01, otherwise non-significant (ns).
NGA - Nigeria, CMR - Cameroon, ZAR - Zaire, TZA - Tanzania, AGO - Angola, SLE - Sierra Leone, GUI - Guinea,
GHA - Ghana.
df - degree of freedom.

TABLE 5. MEAN SQUARES, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES FOR HEIGHT INCREMENT OF *Dura*s

Source	df	NGA	df	CMR	df	ZAR	df	TZA	df	MDG	df	AGO	df	SEN	df	GAM	df	SLE	df	GUI	df	GHA
Family	145	5.4049**	89	0.8855**	55	0.5857**	50	1.1100**	10	0.0444ns	29	2.7946**	29	1.2722**	31	0.8180**	29	2.8248**	20	3.3127**	49	3.1195**
Within family	2 363	0.5115	1 263	0.1304	657	0.1104	1 962	0.1471	6	0.0166	710	0.3108	317	0.2867	151	0.2346	517	0.3502	369	0.1919	2388	0.2154
σ^2_f		0.28381		0.05028		0.03749		0.02446		-		0.10086		0.10945		0.10286		0.13578		0.16811		0.05969
σ^2_w		0.51151		0.13041		0.11039		0.14713		-		0.31080		0.28665		0.23459		0.35019		0.19189		0.21538
Total		0.79532		0.18069		0.14788		0.17159		-		0.41166		0.39610		0.33745		0.48597		0.36000		0.27507
Heritability (h^2_B)		71.37%		55.65%		50.70%		28.51%		-		49.00%		55.26%		60.96%		55.88%		93.39%		43.40%

Note: ** Significant at P≤0.01, otherwise non-significant (ns).
NGA - Nigeria, CMR - Cameroon, ZAR - Zaire, TZA - Tanzania, MDG - Madagascar, AGO - Angola, SEN - Senegal, GAM - Gambia,
SLE - Sierra Leone, GUI - Guinea, GHA - Ghana. df - degree of freedom.

TABLE 6. MEAN SQUARE, VARIANCE COMPONENTS AND HERITABILITY ESTIMATES FOR HEIGHT INCREMENT OF *Tenera*s

Source	df	NGA	df	CMR	df	ZAR	df	TZA	df	AGO	df	SLE	df	GUI	df	GHA
Family	145	4.8423**	57	0.2902**	12	0.4059**	50	0.3585**	24	1.4995**	10	1.1294**	10	0.4815ns	35	0.5870**
Within family	1 889	0.4819	266	0.0958	32	0.0672	515	0.1103	160	0.2450	15	0.2788	9	0.1786	131	0.2223
σ^2_f		0.31326		0.03504		0.11238		0.02269		0.17171		0.37742		-		0.08201
σ^2_w		0.48193		0.09581		0.06715		0.11034		0.24501		0.27880		-		0.22234
Total		0.79519		0.13085		0.17953		0.13303		0.41672		0.65622		-		0.30435
Heritability (h^2_B)		78.79%		53.56%		100.00%		34.11%		82.41%		100.00%		-		53.89%

Note: ** Significant at $P \leq 0.01$, otherwise non-significant.
NGA - Nigeria, CMR - Cameroon, ZAR - Zaire, TZA - Tanzania, AGO - Angola, SLE - Sierra Leone, GUI - Guinea, GHA - Ghana. df - degree of freedom.

TABLE 7. EVALUATION OF COMPACTNESS AMONG *Dura*s IN THE MPOB GERMPLASM

No.	Germplasm	N	Rachis length (m)		Height increment (m yr^{-1})		Yield performance			Bunch analysis		
			Mean	Coeff. of variation (CV)	Mean	Coeff. of variation (CV)	Fresh fruit bunch (kg palm^{-1} yr^{-1})	Bunch number (No.)	Average bunch weight (kg palm^{-1} yr^{-1})	Mesocarp to fruit (%)	Oil to bunch (%)	Oil yield (kg)
1.	Nigeria	2 507	**5.92^{a}**	10.19	0.40^{b}	22.45	153.74^{a}	12.85^{f}	12.60^{b}	48.21^{b}	15.89^{a}	24.26^{a}
2.	Cameroon	1 334	4.62^{c}	11.56	0.27^{d}	25.37	91.83^{ef}	14.02^{d}	6.77^{e}	42.24^{cd}	11.95^{de}	11.15^{e}
3.	Zaire	709	4.73^{c}	9.93	0.25^{e}	25.43	92.21^{def}	12.92^{ef}	7.44^{d}	48.80^{ab}	15.05^{b}	14.47^{c}
4.	Tanzania	2 013	4.41^{d}	10.37	**0.19^{f}**	35.93	124.04^{b}	13.33^{def}	9.45^{c}	47.65^{b}	13.92^{c}	16.74^{b}
5.	Madagascar	17	**3.22^{i}**	18.09	0.21^{f}	14.49	14.01^{h}	5.19^{g}	2.78^{g}	36.82^{ef}	8.47^{g}	1.29^{h}
6.	Angola	733	5.56^{b}	12.21	0.45^{a}	23.63	159.73^{a}	12.40^{f}	13.34^{a}	50.20^{a}	15.66^{ab}	24.97^{a}
7.	Senegal	359	3.87^{g}	11.41	**0.47^{a}**	22.30	100.11^{d}	20.01^{b}	5.04^{f}	34.77^{g}	8.37^{g}	6.64^{g}
8.	Gambia	183	3.52^{h}	10.44	0.46^{a}	20.89	66.17^{g}	21.30^{a}	3.12^{g}	38.11^{e}	11.14^{f}	7.60^{g}
9.	Sierra Leone	547	4.15^{e}	13.81	0.45^{a}	25.61	115.09^{c}	17.39^{c}	6.77^{e}	35.82f^{g}	10.61^{f}	10.03^{ef}
10.	Guinea	390	4.00^{f}	11.90	0.34^{c}	29.34	98.20^{de}	13.00^{def}	7.69^{d}	43.96^{c}	12.06^{d}	12.74^{d}
11.	Ghana	2 259	4.69^{c}	11.80	0.27^{de}	31.83	87.87^{f}	13.89^{de}	6.60^{e}	41.77^{d}	11.21^{ef}	9.23^{f}
12.	Advanced *Dura*	382	5.50	11.19	0.40	32.65	103.38	7.88	13.23	59.14	16.80	17.48
	Mean	11 051	4.87	11.17	0.34	27.19						
	LSD		0.13		0.02							

Note: Means with the same letter are not significantly different at $p \leq 0.05$ based on Least Significant Difference (LSD).
Figures in bold within the mean column are minimum and maximum values.

TABLE 8. EVALUATION OF COMPACTNESS AMONG *Tenera*s IN THE MPOB GERMPLASM

No.	Germplasm	N	Rachis length (m)		Height increment (m yr^{-1})		Yield performance			Bunch analysis		
			Mean	Coeff. of variation (CV)	Mean	Coeff. of variation (CV)	Fresh fruit bunch (kg $palm^{-1}$ yr^{-1})	Bunch number (No.)	Average bunch weight (kg $palm^{-1}$ yr^{-1})	Mesocarp to fruit (%)	Oil to bunch (%)	Oil yield (kg)
1.	Nigeria	2 035	**5.90**^{a}	9.58	0.40^{b}	22.42	161.98^{b}	14.72^{b}	11.49^{b}	75.04^{a}	22.69^{a}	36.46^{a}
2.	Cameroon	324	4.80^{c}	12.24	0.26^{c}	22.90	101.59^{d}	14.81^{b}	7.18^{f}	66.27^{d}	17.76^{d}	17.90^{e}
3.	Zaire	45	5.03^{b}	13.00	0.24^{c}	27.78	91.10^{d}	10.67^{e}	8.53^{e}	72.04^{bc}	22.40^{a}	21.32^{d}
4.	Tanzania	566	**4.44**^{d}	10.14	**0.19**^{d}	32.07	130.89^{c}	12.89^{cd}	10.38^{cd}	70.25^{c}	19.66^{bc}	25.32^{c}
5.	Angola	189	5.75^{a}	11.48	**0.45**^{a}	24.69	161.23^{b}	12.52^{d}	13.22^{a}	73.76^{ab}	22.50^{a}	37.28^{a}
6.	Sierra Leone	26	4.74^{c}	13.66	0.40^{b}	32.57	193.16^{a}	18.17^{a}	11.01^{bc}	75.08^{a}	19.31^{bc}	31.92^{b}
7.	Guinea	20	4.49^{d}	13.72	0.39^{b}	13.72	139.92^{c}	14.18^{bc}	9.98^{d}	75.57^{a}	20.45^{b}	32.98^{b}
8.	Ghana	167	4.90^{bc}	11.54	0.26^{c}	35.34	95.28^{d}	12.48^{d}	7.86^{ef}	70.28^{c}	18.95^{cd}	16.54^{e}
9.	Standard cross	19	5.04	9.87	0.49	21.17	174.75	12.31	14.33	82.85	22.15	41.67
	Mean	3 372	5.46	10.21	0.40	24.87						
	LSD		0.20		0.03							

Note: Means with the same letter are not significantly different at $p \leq 0.05$ based on Least Significant Difference (LSD).
Figures in bold within the mean column are minimum and maximum values.

TABLE 9. PHENOTYPIC CORRELATION OF RACHIS LENGTH TO BUNCH YIELD AND VEGETATIVE CHARACTERS OF *Dura*

	FFB	BNO	ABW	BI	FP	PCS	LL	LW	LN	HT	DIA
RL-NGA	0.17**	-0.16**	0.31**	-0.22**	-0.20**	0.63**	0.33**	0.52**	0.49**	0.25**	0.19**
RLCMR	0.36**	0.05ns	0.42**	-0.01ns	-0.23**	0.52**	0.52**	0.38**	0.47**	0.26**	0.22**
RL-ZRE	0.15**	-0.13**	0.39**	-0.20**	-0.17**	0.49**	0.37**	0.50**	0.25**	0.29**	0.27**
RL-TZA	0.39**	0.15**	0.39**	0.22**	0.04ns	0.38**	0.26**	0.22**	0.47**	0.36**	0.12**
RL-MDG	0.36ns	0.37ns	-0.41ns	0.26ns	0.60*	0.42ns	0.60*	0.34ns	0.75**	0.33ns	0.20ns
RL-AGO	0.28**	-0.25**	0.46**	-0.15**	-0.39**	0.61**	0.43**	0.37**	0.55**	0.10ns	0.26**
RL-SEN	0.18**	-0.07ns	0.34**	-0.08ns	-0.24**	0.60**	0.47**	0.18**	0.34**	-0.06ns	0.23**
RL-GAM	0.15*	-0.01ns	0.31**	-0.02ns	-0.23**	0.50**	0.15*	0.26**	0.30**	0.05ns	0.28**
RL-SLE	0.62**	0.20**	0.56**	0.28**	-0.43**	0.75**	0.48**	0.47**	0.63**	0.19**	0.18**
RL-GUI	0.37**	-0.03ns	0.50**	0.13*	-0.37**	0.59**	0.45**	0.35**	0.40**	0.17**	0.19**
RL-GHA	0.27**	-0.16**	0.48**	-0.03ns	-0.48**	0.70**	0.40**	0.46**	0.50**	0.17**	0.10**

Note: *, ** Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively. Otherwise, non-significant (ns).
FFB - fresh fruit bunch, BNO - bunch number, ABW - average bunch weight, BI - bunch index, FP - frond production, PCS - petiole cross-section, LL - leaflet length, LW - leaflet width, LN - leaflet number, HT - palm height, DIA - trunk diameter.

TABLE 10. PHENOTYPIC CORRELATION OF RACHIS LENGTH TO BUNCH YIELD AND VEGETATIVE CHARACTERS OF *Tenera*

	FFB	BNO	ABW	BI	FP	PCS	LL	LW	LN	HT	DIA
RL-NGA	0.18**	-0.12**	0.27**	-0.17**	0.18**	0.60**	0.39**	0.35**	0.51**	0.02ns	0.13**
RL-CMR	0.42**	-0.10ns	0.58**	0.04ns	-0.42ns	0.65**	0.58**	0.50**	0.56**	0.24**	0.18*
RL-ZRE	0.59**	0.19ns	0.71**	0.15ns	-0.29ns	0.88**	0.58**	0.84**	0.70**	0.30*	0.28ns
RL-TZA	0.44**	0.21**	0.39**	0.28**	0.002ns	0.41**	0.28**	0.23**	0.62**	0.36**	0.15**
RL-AGO	0.32**	-0.10ns	0.34**	-0.10ns	-0.37**	0.62**	0.42**	0.38**	0.44**	0.27**	0.12ns
RL-SLE	0.40*	-0.23ns	0.58**	0.40*	-0.53**	0.30ns	0.25ns	0.22ns	0.55**	-0.10ns	-0.24ns
RL-GUI	0.44ns	0.11ns	0.58**	0.14ns	0.03ns	0.69**	0.13ns	0.21ns	0.84**	0.65**	0.18ns
RL-GHA	0.20*	-0.26**	0.49**	-0.12ns	-0.48**	0.70**	0.31**	0.62**	0.65**	0.39**	0.14ns

Note: *, ** Significant at P≤0.05 and P≤0.01, respectively. Otherwise, non-significant (ns).
FFB - fresh fruit bunch, BNO - bunch number, ABW - average bunch weight, BI - bunch index, FP - frond production, PCS - petiole, cross-section, LL - leaflet length, LW - leaflet width, LN - leaflet number, HT - palm height, DIA - trunk diameter.

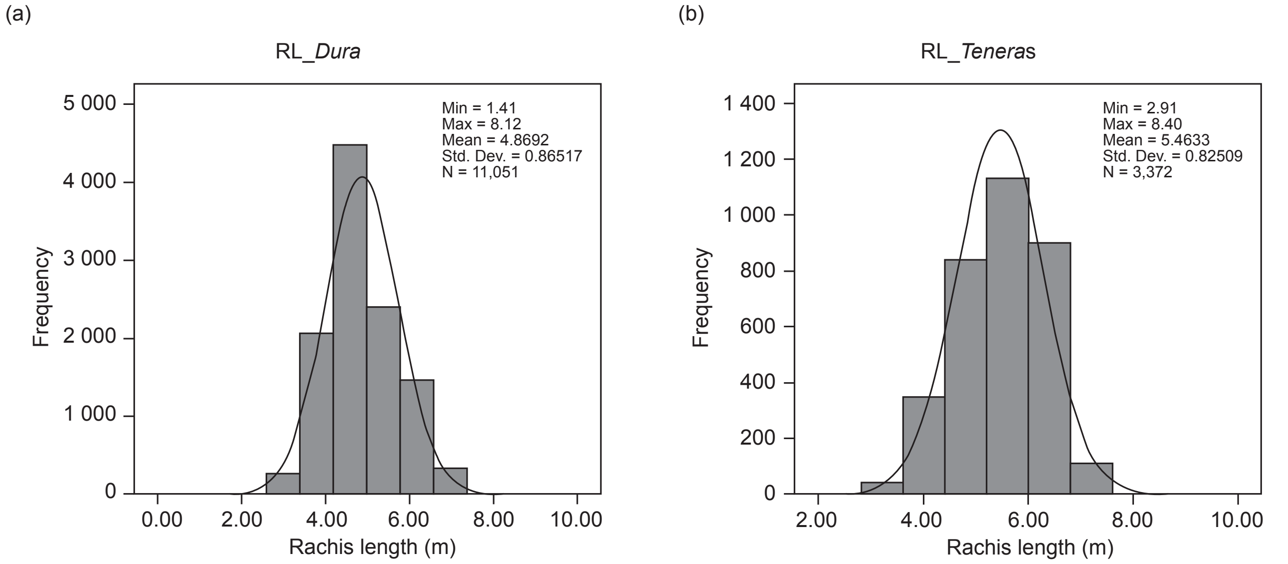


Figure 1. Frequency distribution of rachis length (RL) among duras *(a) and* teneras *(b) in MPOB germplasms.*

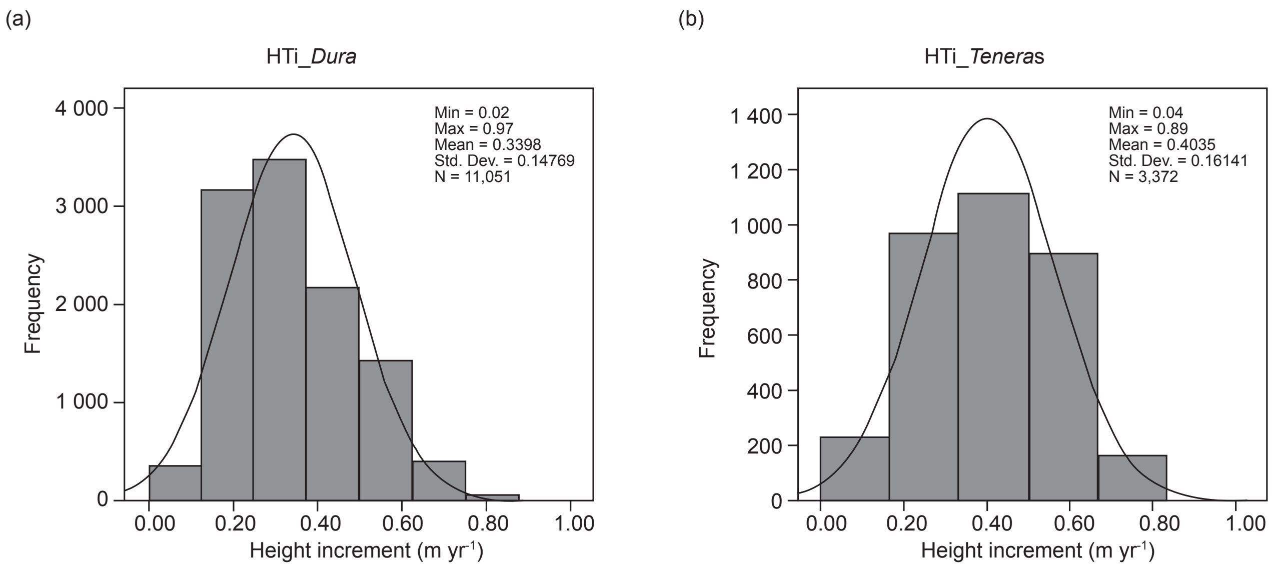
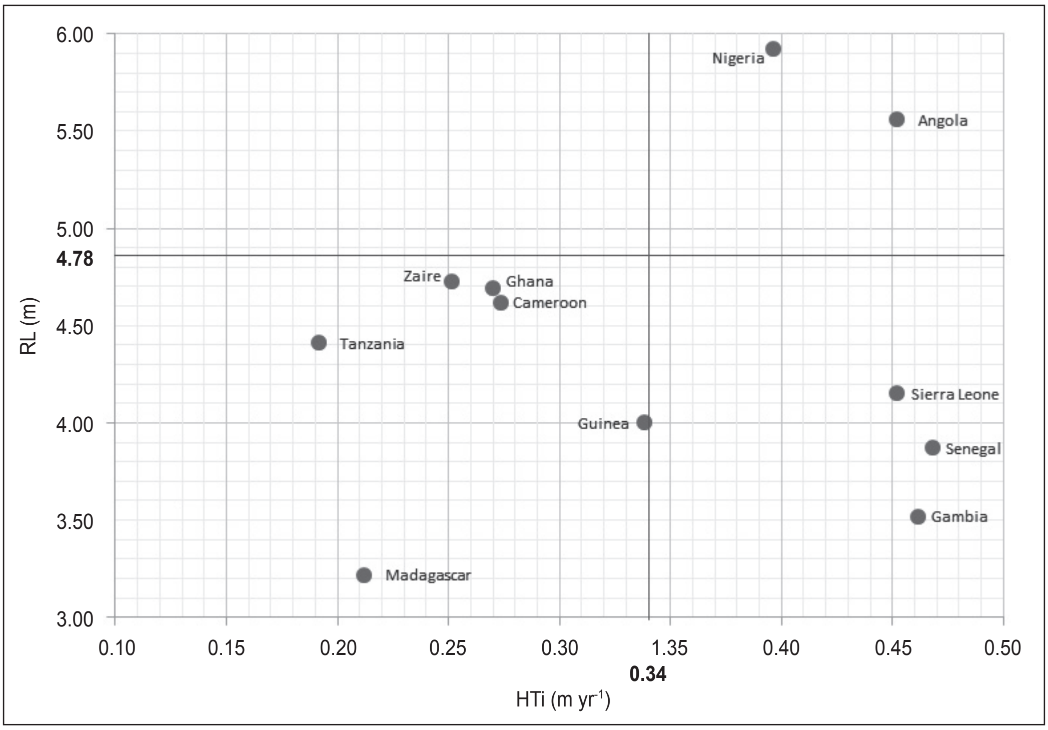
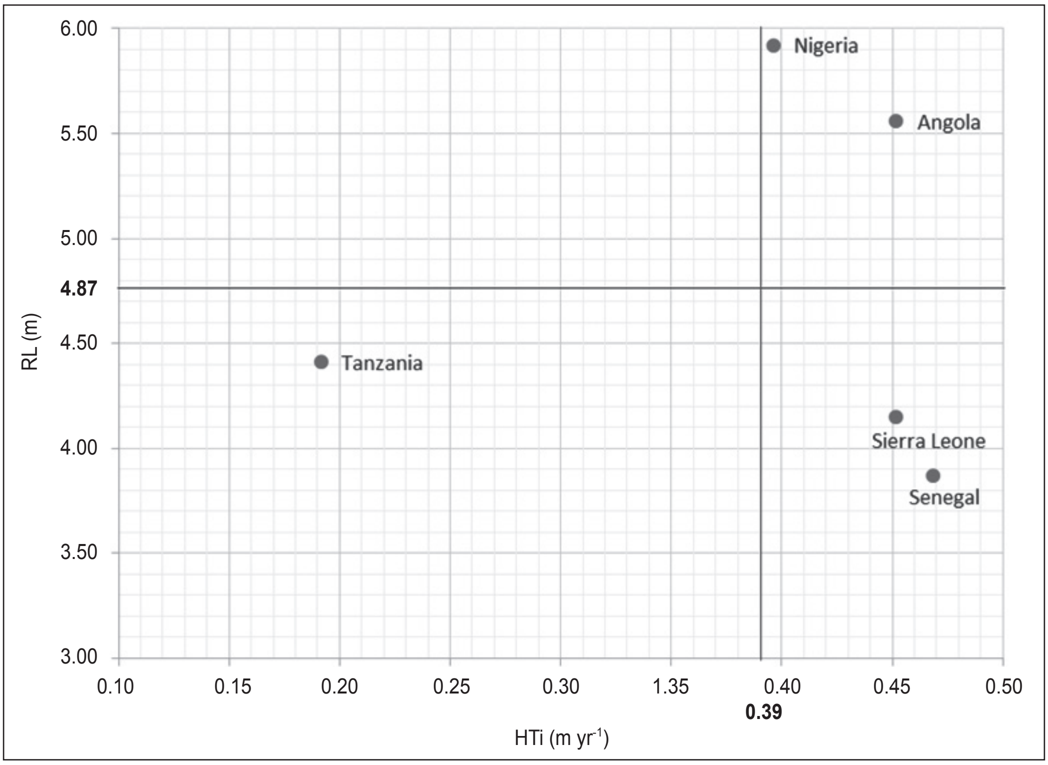


Figure 2. Frequency distribution of height increment (HTi) among duras *(a) and* teneras *(b) in MPOB germplasms.*



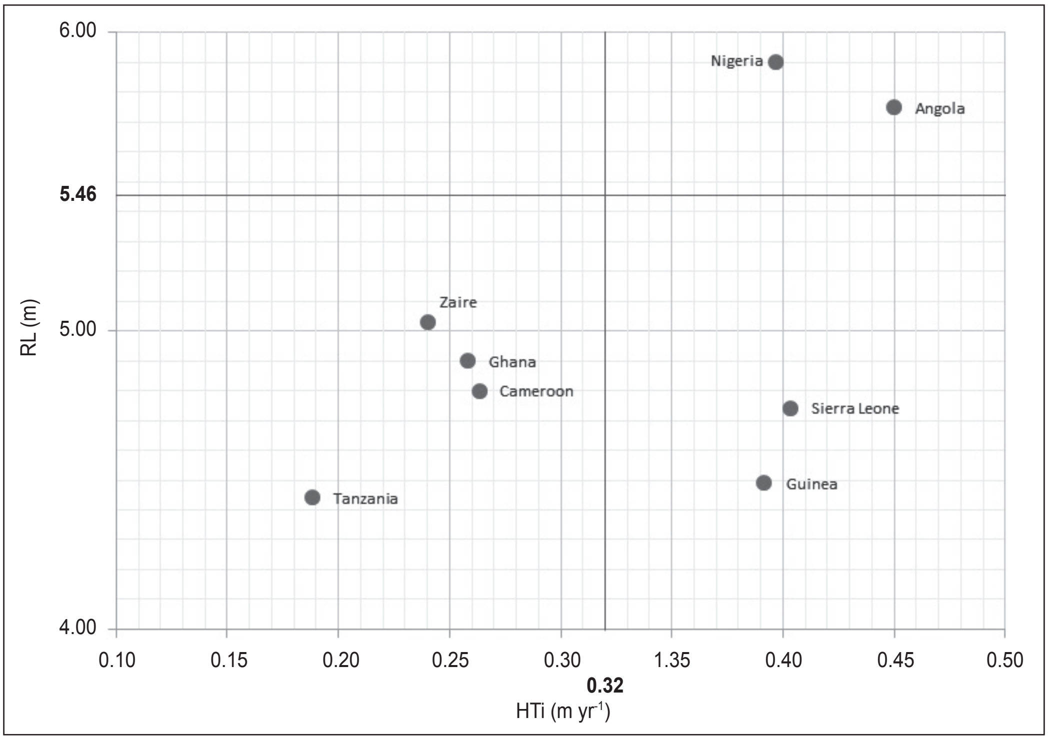
Note: (–) - grand mean.
RL - rachis length.
HTi - height increment.

Figure 3. Scatter plot of compact palms excluding duras *with fresh fruit bunch yield of less than 100 kg palm^{-1} yr^{-1} in MPOB germplasm.*



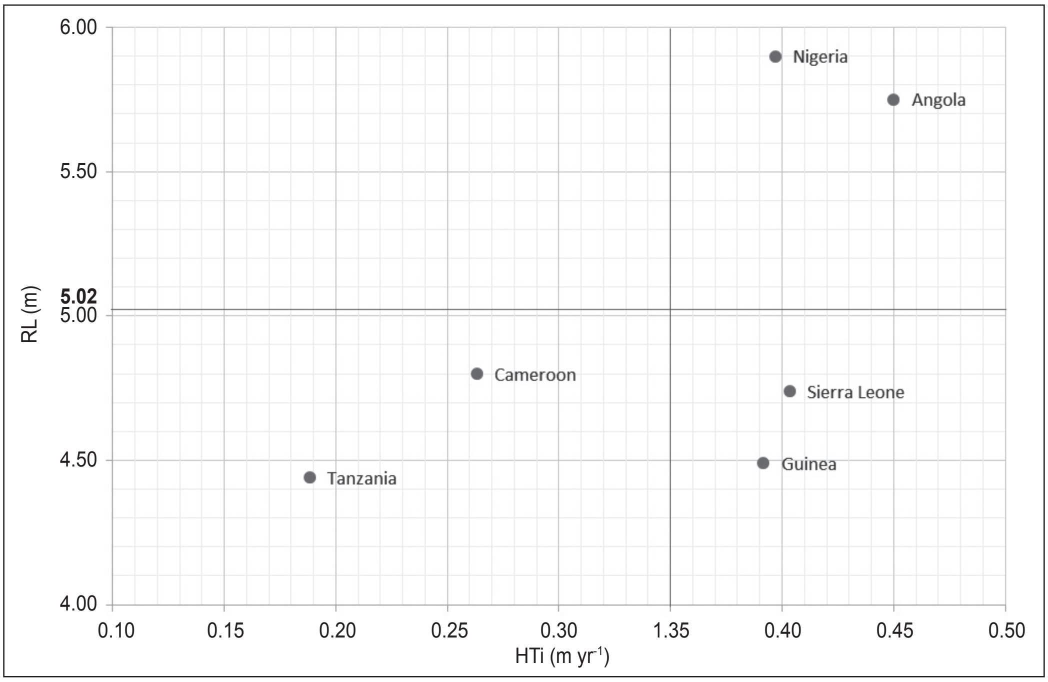
Note: (–) - grand mean.
RL - rachis length.
HTi - height increment.

Figure 4. Scatter plot of compact palms among duras *in MPOB germplasm.*



Note: (–) - grand mean. RL - rachis length. HTi - height increment.

Figure 5. Scatter plot of compact palms among teneras *in MPOB germplasm.*



Note: (–) - grand mean. RL - rachis length. HTi - height increment.

Figure 6. Scatter plot of compact palms excluding teneras *with fresh fruit bunch yield of less than 100 kg palm^{-1} yr^{-1} in MPOB germplasm.*

RL of all germplasms was negatively correlated to frond production (FP) except for Madagascar which was positive and high (>0.50) in *dura*s. As for *tenera*s, RL was found to be positively and significantly correlated with frond production in Nigeria. Correlation analysis also showed strong relationships for other pairs of traits. There was medium to high positive correlation between RL and petiole cross-section (PCS), leaflet length (LL), leaflet width (LW) and leaf number (LN). However, there was low to medium positive correlation between RL and palm height (HT) among the germplasms. Selection of one trait will bring along the effect of other traits. Therefore, selecting for low RL coincided with lower height increment. Isa *et al.* (2008) reported that the oil palms with lower HTi found in some Nigerian derived progenies are amenable to easier harvesting and mechanisation. The correlation between RL and trunk diameter (DIA) was low to medium amongst the germplasm in *dura*s. It was also noted that there was no significant correlation between RL of most germplasms to DIA in *tenera*s.

CONCLUSION

Based on the results from this study, the Tanzania germplasm showed good potential as breeding material for compactness with reasonable yield. It is envisaged that the introduction of these materials into commercial populations would improve planting materials in this country. Further efforts would be to introgress the short RL (less than 5 m) and low HTi (less than 0.3 m yr^{-1}) palms into advanced breeding populations. Through the new combination, the best materials would be further evaluated and later exploited for future commercial seed production. It is recommended that progeny testing and evaluation of genotype-environment (GxE) interactions should be obtained before the germplasm can be used commercially.

ACKNOWLEDGEMENT

The authors would like to thank the Director-General of MPOB for permission to publish this article.

REFERENCES

Alvarado, A; Escobar, R and Peralta, F (2010). ASD's oil palm breeding program and its contributions to the oil palm industry. *ASD Oil Palm Papers*, *34*: 1-16.

Barcelos, E; De Almeida Rios, S; Cunha, R N V; Lopes, R; Motoike, S Y; Babiychuk, E; Skirycz, A and Kushnir, S (2015). Oil palm natural diversity and the potential for yield improvement. *Front. Plant Sci*., *6*: 190.

Breure, C J and Corley, R H V (1983). Selection of oil palms for high density planting. *Euphytica*, *32*: 177-186.

Corley, R H V and Breure, C J (1981). *Measurements in Oil Palm Experiments.* Internal Report. Unipamol Malaysia and Harisons Fleming Advisory Services. 17 pp.

Corley, R H V and Tinker, P B (2003). *The Oil Palm*. Oxford: John Wiley and Sons. 562 pp.

Falconer, D S and Mackay, T F C (1996). *Introduction to Quantitative Genetics*. Fourth edition. Longmans Green, Harlow, Essex, UK. 464 pp.

Guzman, N and Peralta, F (2010). Advances in tissue culture propagation of compact oil palm clones in Costa Rica. *Proc. of the Advances in Oil Palm Tissue Culture*. Yogyakarta, Indonesia. p. 59-66.

Isa, Z A; Mohd Din, A; Maizura, I; Noh A; Kushairi, A and Rajanaidu, N (2006). PS12: Breeding population for high oleic acid palm oil. *MPOB Information Series No. 313*: 2 pp.

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

Jusoh, L; Mohd Noor, M; Mohd Tayeb, D and Kushairi, A (2003). Economics of higher planting in oil palm plantations. *Oil Palm Industry Economic J. Vol. 3(2)*: 32-39.

Kushairi, A; Rajanaidu, N and Jalani, B S (1999). PORIM Series 2. *PORIM Information Series No. 101*: 2 pp.

Kushairi, A; Rajanaidu, N; Mohd Din, A; Isa, Z A; Noh, A and Junaidah, J (2003). PS6: Breeding populations selected for large fruit *dura*s. *MPOB Information Series No. 184*: 2 pp.

Kushairi, A; Singh, R and Ong-Abdullah, M (2018). The oil palm industry in Malaysia: Thriving with transformative technologies. *J. Oil Palm Res. Vol. 29 (2)*: 431-439.

Noh, A; Kushairi, A; Mohd Din, A; Maizura, I; Isa, Z A and Rajanaidu, N (2005). PS10: Breeding populations selected for long stalk. *MPOB Information Series No. 263*: 2 pp.

Noh, A; Rajanaidu, N; Kushairi, A; Mohd Rafii, Y; Mohd Din, A; Mohd Isa, Z A and Saleh, G (2002). Variability in fatty acid composition, iodine value and carotene content in the MPOB oil palm germplasm collection from Angola. *J. Oil Palm Res. Vol. 14*: 18-23.

Okoye, M N; Okwuagwu, C O and Uguru, M I (2009). Population improvement for fresh fruit bunch yield and yield components in oil palm (*Elaeis guineensis* Jacq.). *American-Eurasian J. Scientific Research*, *4(2)*: 59-63.

Okoye, M N; Bakoume, C; Uguru, M I and Singh, R (2018). Genetic diversity and relatedness of oil palm progenies determined by microsatellite and agronomic markers. *African J. Biotechnology*, *17(18)*: 614-625.

Palat, T; Chayawat, N and Corley, R H V (2012). Maximising oil palm yield by high density planting and thinning. *The Planter*, *88*: 241-256.

Phalan, B; Green, R E; Dicks, L V; Dotta, G; Feniuk, C; Lamb, A; Strassburg, B B N; Williams, D R; Zu Ermgassen, E K H J and Balmford, A (2016). How can higher-yield farming help to spare nature? Mechanisms to link yield increases with conservation. *Science*, *351(6272)*: 450-451.

Rajanaidu, N; Ainul, M M; Kushairi, A and Mohd Din, A (2013). Historical review of oil palm breeding for the past 50 years - Malaysian journey. *Proc. of the International Seminar on Oil Palm Breeding - Yesterday, Today and Tomorrow*. p. 11-28.

Rajanaidu, N (1986). The oil palm (*Elaeis guineensis*) collections in Africa. *Proc. of the International Workshop on Oil Palm Germplasm and Utilisation*. PORIM, Bangi. p. 59-83.

Rajanaidu, N and Rao, V (1987). Oil palm genetic collections: Their performance and use to the industry. *Proc. of the International Oil Conference in Agriculture*. p. 59-85.

Rajanaidu, N; Kushairi, A; Rafii, M; Mohd Din, A; Maizura, I and Jalani, B S (2000). Oil palm breeding and genetic resources. *Advances in Oil Palm Research* (Yusof, B; Jalani, B S and Chan, K W eds.). Vol. 1. MPOB, Bangi. p. 171-237.

Samsul, K R; Zamzuri, I; Fadila, A M; Nor Azwani, A B; Naqiudin, M H; Dalilah, A B and Tarmizi, A H (2018). Clonal Palm Series 2 (CPS2). *MPOB Information Series No. 782*: 2 pp.

Simmonds, N W (1986). *Principles of Crop Improvement*. Singapore: ELBS. 408 pp.

Woittiez, L S; Van Wijk, M T; Slingerland, M; Van Noorwijk, M and Giller, K E (2017). Yield gaps in oil palm: A quantitative review of contributing factors. *Europ. J. Agronomy*, *83*: 57-77.

Zamzuri, I (2011). MPOB clonal propagation programme. *Proc. of the International Seminar on Breeding for Sustainability in Oil Palm*. MPOB, Bangi. p. 110-124.