ESTIMATES OF REPEATABILITY AND PATH COEFFICIENT OF BUNCH AND FRUIT TRAITS IN BANG BOET *Dura* OIL PALM

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ABSTRACT

A study was conducted to estimate repeatability, minimum number of evaluations to which a trait should be subjected, and the inter-relationship of 19 traits related to bunch and fruit in Bang Boet dura *oil palms. Repeatability values were found varying between 0.098 - 0.691. The optimum number of bunches for observation of bunch weight, fruit weight per bunch, stalk weight per bunch, number of fruits per bunch, weight of large size fruits, and number of large size fruits were three to six bunches, while the number to assess weight of small size fruits, weight of medium size fruits, number of medium size fruits and number of small size fruits were 7-11 bunches. The number of bunches for determing percentage of crude palm oil and palm kernel oil per bunch should be four and eight bunches, respectively, whereas the optimum number of fruits for observation of kernel thickness, fruit width, fruit length, weight per fruit, percentages of mesocarp, shell and kernel were four to nine fruits, and for endocarp and mesocarp thickness were 18-22 fruits. High positive correlations were observed between bunch weight and fruit weight per bunch, bunch weight and stalk weight per bunch, fruit weight per bunch and weight of large size fruits, bunch weight and weight of large size fruits, and fruit weight per bunch and number of large size fruits, with the values of 0.98, 0.92, 0.91, 0.88 and 0.88, respectively. Path coefficient analysis showed that oil palm yield was directly influenced by bunch weight and number of bunches per plant. Oil palm bunch weight was determined mainly by fruit weight per bunch, which was directly affected by weight of large size fruits. High percentage of mesocarp per fruit influenced the percentage of oil per bunch. Oil palm breeders can apply this information to select for high yield through these yield components.*

Keywords: Bang Boet *dura* oil palm, correlation, repeatability, path coefficient.

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INTRODUCTION

African oil palm (*Elaeis guineensis* Jacq.) is a perennial crop plant that originated from West and Central Africa, which is located between 16°N and 15°S of the equator. The plant adapts well to a wet tropical climate of the coastline (Hartley, 1988). Besides being used as cooking oil, palm oil is also used as a main raw material for biodiesel.

Historically, four *dura* seedlings were introduced from Reunion and Mauritius to Bogor, Indonesia in 1848 (Hartley, 1988). Seeds from these plants were widely distributed. One set was planted at Deli in Sumatra and was thus named 'Deli palm' (Corley and Tinker, 2003). Although the Deli *dura*, has a thick kernel shell, it has been used as a mother palm for almost all major oil palm commercial hybrid seed production (Soh *et al*., 2003). In 1937, seeds

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from Deli palms were introduced into Thailand and a few were grown at Bang Boet Farm - now known as the Sitthiporn Kriddakara Research Centre of Kasetsart University. Their *dura* progenies, known as Bang Boet *dura* were employed as a mother stock to cross with *pisifera* palms introduced from abroad or selected from the progenies of superior *tenera* clones. A number of *tenera* plants were produced and grown in the southern part of Thailand thus establishing one of the first oil palm plantations in the country.

The oil palm is a perennial tree. Each breeding cycle takes about 19 years of evaluation in a large area, in order to select superior clones (Wong and Bernardo, 2008). Since each trait can be evaluated with different precision and accuracy, an optimum number of measurements should be determined in order to save time and money required for the evaluation process. One way to identify the suitable number of measurements is through the calculation of repeatability (R). Repeatability reflects similarity among the phenotypic values observed in different periods of the same individual (Falconer and Mackay, 1996). Repeatability estimates help to ascertain an optimum number of repeated measurements of traits to obtain sufficient information for data evaluation to make a decision on such cultivars or crosses. The coefficient of repeatability also largely defines the upper limit of heritability (Dohm, 2002). It can be estimated without much experimental sophistication (Albuquerque *et al*., 2004). From a statistical point of view, repeatability can be defined as correlation between measurements on the same individual whose evaluations were repeated over time or space (Hansche, 1983). Breeders are interested in repeatability coefficient because it can help increasing accuracy in measurement of traits with reasonable time and effort. De Souza *et al*. (2003) determined repeatability and the minimum number of evaluations in five traits related to bunch, and berry yield of grapevine. The estimated repeatability values ranged from 0.4750 – 0.8372, giving the coefficient of determination from 81.9% to 96.26%. Total soluble solid, total tritrable acidity and bunch length showed the R values of 0.52, 0.50 and 0.47, giving the optimum number of observations at 8, 9 and 10 cycles, respectively. Da Costa (2004) determined coefficients of R and the minimum number of evaluations for mango and found that fruit longitudinal diameter (FLD), fruit transversal diameter (FTD), the ratio of FLD/FTD and stone longitudinal diameter all gave the R values of 0.91 and required two evaluations to attain a decisive evaluation. Pulp weight and skin weight were lower in R values, which required a minimum of four evaluations, while the total number of fruits per tree and fruit production per tree gave the R of 0.51 and 0.53 with six and five recommended evaluations, respectively. Recently, Cedillo *et al*. (2008) worked on repeatability and the correlation of African oil palm using six trees of five *dura* and one *tenera*. The data were collected on number of bunches and five-year yield during 1992 to 1996. They found that at least four years of evaluation (1992-1995 or 1993-1996) gave sufficient repeatability of 0.64 and 0.68, with the necessary coefficients of reliability of 87.6% and 89.6%, respectively. Evaluation of *dura* oil palm is a breeder's common practice, since the plants are compared in each cycle of selection as well as in seed production.

In plant breeding, it is also interesting to measure relationship between traits. This is often done through the calculation of correlation coefficient, which is a measurement of linear relationship between two dependent variables, giving a joint response of -1 to +1 (Steel *et al*., 1997). It is positive when the two variables vary in the same direction and negative when in the opposite direction. The genetic correlation involves associations of heritable nature, and is consequently of importance to plant and animal improvement programs.

Trait relationship can also be done through path analysis, in order to explain the effect of independent variables (X_i) on dependent variables (Y_i). In oil palm, the independent variables are yield components, *i.e.* number of bunches per year, number of fruits per bunch, average fruit weight and axial bunch weight. They can show both direct and indirect effects on annual bunch yield, the dependent variable.

In this study, we determined the optimum number of bunches and fruits required for data collection of traits related to yield through the estimate of repeatability in Bang Boet *dura* oil palm. Correlation coefficients and path coefficients among traits related to bunch and fruit were also calculated.

MATERIALS AND METHODS

Thirty-three *dura* oil palm plants were grown from seeds of the original Bang Boet *dura* trees and planted in a private farm in Pathio district, Chumphon province, southern Thailand in the year 2000. The plants set fruits three to four years after planting, but bunch and fruit sizes became stable from seven to eight years after planting. Data on bunch and fruit components were collected throughout the year 2009. Briefly, each mature bunch was weighed before separating all fruits from the bunch, then fruit and stalk weight per bunch as well as number of fruits per bunch were counted. The fruits were divided into three sizes (large, medium and small), with the weight ≥ 7, 5-7, and ≤ 5 g/fruit, respectively. They were weighed, counted and randomed for four fruits per size, weighed and cut vertically to measure mesocarp thickness, fruit length and width (in cm).

Twenty traits related to yield of oil palm were observed. They were weight (kg) per bunch (W/B), number of bunches per year (NB), number of fruits per bunch (NF/B), fruit weight (kg) per bunch (FW/B), stalk weight (kg) per bunch (SW/B), weight (kg) and number of large size fruits (WLF and NLF) per bunch, weight (kg) and number of medium size fruits (WMF and NMF) per bunch, weight (kg) and number of small size fruits (WSF and NSF) per bunch, mesocarp, shell and kernel thickness in cm (MT, ST and KT), fruit width and length in cm (FWD and FL), weight (g) per fruit (W/F), % mesocarp, % shell and % kernel per fruit (% M/F, % S/F and % K/F). The data were analysed for phenotypic variation among the *dura* oil palm plants and declared their difference by least significant difference (LSD) test using R program (Development Core Team, 2006). Each observation has the following statistical model:

$$Y_{km} = \mu + \alpha_k + e_{km}$$

where Y_{km} is the m^{th} measurement observed from the k^{th} plant, μ is the population mean, α_k is effect of the k^{th} plant and e_{km} is effect of environment on the m^{th} measurement.

R and its standard error (SE) of each trait were estimated from a one-way analysis of variance following Becker (1984).

$$\text{Repeatability (R)} = \sigma^2_W/(\sigma^2_W + \sigma^2_E)$$

where σ^2_W is the variance component determining difference among oil palm plants, and σ^2_E is the variance between measurements within the same oil palm plants.

A standard error of repeatability [S.E. (R)] was calculated from the formula:

$$S.E.(R) = \sqrt{\frac{[2(m.-1)(1-R)^2][1+(k_1-1)R]^2}{k_1^2(m.-N)(N-1)}}$$

where k_1 is the number of bunches or fruits collected from each oil palm plant and can be calculated as $k_1 = \frac{1}{N-1}\left[m. - \left(\frac{\Sigma m_k^2}{m.}\right)\right]$. N is total number of plants, m_k is number of bunches or fruits of the k^{th} plant, and m. is total number of bunches or fruits observed.

The relative efficiency (r) showing an increase in accuracy from each additional measurement was used as the criteria to determine the optimum number of measurements in each character as follows:

$$\text{Relative efficiency (r)} = n/[1+(n-1) R],$$

where n is the number of bunches or fruits being measured and R is the repeatability coefficient. The optimum number of bunches or fruits were judged based on an increase in relative efficiency value. If the additional measurement gives an increase in relative efficiency of less than 10% of the previous number, the current number is considered optimum.

Correlation coefficient and path analysis were performed according to Jerrold (1984), to demonstrate direct and indirect effect of yield components on oil palm bunch yield.

RESULTS AND DISCUSSION

Analysis of variance showed that yield components were significantly different among 33 Bang Boet *dura* oil palm plants in this study (*Table 1*). These plants were different in all traits measured, except for number of bunches per year (NB/Y), mesocarp thickness (MT) and shell thickness (ST).

Means of yield-related traits in each *dura* oil palm plant are presented in *Table 2*. Plant number 25 (I9) gave the highest W/B of 43.25 kg, which was not significantly different from that of #27 (I13) (40.60 kg), while #4 (B17) gave the lowest average bunch weight of 15.50 kg. Plant #25 and #27 also gave the highest FW/B and SW/B (27.55 kg and 15.70 kg) and (25.00 kg and 15.60 kg), respectively, while the lowest one was #4 (B17) (8.60 kg and 6.90 kg). Plant #22 (G14) and #27 gave the highest NF/B (3020 and 2926 fruits) which were not different from #25 and #7 (C15) (2876 and 2847 fruits), while #20 (G5) gave the lowest number of fruits at 1128. For weight and number of large, medium and small size fruits, plant #25, #22 and #27 were the highest, while #6 (C14), #20 and #17 (F13) were the lowest. Kernel thickness ranged from 0.67-1.25 cm, with the highest found in #7 (1.25 cm) and the lowest in #28 (J3) (0.67 cm). Plant #13 (D17) gave the longest fruit of 2.60 cm, while #28 (J3) was the shortest at 1.96 cm. For FWD and W/F, #18 (F17) produced the highest with 2.04 cm and 10.13 g, while #1 (B4) gave the lowest at 1.53 cm and 4.76 g. The % M/F for #1 was the highest (58.01%), while #10 (D1) (36.13%) gave the lowest. Conversely, % S/F of #10 and #1 were the highest (46.41%) and lowest (26.45%), respectively. The highest percentage of kernel per fruit (% K/F) was observed in #3 (B16) and #5 (C13) (25.29 and 25.26 %), while the lowest percentage was in #14 (E1) (9.59%). These results showed that, on the average, the proportion of mesocarp per fruit, shell per fruit and kernel per fruit among this *dura* germplasm were 48.24: 34.29: 17.47 or 2.77: 1.97: 1.00. This proportion can be used as a reference characteristic of this *dura* germplasm in the future.

The estimated repeatability (R) for traits observed on bunch basis is shown in *Table 3*. The values varied from 0.201±0.105 for NSF to 0.691±0.072 for W/B. W/B, FW/B, SW/B and WLF showing relatively strong genetic effect and could be measured with high reliability from a sample

TABLE 1. MEAN SQUARES FROM ANALYSIS OF VARIANCE FOR BUNCH AND FRUIT TRAITS IN 33 BANG BOET *Dura* OIL PALMS

Sources	df	Mean squares								
		NB/Y	W/B	NF/B	FW/B	SW/B	WLF	NLF	WMF	NMF
Between plants	32	1.27^{ns}	134.83**	912 831**	61.46**	18.62**	19.82**	139 023**	5.43**	112 844**
Within plants	77	1.76	15.98	250 865	8.07	3.68	3.47	42 529	2.53	57 387

Sources	df	Mean squares										
		WSF	NSF	MT	ST	KT	FL	FWI	W/F	%M/F	%S/F	%K/F
Between plants	32	5.76**	185 113**	0.01 ^{ns}	0.008 ^{ns}	0.06**	0.13**	0.06**	7.33**	64.35**	55.40*	41.63**
Within plants	77	2.18	100 987	0.008	0.005	0.01	0.05	0.01	1.53	30.87	23.97	8.93

Note: *,** Significantly different at P<0.05 and P<0.01, respectively, ns: non-significant. NB/Y = number of bunches per year, W/B = weight (kg) per bunch, NF/B = number of fruits per bunch, FW/B = fruit weight (kg) per bunch, SW/B = stalk weight (kg) per bunch, WLF = weight (kg) of large size fruits, NLF = number of large size fruits, WMF = weight (kg) of medium size fruits, NMF = number of medium size fruits, WSF = weight (kg) of small size fruits, NSF = number of small size fruits, MT = mesocarp thickness (cm), ST = shell thickness (cm), KT = kernel thickness (cm), FL = fruit length (cm), FWI = fruit width (cm), W/F = weight (g) per fruit, % M/F = mesocarp per fruit (%), % S/F = shell per fruit (%) and % K/F = kernel per fruit (%).

of three to four bunches. The NF/B, NLF, WSF and WMF were of medium repeatability and required collecting data from five to eight bunches. The traits that needed observations from up to 10-11 bunches were NMF and NSF. In high repeatability traits such as W/B, its accuracy increased 18% from the first to the second measurement, and thus observations from only three bunches are sufficient in attaining the required accuracy. Since bunch weight is highly repeatable, it is theoretically highly heritable. The traits observed on fruits, *i.e.* FW, % K/F, FWI and KT required observations on only four to five fruits, while FL, % S/F and % M/F could be measured with sufficient reliability from seven to nine fruits. ST and MT were affected largely by environment and varied so much that at least 18-22 fruits should be observed to obtain reliable data. Rafii *et al*. (2002) noted that low genetic variability for yield and its components theoretically implied measurement from more bunches. Most of fruit components shown in *Table 3* revealed medium to low repeatabilities as compared to bunch components. The environmental condition during fruit development affected competition between fruits in the same bunch and caused high variation on traits related to mesocarp and endocarp, especially their thickness. Ahmad (2007) studied *tenera* hybrids from diverse *dura* crossed with AVROS *pisifera* and found that number of bunches was not different among plants, while % M/F, % S/F and % K/F were high in genetic variation.

In this study, repeatability values of 19 yield-related traits in Bang Boet *dura* oil palm can be classified into three groups. The first group with a strong genetic control and less environmental effect were W/B, FW/B, SW/B, WLF, FW and % K/F. The second group with moderate environmental effect comprised NF/B, NLF, WMF, NMF, WSF, NSF, KT, FWI, % M/F and % S/F, while the third group, ST and MT were highly influenced by environmental factors. Our results are comparable to those reported in cacao by Dias and Kageyama (1998) who estimated using analysis of variance of five years's data during 1986-1990. Their R values varied from 0.41-0.95 in number of healthy fruits per plant (NHFP), number of collected fruits per plant (NCFP), weight of wet seeds per plant and per fruit (WHSP and WHSF), and percentage of diseased fruits per plant (PDFP). They concluded that two harvested years were sufficient to evaluate NHFP, NCFP, WHSP and WHSF with determination coefficient of greater than 90%, except for PDFP that gave the lowest coefficient of 78%. Optimum number of bunches and fruits found in our study are similar to those reported earlier by Cedillo *et al*. (2008) who worked on correlation and repeatability in progenies of African oil palm. They indicated that at least four years of successive harvests are required to exploit the genotypic potential of the evaluated progenies. Leon *et al*. (2004) reported that correlation between years can be used as an indicator for predicting oil content in olive in the following years. Our information is based on one year data and thus cannot be used to predict oil palm performance over years.

Table 4 shows correlations between yield and its components with strong associations between W/B and FW/B (0.98), W/B and SW/B (0.92), FW/B and WLF (0.91), FWI and FL (0.90), W/F and FL (0.93), and W/F and FWI (0.97). FW/B, SW/B, NF/B, WLF, NLF, WMF, NMF, WSF and NSF exhibited positive correlations with W/B, while % M/F

TABLE 2. MEANS FOR BUNCH AND FRUIT TRAITS OF 33 BANG BOET *Dura* OIL PALMS

Plant No.	Plant code	W/B (kg)	FW/B (kg)	SW/B (kg)	NF/B (fruits)	WLF (kg)	NLF (fruits)	WMF (kg)	NMF (fruits)	WSF (kg)	NSF (fruits)	KT (cm)	FL (cm)	FWI (cm)	W/F (g)	%M/F	%S/F	%K/F
1	B4	32.0 b-d	18.6 c-e	13.4 a-d	1 907 a-f	7.20 b-i	580 b-h	6.00 a-e	577 b-d	5.40 a-d	750 a-c	1.22 a-c	2.68 a	2.06 a	10.74 a	54.7 ab	29.4 cd	15.9 b-g
2	B15	19.0 hi	10.4 gh	8.6 gh	1 576 c-f	3.15 i-k	396 d-h	4.88 b-e	682 b-d	2.40 de	498 bc	1.20 a-c	2.31 a-e	1.81 a-l	6.88 e-j	41.6 c-e	33.2 b-d	25.2 a
3	B16	22.0 f-i	12.0 f-h	10.0 c-h	1 716 c-f	5.60 c-k	644 a-h	3.60 de	542 b-d	2.80 de	530 bc	0.98 c-i	2.25 a-e	1.83 a-l	7.13 d-j	51.8 a-d	32.2 b-d	16.0 b-g
4	B17	15.5 i	8.6 h	6.9 h	1 589 c-f	2.70 jk	348 e-h	4.50 b-e	821 a-d	1.40 e	420 bc	0.90 d-j	2.02 de	1.6 kl	5.01 j	52.3 a-d	29.7 cd	18.0 b-e
5	C13	21.3 g-i	12.7 e-h	8.6 gh	1 953 a-f	4.12 f-k	572 b-h	5.76 a-e	794 b-d	2.78 de	588 a-c	1.10 a-g	2.33 a-e	1.74 d-l	7.04 e-j	47.2 a-e	27.6 d	25.3 a
6	C14	16.5 hi	9.5 gh	6.9 gh	1 513 d-f	2.47 jk	237 h	3.73 c-e	536 b-d	3.33 b-e	740 a-c	0.96 c-i	2.19 a-e	1.71 f-l	6.83 f-j	51.1 a-d	29.7 cd	19.2 a-d
7	C15	35.9 a-c	22.5 a-c	13.4 a-d	2 847 ab	9.40 b-d	992 ab	6.60 a-e	823 a-d	6.47 ab	1 032 ab	1.25ab	2.41 a-e	1.90 a-i	8.39 a-h	47.2 a-e	32.9 b-d	19.8 a-d
8	C16	24.3 d-i	13.1 d-h	11.2 b-g	1 844 b-f	5.53 c-k	572 b-h	4.20 c-e	597 b-d	3.40 b-e	676 a-c	1.06 a-h	2.30 a-e	1.82 a-l	7.17 c-j	44.5 b-e	38.7 a-c	16.8 b-f
9	C19	21.4 g-i	12.1 f-h	9.2 d-h	1 706 c-f	4.70 f-k	443 c-h	4.40 b-e	613 b-d	3.00 c-e	650 a-c	0.98 c-i	2.33 a-e	1.65 i-l	6.69 g-j	52.6 a-c	29.2 cd	18.1 b-e
10	D1	21.9 f-i	14.1 d-h	7.7 gh	1 579 c-f	6.53 b-k	610 b-h	5.07 b-e	595 b-d	2.53 de	374 bc	1.15 a-e	2.41 a-e	1.92 a-h	8.37 a-h	36.13 e	46.4a	17.5 b-f
11	D12	18.8 hi	10.0 gh	8.8 f-h	2 128 a-f	2.70 jk	360 e-h	4.30 b-e	815 a-d	3.00 c-e	953 a-c	0.79 ij	2.00 de	1.59 l	4.98 j	49.9 a-d	31.6 b-d	18.5 b-e
12	D14	19.5 hi	9.0 gh	10.4 b-h	1 451 d-f	2.40 k	282 gh	3.95 c-e	600 b-d	2.65 de	569 a-c	0.88 f-j	2.06 c-e	1.62 j-l	6.24 g-j	51.4 a-d	30.3 cd	18.3 b-e
13	D17	21.6 f-i	12.5 e-h	9.2 d-h	1 488 d-f	5.08 e-k	426 c-h	5.10 b-e	607 b-d	2.30 de	455 bc	1.07 a-g	2.60 ab	1.90 a-i	8.75 a-g	53.0 a-c	29.2 cd	17.9 b-e
14	E1	22.2 f-i	13.1 d-h	9.1 e-h	2 223 a-f	4.00 g-k	481 c-h	5.13 a-e	775 b-d	4.00 b-e	967 ab	0.80 h-j	2.03 c-e	1.64 i-l	6.14 g-j	53.1 a-c	37.3 a-d	9.6 g
15	E13	19.8 hi	11.2 gh	8.6 gh	1 401 d-f	3.56 h-k	324 f-h	4.52 b-e	526 b-d	3.10 c-e	551 bc	1.05 a-i	2.59 ab	1.87 a-j	8.59 a-h	49.0 a-d	33.0 b-d	18.0 b-e
16	E14	32.2 b-d	19.1 b-d	13.1 a-e	2 640 a-c	7.43 b-h	755 a-f	7.20 a-c	991 ab	4.50 a-e	894 a-c	1.05 a-i	2.26 a-e	1.79 b-l	7.15 d-j	46.6 a-e	34.1 b-d	19.4 a-d
17	F13	28.8 c-g	14.5 d-h	14.3 ab	1 325 ef	7.80 b-g	528 c-h	5.40 a-e	550 b-d	1.30 e	248 c	1.12 a-g	2.59 ab	1.99 a-e	10.06 ab	45.2 b-e	39.1 a-c	15.7 b-g
18	F17	23.0 e-i	13.8 d-h	9.2 d-h	1 486 d-f	8.27 b-f	626 a-h	3.60 de	536 b-d	1.93 e	323 bc	1.16 a-d	2.52 a-c	2.04 ab	10.13 ab	50.4 a-d	34.4 b-d	15.2 c-g
19	G1	24.2 d-i	15.3 d-g	8.9 e-h	1 442 d-f	8.20 b-f	581 b-h	4.33 b-e	452 cd	2.80 de	409 bc	0.86 g-j	2.48 a-d	2.03 abc	9.60 a-e	48.8 a-d	36.9 a-d	14.3 d-g
20	G5	18.2 hi	9.6 gh	8.6 gh	1 128 f	4.20 f-k	314 f-h	3.40 e	376 d	2.00 e	439 bc	0.9 e-j	2.39 a-e	1.82 a-l	8.41 a-h	52.1 a-d	32.9 b-d	15.0 d-g
21	G13	21.0 g-i	12.6 e-h	8.3 gh	1 723 c-f	4.48 f-k	455 c-h	4.32 b-e	633 b-d	3.84 b-e	636 a-c	1.0 b-i	2.39 a-e	1.86 a-k	7.93 b-i	51.5 a-d	31.4 b-d	17.1 b-f
22	G14	31.9 b-d	18.3 c-f	13.6 a-c	3 020 a	5.33 d-k	720 a-g	8.67 a	1340 a	4.33 b-e	960 ab	1.06 a-h	2.12 b-e	1.69 g-l	6.14 g-j	39.9 de	37.8 a-d	22.2 ab
23	H10	22.4 f-i	12.8 e-h	9.6 c-h	1 646 c-f	5.02 e-k	430 c-h	4.16 c-e	550 b-d	3.60 b-e	666 a-c	1.16 a-e	2.55 ab	1.83 a-l	8.36 a-h	44.8 b-e	35.8 a-d	19.3 a-d
24	H14	20.5 g-i	13.5 d-h	7.1 gh	2 481 a-d	5.40 d-k	737 a-g	4.80 b-e	914 a-c	3.27 b-e	830 a-c	1.03 a-i	2.01 de	1.59 l	5.26 ij	44.6 b-e	33.7 b-d	21.7 a-c
25	I9	43.2 a	27.6 a	15.7 a	2 876 ab	13.60 a	1071 a	7.80 ab	877 a-d	6.15 a-c	928 a-c	1.07 a-g	2.58 ab	1.96 a-g	9.87 a-d	57.7 a	30.2 cd	12.1 e-g
26	I11	31.5 c-e	18.5 c-e	13.0 a-f	1 959 a-f	9.03 b-e	709 a-g	6.47 a-e	704 b-d	3.00 c-e	547 bc	1.27a	2.44 a-e	2.00 a-d	9.92 a-c	42.1 c-e	41.8 ab	16.0 b-g
27	I13	40.6 ab	25.0 ab	15.6 a	2 926 ab	10.35 ab	870 a-c	7.00 a-d	784 b-d	7.65 a	1 272 a	1.06 a-h	2.51 a-c	1.97 a-f	9.52 a-f	47.1 a-e	39.4 a-c	13.5 d-g
28	J3	18.7 hi	10.2 gh	8.5 gh	2 154 a-f	3.10 i-k	436 c-h	3.60 de	704 b-d	3.47 b-e	1 014 ab	0.67 j	1.96 e	1.59 l	5.39 ij	54.6 ab	34.4 b-d	11.0 fg
29	J6	30.3 c-f	19.2 b-d	11.1 b-h	2 077 a-f	9.67 a-c	799 a-e	6.27 a-e	707 b-d	3.27 b-e	571 a-c	1.15 a-e	2.45 a-d	1.93 a-h	8.81 a-g	47.9 a-e	35.6 a-d	16.4 b-f
30	J7	22.5 f-i	14.0 d-h	8.5 gh	2 294 a-e	5.47 d-k	689 a-h	5.07 b-e	845 a-d	3.47 b-e	759 a-c	0.98 c-i	2.17 b-e	1.63 j-l	5.95 h-j	47.4 a-e	36.1 a-d	16.8 b-f
31	J8	20.8 g-i	11.9 gh	8.9 e-h	1 715 c-f	4.77 f-k	513 c-h	3.87 c-e	520 b-d	3.27 b-e	683 a-c	1.13 a-f	2.28 a-e	1.77 c-l	6.94 e-j	46.8 a-e	35.5 b-d	17.8 b-e
32	K6	25.0 d-h	14.4 d-h	10.6 b-h	2 378 a-e	6.43 b-k	821 a-d	4.23 c-e	684 b-d	3.77 b-e	873 a-c	1.12 a-g	2.17 b-e	1.72 e-l	6.32 g-j	44.1 b-e	36.0 a-d	19.9 a-d
33	M7	22.3 f-i	15.0 d-g	7.3 gh	2 364 a-e	6.58 b-j	700 a-g	4.55 b-e	766 b-d	3.90 b-e	898 a-c	0.96 c-i	2.04 c-e	1.68 h-l	6.16 g-j	45.5 a-e	39.8 a-c	14.7 d-g
Mean		24.0	14.1	9.9	1 938	5.7	565	4.97	683	3.44	688	1.04	2.32	1.80	7.57	47.9	34.5	17.7
CV (%)		16.63	20.13	19.33	25.84	32.68	36.44	31.98	35.04	42.9	46.15	11.49	9.49	6.69	16.34	11.61	14.21	16.92

Note: W/B = weight (kg) per bunch, FW/B = fruit weight (kg) per bunch, SW/B = stalk weight (kg) per bunch, NF/B = number of fruits per bunch, WLF = weight (kg) of large size fruits, NLF = number of large size fruits, WMF = weight (kg) of medium size fruits, NMF = number of medium size fruits, WSF = weight (kg) of small size fruits, NSF = number of small size fruits, MT = mesocarp thickness (cm), ST = shell thickness (cm), KT = kernel thickness (cm), FL = fruit length (cm), FWD = fruit width (cm), W/F = weight (g) per fruit, % M/F = mesocarp per fruit (%), % S/F = shell per fruit (%) and % K/F = kernel per fruit (%).

TABLE 3. VARIANCE COMPONENTS OF BUNCH AND FRUIT TRAITS, REPEATABILITY (R), AND OPTIMUM NUMBER OF BUNCHES AND FRUITS REQUIRED TO MEASURE YIELD-RELATED TRAITS FROM 33 BANG BOET *Dura* OIL PALMS

Bunch trait	σ_W^2	σ_E^2	Repeatability (R)	Optimum number of bunches
Weight per bunch (W/B)	35.790	16.000	0.691±0.072	3
Fruit weight per bunch (FW/B)	16.085	8.070	0.666±0.067	3
Stalk weight per bunch (SW/B)	4.501	3.680	0.550±0.092	4
Number of fruits per bunch (NF/B)	199 428	250 865	0.443±0.101	5
Weight of large size fruits (WLF)	4.926	3.470	0.587±0.087	4
Number of large size fruits (NLF)	29,070	42 530	0.406±0.103	6
Weight of medium size fruits (WMF)	0.873	2.529	0.257±0.106	8
Number of medium size fruits (NMF)	16 707	57 387	0.225±0.106	10
Weight of small size fruits (WSF)	1.808	2.179	0.331±0.106	7
Number of small size fruits (NSF)	25 344	100 987	0.201±0.105	11
Fruit trait	σ_W^2	σ_E^2	**Repeatability (R)**	**Optimum number of fruits**
Mesocarp thickness (MT)	0.001	0.008	0.098±0.099	22
Shell thickness (ST)	0.001	0.005	0.121±0.101	18
Kernel thickness (KT)	0.013	0.014	0.485±0.098	5
Fruit width (FWI)	0.014	0.014	0.489±0.098	5
Fruit length (FL)	0.025	0.048	0.340±0.106	7
Weight per fruit (W/F)	1.748	1.530	0.533±0.094	4
% mesocarp per fruit (% M/F)	10.086	30.870	0.246±0.106	9
% shell per fruit (% S/F)	9.469	23.970	0.283±0.106	8
% kernel per fruit (% K/F)	9.851	8.930	0.525±0.094	4

Note: σ_W^2 = variance component of variation among oil palm plants.
σ_E^2 = variance component of variation between measurements within the same oil palm plants.

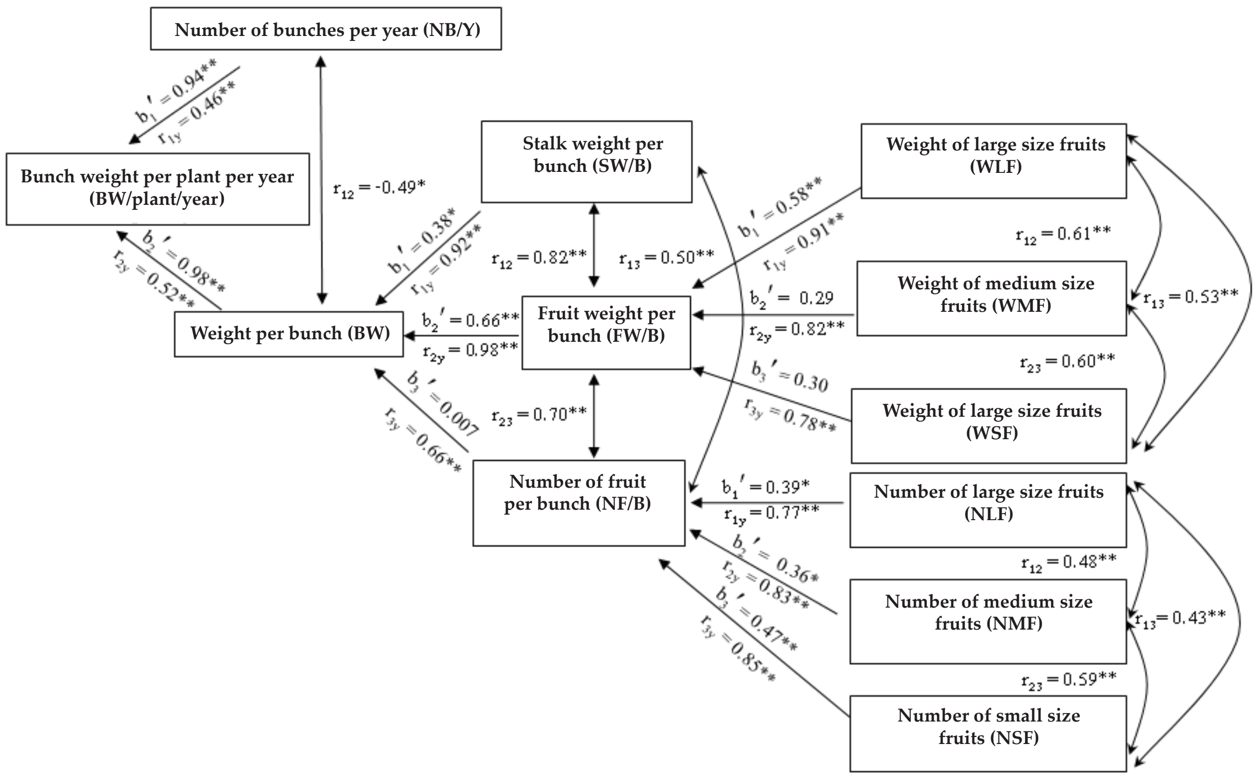

Figure 1. Path coefficient relationship between yield and yield components in 33 Bang Boet dura *oil palms.*

TABLE 4. CORRELATIONS BETWEEN YIELD-RELATED TRAITS IN 33 BANG BOET *Dura* OIL PALMS

Traits	W/B	FW/B	SW/B	NF/B	WLF	NLF	WMF	NMF	WSF	NSF	MT	ST	KT	FL	FWD	W/F	%M/F	%S/F
FW/B	0.98**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
SW/B	0.92**	0.82**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NF/B	0.66**	0.70**	0.50**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WLF	0.88**	0.91**	0.72**	0.45**	-	-	-	-	-	-	-	-	-	-	-	-	-	-
NLF	0.81**	0.87**	0.61**	0.77**	0.84**	-	-	-	-	-	-	-	-	-	-	-	-	-
WMF	0.83**	0.82**	0.74**	0.72**	0.61**	0.67**	-	-	-	-	-	-	-	-	-	-	-	-
NMF	0.39*	0.41*	0.30	0.83**	0.14	0.48**	0.73**	-	-	-	-	-	-	-	-	-	-	-
WSF	0.75**	0.78**	0.61**	0.78**	0.53**	0.64**	0.60**	0.40*	-	-	-	-	-	-	-	-	-	-
NSF	0.42*	0.45**	0.32	0.85**	0.14	0.43*	0.41*	0.59**	0.82**	-	-	-	-	-	-	-	-	-
MT	0.16	0.06	0.31	-0.32	0.21	-0.09	-0.15	-0.48*	-0.03	-0.24	-	-	-	-	-	-	-	-
ST	0.63**	0.61**	0.59**	0.31	0.65**	0.55**	0.40*	0.10	0.40*	0.13	0.18	-	-	-	-	-	-	-
KT	0.46**	0.46**	0.41*	0.09	0.49**	0.44**	0.41*	0.00	0.19	-0.19	0.01	0.17	-	-	-	-	-	-
FL	0.46**	0.43*	0.45**	-0.24	0.55**	0.19	0.24	-0.41*	0.15	-0.36*	0.49**	0.35*	0.63**	-	-	-	-	-
FWD	0.54**	0.52**	0.51**	-0.16	0.68**	0.33	0.27	-0.37*	0.18	-0.34	0.43*	0.42*	0.62**	0.90**	-	-	-	-
W/F	0.56**	0.53**	0.54**	-0.18	0.68**	0.29	0.28	-0.39*	0.20	-0.31	0.48**	0.43*	0.57**	0.93**	0.97**	-	-	-
%M/F	-0.04	-0.06	-0.01	-0.12	-0.04	-0.20	-0.21	-0.24	0.10	0.09	0.40*	0.12	-0.48**	0.04	-0.07	0.06	-	-
%S/F	0.22	0.24	0.16	0.15	0.32	0.31	0.16	0.05	0.04	0.02	-0.16	0.10	0.19	0.02	0.24	0.16	-0.71**	-
%K/F	-0.21	-0.22	-0.18	-0.02	-0.33	-0.11	0.10	0.25	-0.19	-0.14	-0.34	-0.28	0.42*	-0.08	-0.21	-0.27	-0.50**	-0.26

Note: *,** Significant at $P<0.05$ and $P<0.01$, respectively. W/B = weight (kg) per bunch, FW/B = fruit weight (kg) per bunch, SW/B = stalk weight (kg) per bunch, NF/B = number of fruits per bunch, WLF = weight (kg) of large size fruits, NLF = number of large size fruits, WMF = weight (kg) of medium size fruits, NMF = number of medium size fruits, WSF = weight (kg) of small size fruits, NSF = number of small size fruits, MT = mesocarp thickness (cm), ST = shell thickness (cm), KT = kernel thickness (cm), FL = fruit length (cm), FWD = fruit width (cm), W/F = weight (g) per fruit, % M/F = mesocarp per fruit (%), % S/F = shell per fruit (%) and % K/F = kernel per fruit (%).

showed negative correlations with % S/F (-0.71) and % K/F (-0.50), similar to those reported by Obisesan and Fatunla (1982) that oil palm fruits with thick mesocarp had thin shell and small kernel. Cedillo *et al*. (2008) determined direct and indirect effects of yield-related traits on yield or bunch weight per plant per year and residual effects. Our result of path analysis as shown in *Figure 1* shows no residual because causal characters exclusively determine the effect characters. For example, FW/B is exclusively determined by weight of large, medium and small size fruits. Likewise, NF/B is exclusively determined by number of large, medium and small size fruits. Then W/B is dictated by NF/B and stalk weight and fruit weight per bunch. Thus, it can be concluded that bunch weight per plant per year depends solely on W/B and NB which has negative relationship, *i.e.* plants with larger bunches produced less number of bunches (r = -0.49). The W/B then comprises SW/B, FW/B and NF/B with high correlation coefficient of 0.92, 0.98 and 0.66, respectively. Among the three causes of W/B, FW/B showed the strongest positive correlation. This relationship came from the direct effect of FW/B (r = 0.66) as well as the indirect effect through SW/B and NF/B which had high correlations with FW/B at 0.82 and 0.70, respectively. Finally, FW/B was influenced largely by WLF (r = 0.91), while NF/B was determined mainly by NSF (r = 0.85), as depicted in *Figure 1*. NB/Y and W/B contribute almost equally to oil palm yield. W/B itself is a function of SW/B, FW/B and NF/B, with more contribution coming from FW/B. FW/B, in turn, depends largely on WLF more than weight of fruits of the other sizes, while NF/B is controlled equally by number of fruits from all three sizes.

Although these findings are rather specific to Bang Boet *dura*, they can be applied to other *dura* oil palm populations with similar genetic background. The results can also be used as a reference to other studies/breeding programmes involving with *dura* improvement.

CONCLUSION

The repeatability of yield related traits, especially W/B, FW/B, SW/B, WLF, W/F and %K/F were high and thus the optimum number of bunches and fruits required to observe them are three or four. Weight and number of different size fruits are major components contributing to bunch yield in oil palm.

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REFERENCES

AHMAD, N (2007). Genetic performance of oil palm (*Elaeis guineensis* Jacq.) progenies from different *dura* sources in crosses with AVROS *pisifera*. Universiti Putra Malaysia. <http://psasir.upm.edu.my/5493/>, accessed 28 May 2010.

ALBUQUERQUE, A S; BRUCKNER, C H; CRUZ, C D; SALOMÃO, L C C and NEVES, J C L (2004). Repeatability and correlations among peach physical traits. *Crop Breeding and Applied Biotechnology, 4*: 441-445.

BECKER, W A (1984). *Manual of Quantitative Genetics*. Fourth edition. Academic Enterprises, Pullman, Washington.

CEDILLO, D S O; BARROSS, W S; FERREIRA, F M; DIAS, L A S; ROCHA, R B and CRUZ, C D (2008). Correlation and repeatability in progenies of African oil palm. *Acta Sci. Agron., 30*: 197-201.

CORLEY, R H V and TINKER, P B (2003). *The Oil Palm*. Fourth edition. Blackwell Science Ltd, Oxford.

DA COSTA, J G (2004). Estimation of repeatability and number of evaluations for characterisation of mango germplasm. *Acta Hort. (ISHS), 645*: 295-298.

DE SOUZA, L P C and DA COSTA, J G (2003). Estimates of repeatability and path coefficients on grapes. *Crop Breeding and Applied Biotechnology, 3(3)*: 231-236.

DEVELOPMENT CORE TEAM (2006). R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http:/www.R-project.org>, accessed on 10 April 2009.

DIAS, L A S and KAGEYAMA, P Y (1998). Repeatability and minimum harvest period of cacao (*Theobroma cacao* L.) in southern Bahia. *Euphytica, 102*: 29-35.

DOHM, M (2002). Repeatability estimates do not always set an upper limit to heritability. *Functional Ecology, 16*: 273-280.

FALCONER, D S and MACKAY, T F C (1996). *Introduction to Quantitative Genetics*. Fourth edition. Longman, New York.

HANSCHE, P E (1983). Response to selection. *Methods in Fruit Breeding* (Moore, J N and Janick, J eds.). Purdue University Press, West Lafayette, Indiana. p. 154-171.

HARTLEY, C W S (1988). *The Oil Palm*. Third edition. Longman, London.

JERROLD, H Z (1984). *Biostatistical Analysis*. Prentice-Hall, New Jersey.

LEÓN, L; RALLO, L; DEL RIO, C and MARTIN, L M (2004). Variability and early selection on the seedling stage for agronomic traits in progenies from olive crosses. *Plant Breeding, 123*: 73-78.

OBISESAN, I O and FATUNLA, T (1982). Heritability of fresh fruit bunch yield and its components in the oil palm (*Elaeis guineenis* Jacq.). *Theor. Appl. Genet., 65*: 65-68.

RAFII, M Y; RAJANAIDU, N; JALANI, B S and KUSHAIRI, A (2002). Performance and heritability estimations on oil palm progenies tested in different environments. *J. Oil Palm Res. Vol. 14 No. 1*: 15-24.

SOH, A C; WONG, G; HOR, T Y; TAN, C C and CHEW, P S (2003). Oil palm genetic improvement. *Plant Breed. Rev., 22*: 165-220.

STEEL, R; TORRIE, J H and DICKEY, D (1997). *Principles and Procedures of Statistics: A Biometrical Approach*. Third edition. McGraw Hill Book Co. Inc. New York.

WONG, C K and BERNARDO, R (2008). Genomewide selection in oil palm: increasing selection gain per unit time and cost with small populations. *Theor. Appl. Genet., 116*: 815-824.