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SEASONAL VARIATION IN YIELD AND DEVELOPMENTAL PROCESSES IN AN OIL PALM DENSITY TRIAL ON A PEAT SOIL: 2. BUNCH WEIGHT COMPONENTS

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ABSTRACT

Short-term changes in bunch weight were found to contribute to seasonal yield cycles in an oil palm density trial on a peat soil in Perak, West Malaysia. Unusually, the cycle in bunch weight was in phase with that in bunch number. The results of bunch analyses carried out over a 10-year period were examined to identify whether cycles also occurred in bunch components and to examine the effects on oil and kernel yields. The analysis showed that total fruit weight per bunch fluctuated more than the weight of the bunch frame, while within the fruit, the mesocarp showed a greater variation in weight per bunch than the nut. However, while the seasonal changes in fruit-to-bunch (F/B) on a mean monthly basis over years were significant, there were no comparable significant changes in the other bunch component ratios.

There was some evidence based on changes in single fruit weight and fruit number that the changes in F/B might be due to variation in pollination efficiency.

The variation in mesocarp weight per bunch was attributable to variation in both the oil and water contents with little change in the fibre. Similarly, within the nut, the larger shell component tended to vary more than the kernel.

The contribution of bunch weight variation to the variation in total yield and its relationship to bunch number are discussed.

Keywords: oil palm, yield cycles, bunch components, bunch component ratios.

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INTRODUCTION

In a previous paper (Henson and Mohd Tayeb, 2004), we examined the seasonal yield cycles that are a characteristic feature of the yield behaviour in oil palm, making use of long-term data collected in a density trial. In that study, it was observed that the cycles in both bunch number and single bunch weight contributed to the cycle in total FFB production, with the peaks in these two components of yield being closely synchronized. This was unexpected in view of the negative long-term correlation between bunch number and single bunch weight that is almost invariably seen during the ageing of oil palm, with bunch weights increasing while bunch numbers decline (*e.g.* Corley and Gray, 1976). Similar antagonism between bunch weight and number is also apparent in manipulative experiments (*e.g.* Corley and Breure, 1992). Thus, following disbudding, the consequent reduction in bunch number results in a subsequent increase in bunch weight, while with improved pollination, the increase in bunch weight is associated with a reduction in bunch number.

In addition to changes in bunch weight *per se*, there can also be changes in bunch composition, either associated with, or independent of, the weight

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changes. As mesocarp oil and kernel are the components of economic interest, it is especially important to determine how these are influenced by changes in mean bunch weight. This paper examines these and other components of bunch weight in detail.

MATERIALS AND METHODS

Measurements

Details of the experiment, site and environmental conditions are given in preceding papers (Henson and Mohd Tayeb, 2003; 2004). The trial, which included three planting densities of 120, 160 and 200 palms ha^{-1}, was established in 1985 on a deep peat soil in Perak. There were two replicate blocks with the density treatments split into 18 sub-plots with factorial fertilizer treatments. However, as the nutritional treatments had little effect on yields (which were mainly a function of density) they were not further considered. Also, as density had no significant effect on the yield cycles (Henson and Mohd Tayeb, 2004), or on the bunch component ratios (Henson and Mohd Tayeb, 2003), data from the three density treatments were pooled.

Bunches were randomly sampled from all the plots for a period of 10 years beginning January 1992. Bunch analysis was then carried out using the method of Blaak *et al*. (1963) as modified by Rao *et al*. (1983). More than 2500 bunches were collected in total, identified in the field by palm number and month and year of collection. However, when two or more bunches had been collected in different months from the same palm in the same year, it was not possible from the laboratory records to identify the month of collection of the individual bunch that was analysed. Consequently, results for about 30% of bunches were discarded, leaving a total of 1737 bunches with known months of sampling to be used in the analysis.

Other Data Sources

Yield data for two commercial fields were obtained for the sites described by Henson (1997). Monthly data for the national oil and kernel extraction ratios were obtained from the website of MPOB (Malaysian Palm Oil Board, 2002). Meteorological data were obtained from the Malaysian Meteorological Service (MMS).

Data Analysis

In addition to the standard bunch component ratios, a number of additional variables were calculated for each bunch from the initial data. These included the weights and ratios for all main bunch and fruit components, fruit numbers per bunch and fruit numbers per unit frame weight.

The bunch records were sorted into year and month of harvest. The number of bunches collected in any given month varied, however, limiting the reliability of single month data. To improve this, the data were aggregated quarterly. This resulted in a mean of 43.4 ± 3.5 records per quarter over the 10-year period.

In an alternative analysis, the data for each month were averaged over years to give mean monthly values. When doing this, data for the first two years were omitted due to the unusually low values found for certain variables, as were the data for the year 2000 as no bunch records were available in that year for July and August. The data were thus the means of seven years. To determine the significance of seasonal trends, the data were subjected to analysis of variance (months x years). They were then converted to percentages of their means to facilitate comparisons between the different variables.

RESULTS AND DISCUSSION

Cycling of Mean Bunch Weight

It was previously shown (Henson and Mohd Tayeb, 2003) that mean bunch weight in the density trial exhibited a similar annual cycle to that for bunch number. This was surprising as bunch weight and number are generally regarded as being antagonistic. Over the long-term this appears correct as mean bunch weight increased steadily with palm age while bunch number per palm declined (Henson and Mohd Tayeb, 2003).

The short-term variation in mean bunch weight seen in the present trial was also observed for two commercial fields for which long-term yield data over a similar period were available. *Figure 1* compares the monthly bunch weight variation at these sites with that of the density trial. Cycling of mean bunch weight was most regular or pronounced during the middle of the recording period (1991-1996; *Figure 1b*) when cycling at the inland site appeared to follow a similar pattern to that in the density trial. Correlations between the sites in single bunch weight are presented in *Table 1*. When all comparable data were included the correlations between all sites were high, but this was mainly a consequence of the long-term trends. When the long-term trends were removed only the correlations between the coastal and the inland sites were significant. The large differences in mean bunch weights between the sites were counterbalanced by opposite trends in bunch number.

Both the long-term trend and short-term cycling in single bunch fresh weight shown by the fresh fruit bunch (FFB) harvest data from the density trial were reflected in the bunches sampled for laboratory bunch analysis (BA) (*Figure 2*). However, the BA samples had an average weight 7% higher than that of the whole harvest (11.5 ± 0.33 kg s.e.m. compared with 10.8 ± 0.30 kg) and there was a tendency for the bunch weight to vary seasonally more for the BA samples than for the bulk population, giving rise to higher peaks in the former. Nevertheless, for both groups the seasonal trends were similar with peak weights occurring in June to August and minimum weights in January to February. In terms of cycling, the BA samples can be considered as generally representative of the total trial bunch population.

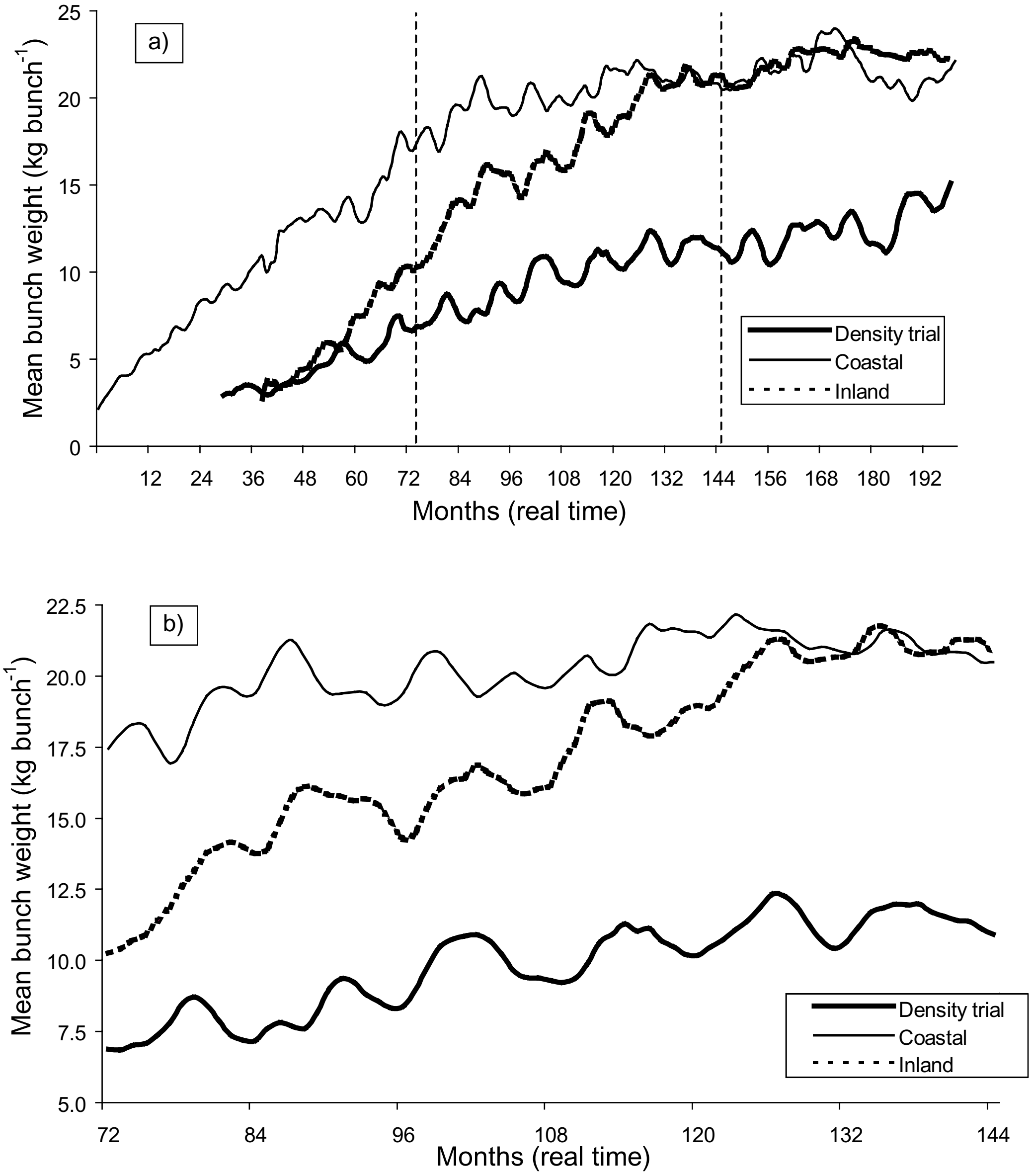

Figure 1. (a) Seasonal variation in mean bunch weight (kg) at three sites in real time from 1986 to mid 2002. Data are monthly running means (n=3). (b) Expansion of data from between the dashed vertical lines in (a).

TABLE 1. CORRELATIONS BETWEEN MONTHLY MEAN SINGLE BUNCH WEIGHTS (running means; n=3) AT THREE SITES (density, coastal and inland) OVER THE ENTIRE SAMPLING PERIOD (1989 to mid 2002) OR THE PERIOD 1992 TO 1997 WHEN THE CYCLES WERE GENERALLY THE MOST PRONOUNCED

		1989 to mid 2002; n=161		1992 to 1997; n=72	
		Density trial	Inland field	Density trial	Inland field
Actual weights	Coastal field	0.90 ***	0.43 ***	0.73 ***	0.83 ***
	Inland field	0.96 ***	-	0.91 ***	-
Weights as % of means after removal of long-term trend	Coastal field	0.17 ns	0.30 **	-0.08 ns	0.27 *
	Inland field	0.16 ns	-	0.19 ns	-

Notes:
(a) Planting and first harvest dates at the sites were as follows:

Site	Planting	First harvest
Density	August 1985	March 1988
Inland	October 1985	December 1988
Coastal	October 1983	November 1985

(b) Correlations were run using the actual weights or the weights expressed as percentages of their mean after removal of the long-term trends. Data presented are correlation coefficients with levels of significance at $P< 0.05$, 0.01 and 0.001 indicated as *, ** and *** respectively; ns = not significant.

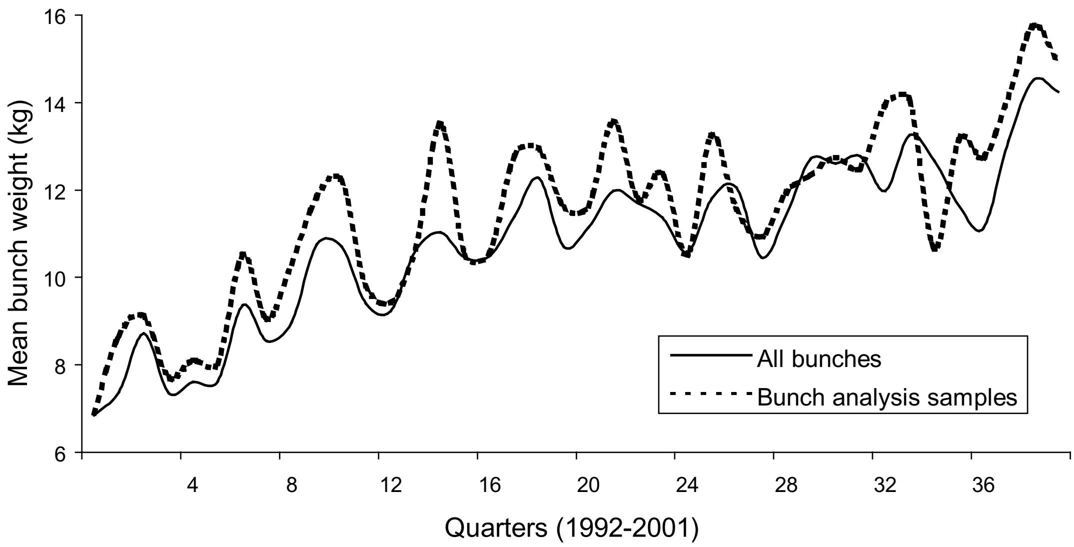

Figure 2. Quarterly variation in mean single bunch fresh weight of all bunches harvested and of bunches used for the bunch component study.

Cycling of Bunch Components

The total bunch weight is made up of the frame (supporting tissues) and the fruits. The latter was both the larger and the more variable component, and apart from the first 18 months of harvesting, it mainly determined the changes in total bunch weight (*Figure 3a*). However, fruit weight was not a constant fraction of bunch weight and the fruit-to-bunch ratio (F/B) and hence, the frame-to-bunch ratio, both varied cyclically (*Figure 3b*).

Not only the total, but also the individual fruit weight displayed a cyclic tendency *(Figure 4a).* The peaks in single fruit weight generally, though not always, coincided with the peaks in bunch and total fruit weight. From the total fruit or nut weight and the single fruit or nut weights recorded during the bunch analysis, it was possible to calculate the number of fruits per bunch. Although this also varied (*Figure 4b*), there were less regular peaks and troughs in numbers than in total fruit weight.

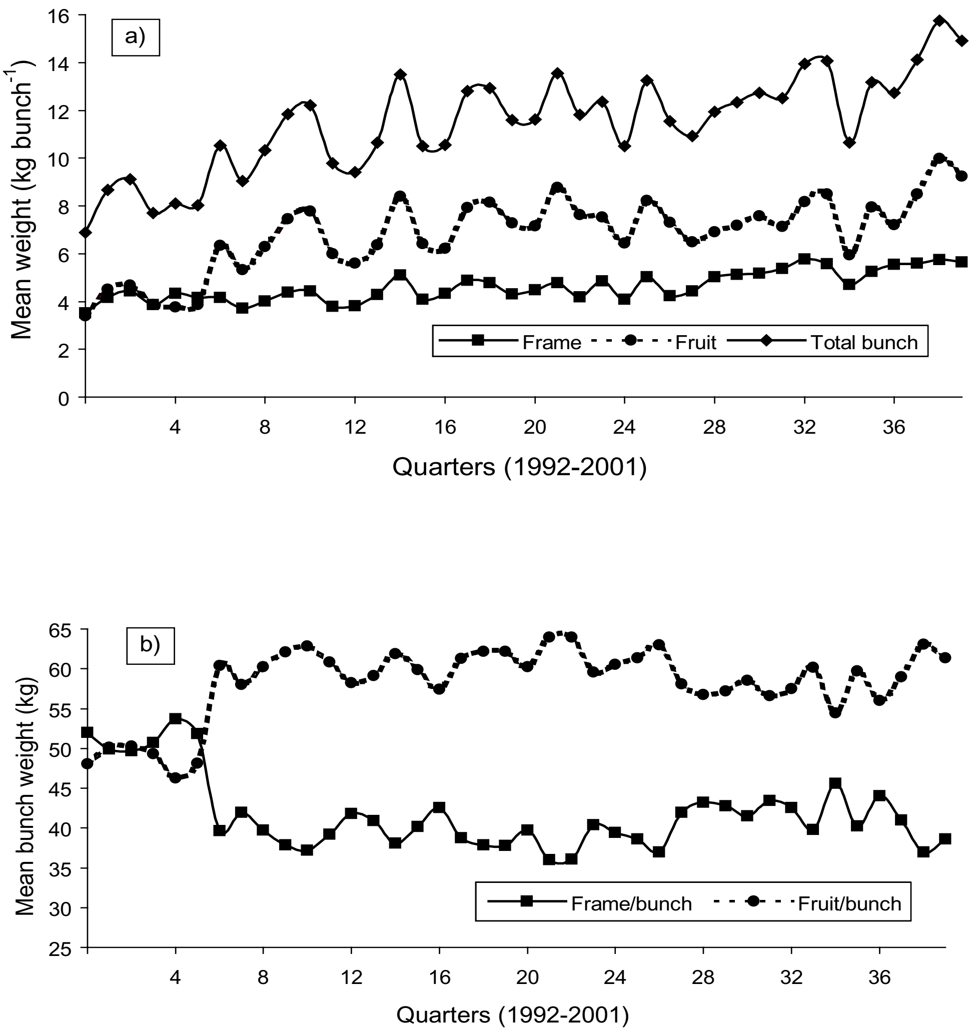

Figure 3. (a) Quarterly variation in frame weight, fruit weight and total weight per bunch. (b) Quarterly variation in fruit/bunch and frame/bunch ratios.

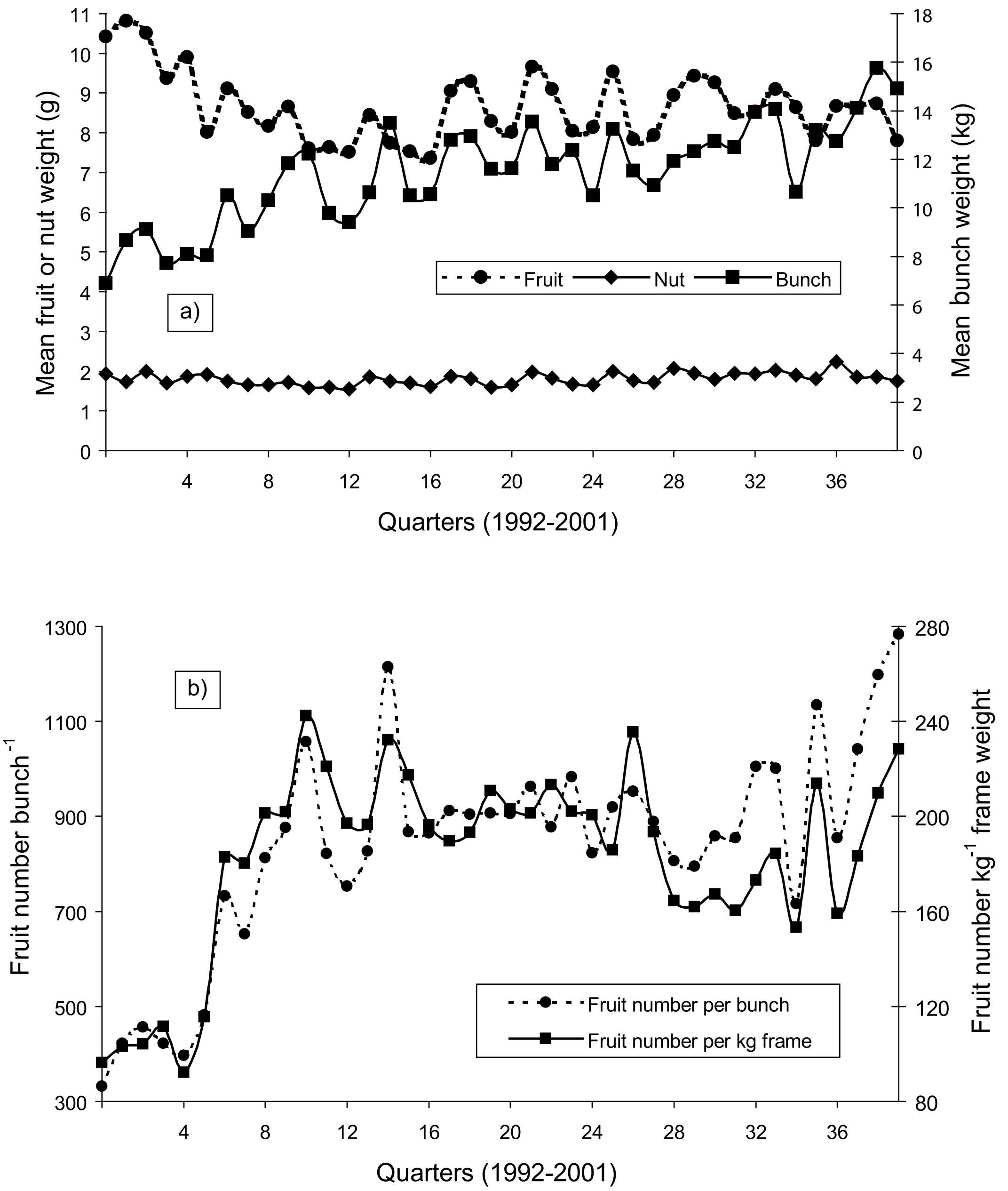

Figure 4. (a) Quarterly variation in individual fruit and nut weights in relation to total bunch weight. (b) Quarterly variation in number of fruits per bunch and number of fruits per unit frame weight.

Fruit number could vary due to variation in either flower number or pollination efficiency. No direct data were available to show which factor was the more important so fruit number was related to the frame weight in the expectation that a large variation in the fruit number-to-frame weight ratio would indicate variable pollination, since it is likely that the flower number should bear a fairly constant relation to the weight of the supporting structure.

In the study by Corley and Breure (1992) on effects of inflorescence removal, the mean flower number per kg frame varied by only 52, ranging from 269 to 321 depending on ablation treatment. The data for fruit number in *Figure 4b* show a much larger range and during the first 18 months of recording, fruit number, total fruit weight and F/B were abnormally low. After this time, there were occasionally large peaks in fruit number per bunch and per unit frame weight that suggest variable levels of pollination.

It is expected that based on competition for space and assimilates, individual fruit weight would increase as fruit numbers decreased. This was so, with the negative correlation between weight and number being stronger when relating weight to number per kg frame ($r = -0.724$: $P<0.001$) than when relating weight to number per bunch ($r = -0.567$; $P<0.001$).

Within the fruit, the mesocarp showed a greater variation in weight per bunch over time than the nut (*Figure 5a*). There were no distinct regular cycles in the mesocarp-to-fruit or nut-to-fruit ratios but a significant ($P<0.001$) declining trend was noted in the former and hence, a corresponding increase in the latter (*Figure 5b*). Such changes are an expected consequence of a decrease in single fruit size concomitant with increased single bunch weight. However, while single fruit weight declined during the first 30 months, there was little long-term change thereafter (*Figure 4a*).

Oil was generally the major component of the mesocarp and its total mass and that of water, both reflected changes in the mesocarp fresh weight (*Figure 6a*). However, as with F/B, the O/wetM and O/dryM ratios also varied seasonally, though somewhat erratically (*Figure 6b*). Both O/dryM and O/wetM showed a significant long-term decline, this being greater for O/wetM. Cyclic behaviour could also be discerned in weight per bunch of the nut and its components, the kernel and shell (*Figure 7*).

F/B and oil-to-bunch (O/B) generally peaked annually (*Figure 8a*). From the seventh quarter onwards, there was a significant long-term decline in O/B ($P<0.001$), though not in F/B; the former being related to the corresponding declines in mesocarp-to-fruit and in oil-to-mesocarp (*Figures 5b* and *6b*). There was less regular cycling in kernel-to-bunch (*Figure 8b*).

The strength of correlations between the bunch components and between the bunch components and mean bunch weight was affected by the aberrantly low values for F/B, O/B and other components during the first 18 months of sampling. *Table 2* gives the results of the correlations performed with or without these early data. (Omitting the early data effectively maximized the shorter-term variation at the expense of the longer-term.) When the first six quarters were excluded, O/B became significantly positively correlated with dry M/F and negatively correlated with K/B whereas otherwise, there were no significant correlations. Dry M/F became independent of F/B and F/B, independent of mean bunch weight. K/B was no longer correlated with F/B and was less dependent, though still positively correlated, with mean bunch weight.

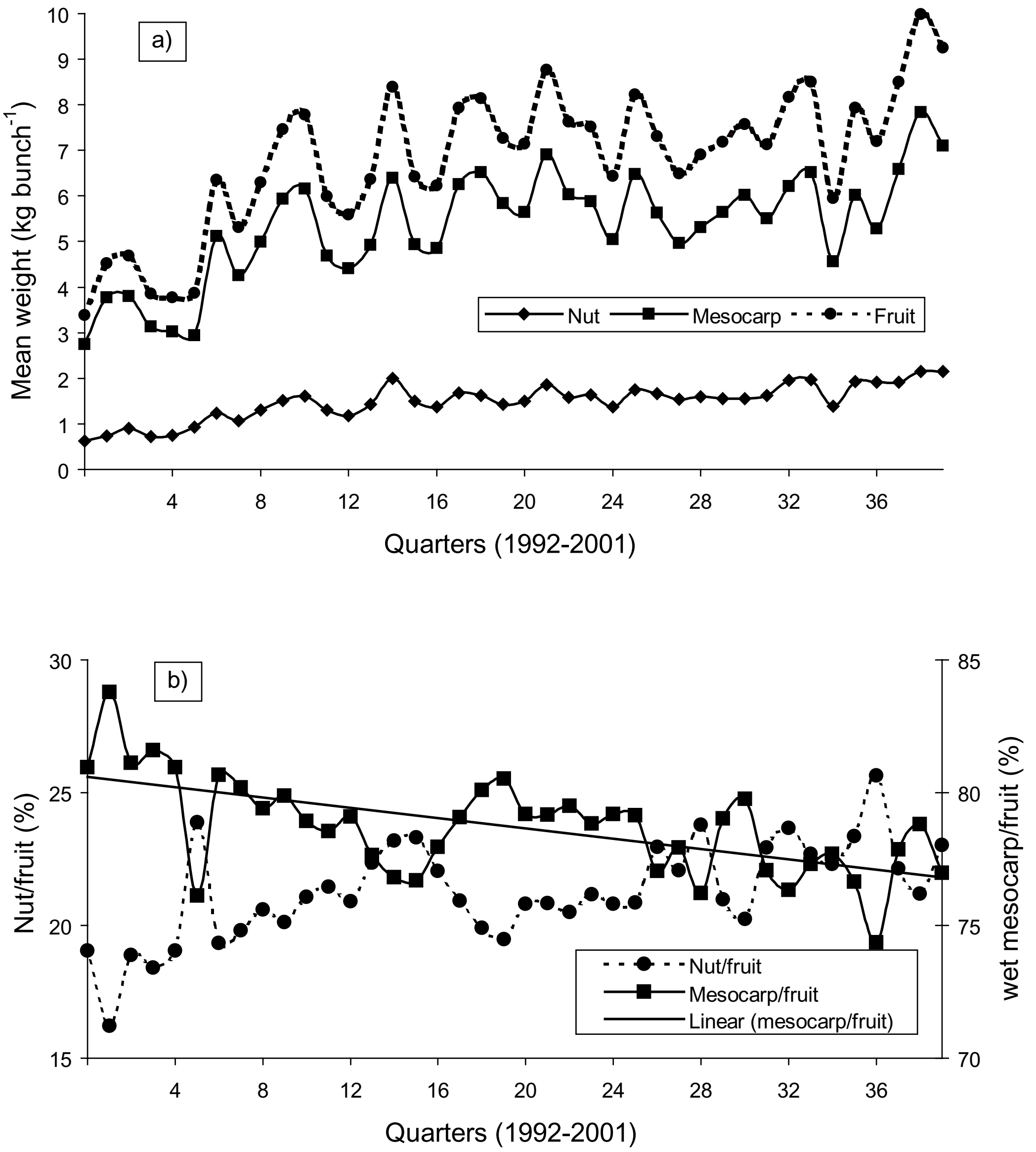

Figure 5. (a) Quarterly variation in total nut weight, wet mesocarp weight and fruit weight per bunch. (b) Quarterly variation in nut/fruit and wet mesocarp/fruit ratios. A long-term decline in mesocarp/fruit ratio (and hence a corresponding increase in nut/fruit) is indicated by the fitted line where y = 80.69a - 0.097x; r^2=0.39; P<0.001.

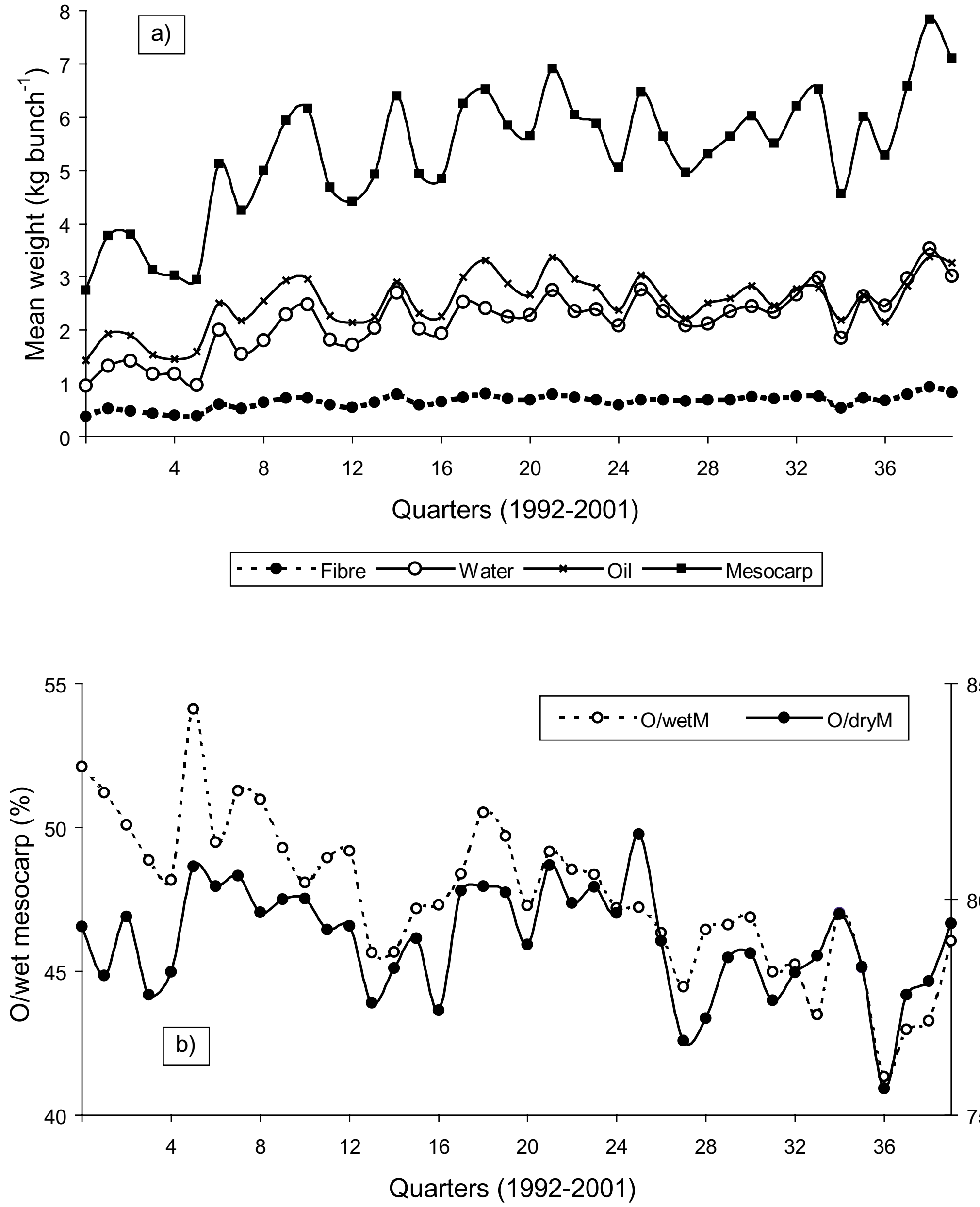

Figure 6. (a) Quarterly variation in total weight of fibre, water, oil and wet mesocarp per bunch. (b) Quarterly variation in oil/dry mesocarp and oil/wet mesocarp.

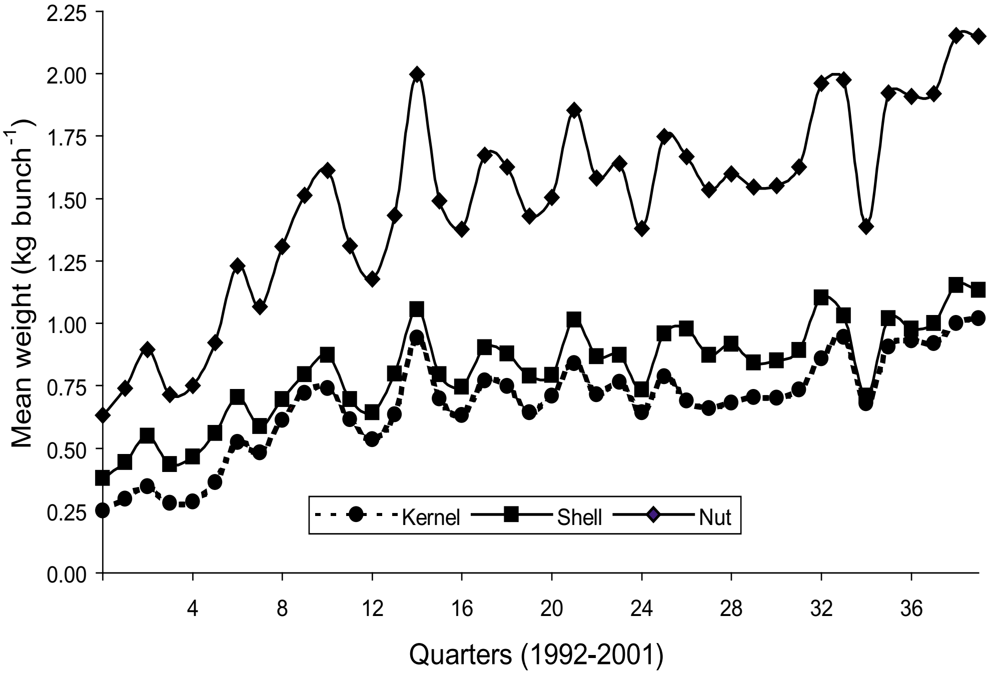

Figure 7. Quarterly variation in mean kernel weight, shell weight and nut weight per bunch.

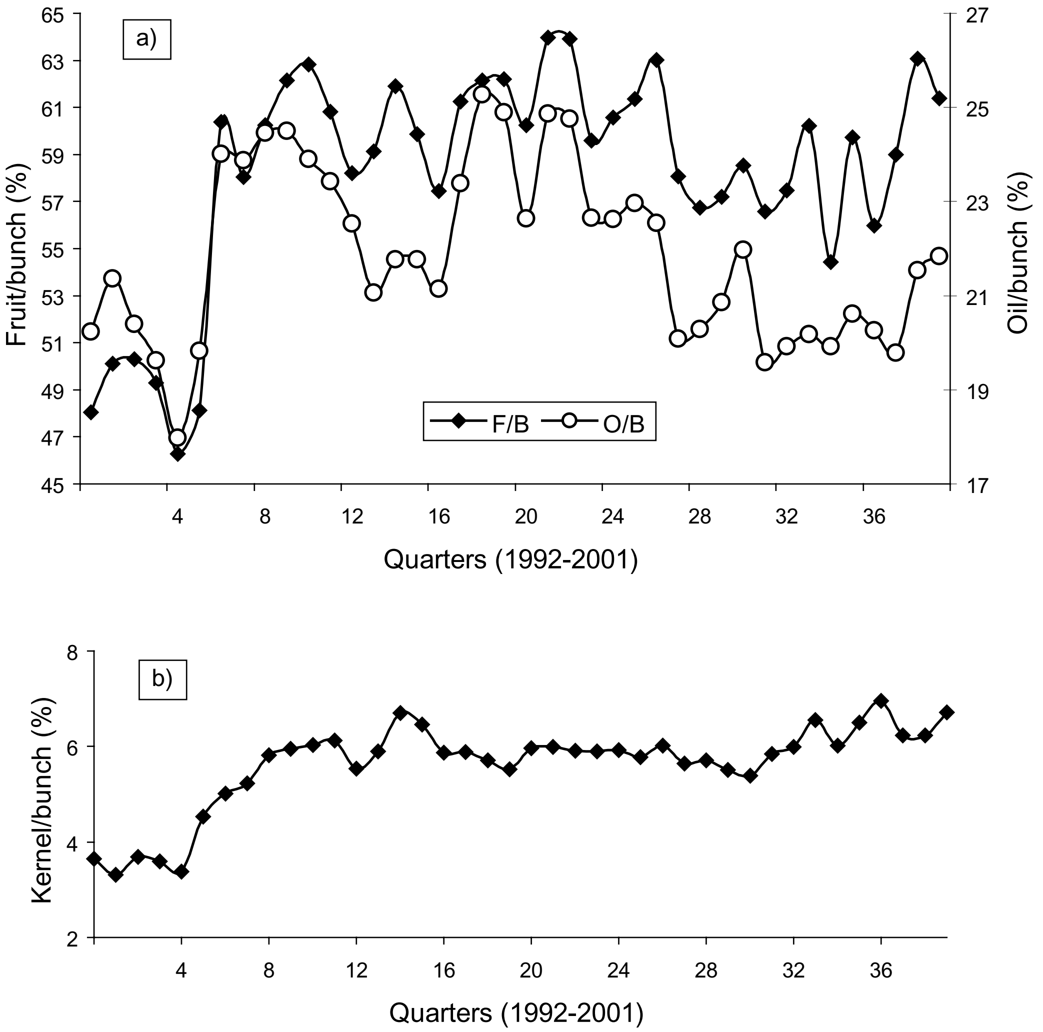

Figure 8. (a). Quarterly variation in fruit/bunch and oil/bunch ratios. (b) Quarterly variation in kernel/bunch ratio.

TABLE 2. COEFFICIENTS OF CORRELATION BETWEEN THE QUARTERLY MEAN VALUES OF FRUIT BUNCH COMPONENTS

	All values; n=40					From mid 1993; n=34				
	O/B	O/dryM	Dry M/F	F/B	mBWt	O/B	O/dryM	Dry M/F	F/B	mBWt
O/dryM	0.64***					0.77***				
dryM/F	0.29 ns	0.46**				0.82***	0.68**			
F/B	0.71***	0.25ns	-0.43**			0.71***	0.54**	0.28 ns		
mBWt	0.17 ns	-0.08ns	-0.74***	0.71***		-0.25ns	-0.13ns	-0.58***	-0.28 ns	
K/B	0.27 ns	-0.09ns	-0.79***	0.79***	0.77***	-0.36*	-0.37*	-0.70***	0.09 ns	0.49**

Notes:
Correlations were calculated using all data (1992 to 2001) or from mid 1993 onwards (at which time the mean values had largely stabilized). The significance of the correlation coefficients at $P< 0.05$, 0.01 and 0.001 are indicated by *, ** and *** respectively; ns = not significant. For rationale and details see text.

Mean Seasonal Trends

As an alternative method of examining the seasonal trends, the data for different months were averaged over years. *Figure 9* shows the mean monthly variation in single bunch weight and in weight per bunch of bunch components. The peaks in bunch weight, fruit weight and other main bunch components occurred in June to August and the minimum values in February. This analysis showed that seasonal variation in the average monthly values of bunch component ratios was generally not significant despite the apparent cycling of these when quarterly data were plotted. (This may have been due to the lack of synchrony in the cycles in different years.) Thus, significant mean monthly changes in O/B and K/B were not obtained so that the variation in oil and kernel yields per bunch was dependent mainly on changes in the bunch weight. F/B was an exception in that significant ($P< 0.001$) mean monthly variation was observed with a peak in August (*Figure 9a*) contributing to double peaks in the weights of total fruit and fruit components (*Figures 9* and *10*).

Fruit number per bunch and per unit frame weight likewise peaked in August although the mean single fruit weight was highest from April to July (*Figure 11*). The single fruit weight did not, therefore, peak in the same month as the total weight of fruit in a bunch. This is consistent with the lower fruit number per kg frame found at around the time of the peak in single fruit weight.

The maximum fruit number in August implies that pollination efficiency, if the cause of the variation in fruit number, would have been at its maximum in February/March (the expected time of anthesis). Likewise, minimal numbers in January and May imply minimal pollination efficiency in July/August and November/December respectively. Corley (1977) reported a minimum fruit set for bunches harvested in May and June in Johor, while marked seasonal reductions in fruit set, attributable to wet conditions during December to February, have recently occurred in Sabah (Rao and Law, 1998; Rao *et al.*, 2001). Poor pollination has been explained as being due to low populations or activity of the pollinating weevil and/or to low numbers of male inflorescences. Fruit number per kg frame weight was found in the present trial to be positively correlated with the number of anthesizing male inflorescences per palm six months earlier ($r= 0.56$; $P<0.001$). Fruit number per unit frame weight, when similarly lagged five or six months with respect to environmental variables, showed no significant correlation with mean monthly rainfall or depth of water table at the density trial site, but was significantly positively correlated ($r=0.82$; $P<0.001$) with mean monthly pan evaporation rate measured at a nearby weather station. This again implies better pollination during drier weather.

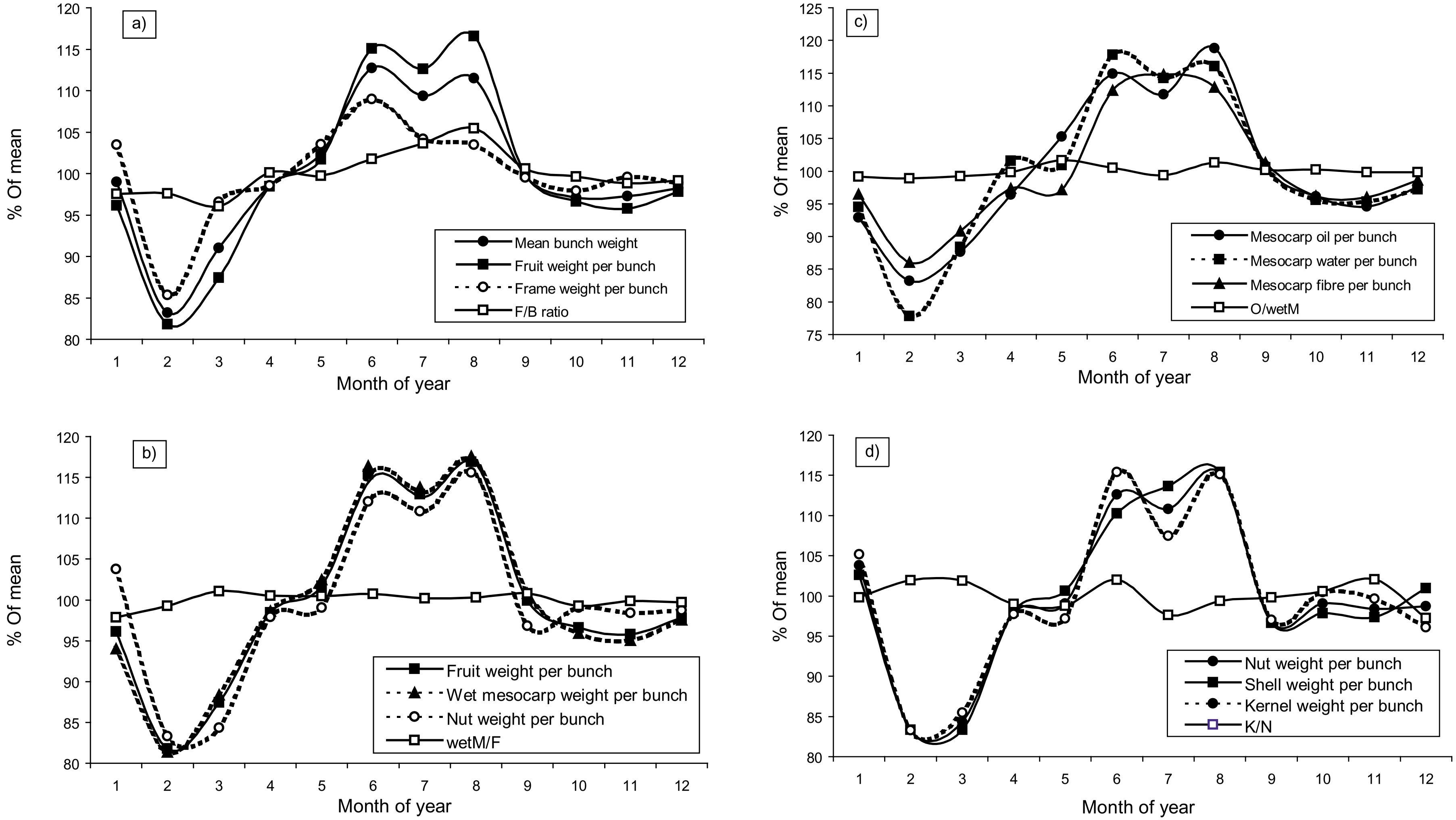

*Figure 9. Monthly variation in weights of bunch, fruit and nut components: means of seven years. The significance of differences between months is indicated in parentheses for each variable, where ns = not significant, * = significant at P<0.05; ** = significant at P<0.01 and *** = significant at P<0.001.*

(a) Bunch components: total bunch (***), fruit (***) and frame (*) weight per bunch and fruit/bunch ratio (***).
(b) Fruit components: fruit (***), wet mesocarp (***) and nut (**) weight per bunch and wet mesocarp/fruit ratio (ns).
(c) Mesocarp components: oil (***), water (***) and fibre (***) weight per bunch and oil/wet mesocarp ratio (ns).
(d) Nut components: nut (**), shell (**) and kernel (*) weight per bunch and kernel/nut ratio (ns).

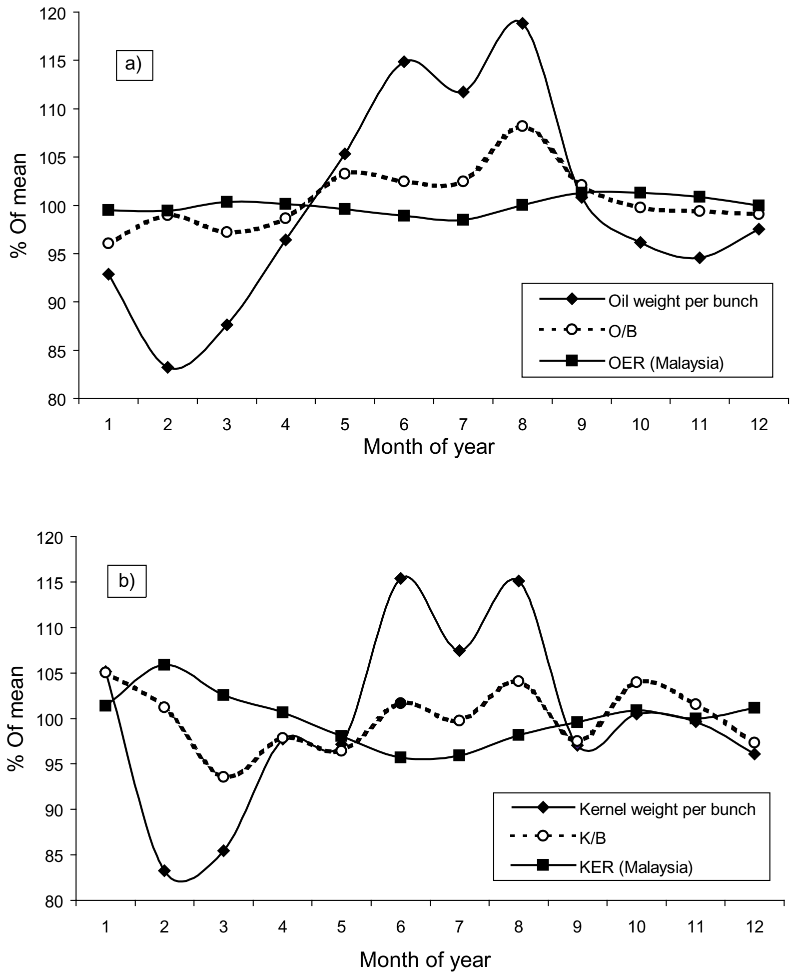

*Figure 10. Monthly variation in oil and kernel weights per bunch, oil/bunch and kernel/bunch ratios and country level mean oil extraction ratio (OER) and kernel extraction ratio (KER): means of seven years. The significance of differences between months is indicated in parentheses for each variable, where ns = not significant at P<0.05; * = significant at P<0.05 and *** = significant at P<0.001. (a) Oil weight per bunch (***), O/B (ns) and OER (*). (b) Kernel weight per bunch (*), K/B (ns) and KER (**).*

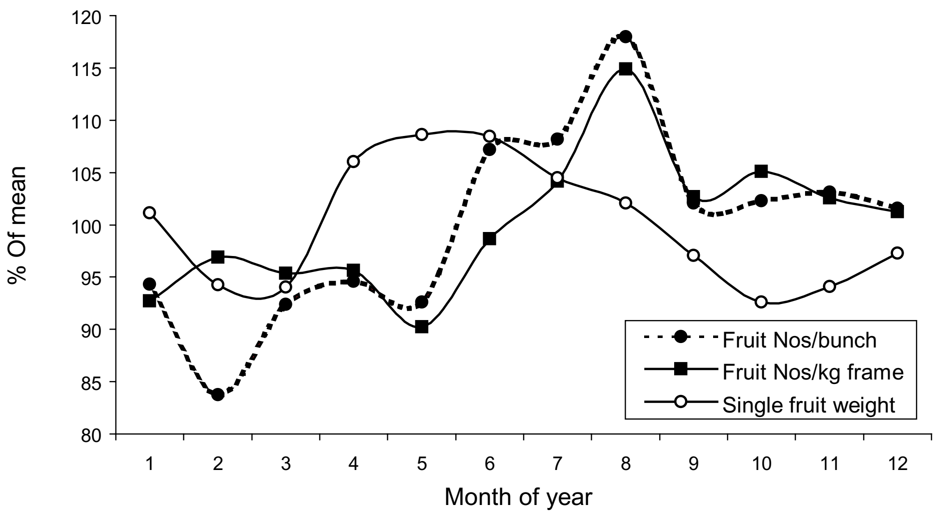

Figure 11. Monthly variation in fruit number per bunch, fruit number per unit frame weight and weight per individual fruit: means of seven years. Differences between months for fruit number per bunch and per unit frame weight were significant at P<0.05, and for single fruit weight at P<0.001.

CONCLUSION

Data presented in this and a previous paper (Henson and Mohd Tayeb, 2004) show that there were regular annual fluctuations in the mean weight of bunches as well as in bunch number. The latter is normally the more pronounced but any cycling in mean bunch weight will also have an influence on the cycling in total yield. The cycles in single bunch weight, though not extensively documented, are probably of widespread occurrence as suggested by their presence in two commercial plantings in contrasting environments. However, in these commercial plantings, unlike the density trial, the peaks in bunch number and weight did not normally coincide, resulting in no significant positive correlations between them (Henson and Mohd Tayeb, 2004), though there was often some overlap. What was surprising in the density trial was that the peaks in mean bunch weight coincided so precisely with the peaks in bunch number (Henson and Mohd Tayeb, 2004), thus exacerbating the cycles in the total bunch yield.

Thus, in the short-term, there appeared to be no direct antagonism between mean bunch weight and number implying a lack of any significant current competition for assimilates between individual bunches. The apparent antagonism between bunch number and mean bunch weight in the longer-term, as represented by the decline in bunch number and concomitant increase in mean bunch weight with age, would involve factors operating over longer-time scales. Thus, there will be a substantial lag period before the effect of high bunch load (represented by the combined action of both mean single bunch weight and number) can influence bunch number through its affects on sex differentiation and/or inflorescence abortion (*e.g.* Breure and Corley, 1992; Corley and Breure, 1992). Similarly, there will also be a delay before any effects are seen in the mean bunch weight.

Generally, the timing of impacts of fruit load on bunch number and weight differ, except that the effects on abortion and mean bunch weight appear to occur at similar times before harvest (Breure and Corley, 1992). In the density trial, abortion was not a significant factor so that the synchrony between the bunch weight and number cycles is even more surprising. The 10-month lag reported for bunch load effects on single bunch weight (Breure and Corley, 1992) is, furthermore, difficult to reconcile with the six months which are commonly observed to separate the yield peaks and troughs.

There seem to have been rather few previous studies that have examined seasonal variation in bunch weight and its constituents in detail. Broekmans (1957) reported seasonal changes in bunch weight of oil palm in West Africa and related these to the number of spikelets and flowers per bunch. Rao *et al.* (2001) reported mean monthly changes in F/B and other bunch component ratios, while there have been several examinations of the seasonal changes in OER. The key finding of the present study is that, with the exception of F/B, there was no significant seasonal variation in bunch component ratios, including O/B and K/B, when averaged over years. This contrasts with the presence over the same period of significant seasonal variation in oil and kernel extraction ratios on the national level (*Figure 10*). In the trial, O/B was more affected by longer-term trends such as the decline in O/M and in M/F.

F/B was obviously a dominant factor in determining the oil and kernel contents of the bunches. Its variation was most likely mainly due to variation in pollination efficiency (Mohd Basri *et al*., 1999; Mohd Haniff and Mohd Roslan, 2002), although in the present experiment, definitive evidence for this from fruit set records was lacking. Recording fruit set, in association with the standard laboratory bunch analysis, is therefore strongly recommended in future trials.

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