ISSN 2201-2796

Oil Palm (*Elaeis guineensis* Jacq.) Bunch Structure Variation and Limitations

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***Abstract*- Palm oil quality and quantity are dependent on fruit ripeness. In normal oil palm bunch development when the outer fruit are mature, inner fruit are still at earlier stages of development and maturation. While this variation and lack of maturation synchrony might be an acceptable evolutionary development, it is a major constraint to commercial production. Normal and abnormal bunch structures were investigated to determine their effects on yield. Substantial quantities, 38 - 81% of fruit produced did not reach maturity, and in one case 50% of fruit were not pollinated. This results in lost yield and wasted resources. By providing bunch structures conducive to equal fruit maturation, commercial yields could increase substantially, in excess of 100% in some cases. Palms with different or more open structures should be identified, assessed and the genes responsible identified. Development of bunch structures similar to those of date palm (*Phoenix dactylifera L.*) and sugar palm (*Arenga pinnata* (Wurmb) Merr.) should be investigated as they would provide unlimited fruit developmental space and allow maturation synchrony.**

***Index Terms*— peduncle, rachis, rachillae, spikelets, parthenocarpic, stenospermocarpic, abnormal bunch structure, potential yield**

I. Introduction

Oil palm yields have made limited progress over the last 20 to 30 years [1]. The reasons are many and varied however variation in fruit development and maturation plays a significant role in limiting the realisation of theoretical yield potential. Palm oil quality and quantity are dependent on fruit ripeness. In normal bunch development it is only the mature outer fruit that contribute significantly and efficiently to yield [2]. The inner fruit which can comprise several different maturation levels are not fully developed when the bunch is harvested. These immature fruit are a problem and require higher management inputs to maximise oil extraction. Over ripe fruit on the other hand have high levels of free fatty acids (FFA) that reduce oil quality. The solution is complex and the only system currently available to minimise these problems is fruit sorting based on maturation stage after sterilsation [3].

In plant breeding, maturation stages are combined to obtain data that allows milling responses to be predicted. It does not provide information on the cause, and most certainly does not address the problem. If the variations in fruit maturation are to be overcome or at least minimised then it is important to understand the factors responsible.

Variations in fruit development are the result of evolution. Oil palm flowers open first at the base and progress upwards and outwards (acropetal) thus fruit growth and development will follow a similar pattern. Combine this with issues of environment stresses and preferential resource allocation and we can begin to understand the variation in fruit development and maturation. In nature such variation is desirable as it extends the period over which fruit matures. As the outer fruit mature and abscise, the inner fruit continue to develop and mature. Long term survival of the species and of any seed dispersal animals is enhanced by the existing bunch structure.

Basic oil palm bunch structure consists of a peduncle (stalk), rachis (bunch stem), and rachillae (spikelets) which hold the flowers. Bunch size varies depending on genotype and environment. In nature this variation is not a problem, however from a commercial perspective where bunches are harvested on evidence of the first fruit becoming ripe, it means full yield potential cannot be achieved. On average only 30 - 60% of flowers develop to give a fruit to bunch ratio of 60 - 70% [4]. The problem is not so much in the percentage flowers that produce fruit, but in fruit maturation synchrony. Maturity in a commercial context is defined as the developmental stage where the extraction of oil quality and quantity is maximised.

The fact that fruit development is variable highlights the commercial limitations associated with bunch structure.

ISSN 2201-2796

Modifications to the bunch structure, in particular expanding the spikelet and fruit interspace may have some potential to increase yield by allowing improved pollination and fruit development. While elongation of the peduncle has been observed in many inflorescences, it has not been observed in the rachis or in the spikelets. The identification of naturally occurring palms with high levels of fruit developmental synchrony, or with elongated and more open bunch structures might be an efficient technique for improving fruit development and maturation, thereby increasing yield.

This aim of this paper is to raise awareness of the oil palm bunch structure variation and limitations.

II. Materials and Methods

Normal bunch (Figure 1) development and efficiency was investigated and a comparison made with bunches identified as having an abnormal structure (Figure 2). All bunches sampled were ready for harvesting.

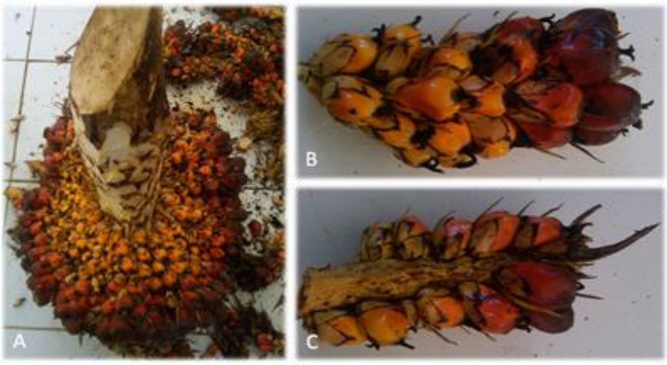

Fig. 1. Normal fruit bunch and spikelet structure showing variation in fruit development – (A) shows bunch dissection, (B) shows fruit development on the outer side of the spikelet (C) shows fruit development on the inner side of the spikelet

Four normal bunches, two large (>20kg) and two small (<20kg) and two abnormal bunches were harvested from blocks of similar ages. Fruit were counted and classified into four developmental groups; Ft1, Ft2, Ft3 and Ft4. These fruit are all developmentally normal; however they are at different stages of maturity. Fruit at Ft1 are physiologically mature i.e. mesocarp and endosperm development is complete and the maximum amount of oil has accumulated, fruit are ready for harvest. Ft2 fruit are in a late stage of development, however they are physiologically immature and not ready for harvest, Ft3 fruit show early stages of development after pollination; however they are physiologically very immature. Fruit Ft4 fruit have not been pollinated and therefore will not develop or contribute to yield. The empty fruit bunch (EFB) was weighed after fruit removal.

All palms are seedling grown and not clonally micro propagated. Data are presented only to provide examples of the variation and development that exists within a sample of commercial bunches. Data were used to determine the productive and non productive fresh biomass and to determine potential yield. Potential yield is based on the assumption that all fruit mature at the same time and is based on the average weight of the mature fruit (Ft1). No statistical analysis has been performed due to the small sample size.

Fig. 2. Abnormal bunch structure - (A) bunch B5 (B) bunch B6 - (C) shows dissection of bunch B5 – note the very short rachis and bifurcated terminal rachillae

III. Results and Discussion

Data from two large normal bunches; B1 and B2 are presented in Table 1. The total number of fruit is similar at 2918 and 2942; however spikelet numbers vary at 174 and 160 resulting in fruit / spikelet ratios of 16.7 and 18.3 respectively. Percentage fruit weight and numbers of fruit at the different developmental stages are very different, although individual fruit weights for each classification are similar. Bunch B1 has better fruit maturation distribution; however there is still only 55.17% of the bunch weight or 61.55% of total fruit numbers at the optimal developmental stage. EFB accounts for 25% of the total bunch weight. In bunch B2 fruit maturation is much worse with approximately equal numbers of fruit in all classifications. The high percentages of fruit highlight the importance of pollination and good fruit development. EFB accounts for 20.41% of total bunch weight. Potential yield is 5.09kg and 15.16kg for bunches B1 and B2 respectively. If we make the assumption that the bunch B2 was harvested prematurely then the outcomes might be similar to B1. It is possible that bunch B2 has suffered stress during bunch development as this would explain the lower EFB weight and slower maturation rate.

Table 2 presents data for two small bunches (B3 and B4). Bunch weight is the same at 9.80kg and total fruit numbers are similar at 936 and 1016 respectively. EFB is different as bunch B3 is 0.90kg or 9.18% of total bunch weight and B4 is 1.70kg or 17.35%. The primary difference lies in fruit maturation. Bunch B3 has 170 Ft1 fruit while B4 has 601. Interestingly B4 does not have any fruit at Ft2 stage. This result shows fruit development that is more commercially desirable. Unfortunately approximately one third of total fruit (395) are at

Ft3. Numbers of fruit at Ft4 are very low which indicates that pollination has been very effective. It is bunches such as this that need to be monitored to determine if the maturation response is stable or if it is the result of environmental stress.

The opposite has occurred with bunch B3 which has approximately 50% of its fruit at the Ft4 stage and limited, but similar numbers at the other stages. In this case pollination was not very effective. Individual fruit weight is higher in bunch B3 than all other bunches. Yield potential for bunch B3 is interesting as bunch weight would increase by 9.82kg which would be >100% increase in bunch harvest weight. Bunch B4 on the other hand would only increase by 0.69kg. The commercial objective is to have bunches with maximum fruit at Ft1 and little or no fruit at the other stages. Unfortunately fruit to spikelet ratio for bunch B4 is not available; however B3 at 8.5fruit/spikelet is low when compared with bunches B1 and B2. The primary difference between the large and small bunches is the EFB mass and the numbers of fruit. The EFB structure, while not proportional to fruit numbers for these samples is likely to play a significant role in pollination and fruit development. A greater EFB weight is consistent with a larger EFB structure. If the average EFB to total fruit ratio is calculated larger bunches have 2.3g EFB per fruit while smaller bunches have 1.3g. An interesting commercial aspect is that the small bunch, B3 had the highest individual average fruit weight for Ft1 (20g), Ft2 (16g) and Ft3 (11g) and the EFB to total fruit ratio is only 0.96g. While this is likely a resource allocation response to the poor pollination it does highlight the potential for low weight EFB to produce large fruit. The results do provide some insight into the complexity of bunch development and fruit maturation which can be used to direct further research.

Two abnormal bunches (B5 and B6) were harvested and analysed (Table 3). The abnormal bunches had a normal looking peduncle with a very short or extremely modified rachis and individual, open spikelets.

TABLE I. ANALYSIS OF LARGE BUNCHES (>20KG) WITH NORMAL STRUCTURE

Bunch No.	Classification	Wt. (kg)	% wt.	No. of fruit	% fruit	Av fruit wt. (g)	No. spikelets	Potential yield increase (kg)
B1	Ft1	19.20	55.17	1796	61.55	11	174	0.00
	Ft2	3.40	9.77	414	14.19	8		1.03
	Ft3	3.00	8.62	577	19.77	5		3.17
	Ft4	0.50	1.44	131	4.49	4		0.90
	EFB	8.70	25.00					0.00
	Totals	**34.80**	**100.00**	**2918**	**100.00**		**16.7 fruit/spikelet**	**5.09**
B2	Ft1	8.40	34.29	713	24.24	12	160	0.00
	Ft2	5.10	20.82	657	22.33	8		2.64
	Ft3	4.20	17.14	738	25.08	6		4.49
	Ft4	1.80	7.35	834	28.35	2		8.03
	EFB	5.00	20.41					0.00
	Total	**24.50**	**100.00**	**2942**	**100.00**		**18.3 fruit/spikelet**	**15.16**

TABLE II. ANALYSIS OF SMALL BUNCHES (<20KG) WITH NORMAL STRUCTURE

Bunch No.	Classification	Wt. (kg)	% wt.	No. of fruit	% fruit	Av fruit wt. (g)	No. spikelets	Potential yield increase (kg)
B3	Ft1	3.40	34.69	170	18.16	20	110	0.00
	Ft2	2.40	24.49	146	15.60	16		2.92
	Ft3	1.60	16.33	150	16.03	11		3.00
	Ft4	1.50	15.31	470	50.21	3		7.90
	EFB	0.90	9.18					0.00
	Total	**9.80**	**100.00**	**936**	**100.00**		**8.5 fruit/spikelet**	**9.82**
B4	Ft1	5.20	53.06	601	59.15	9		0.00
	Ft2	0.00	0.00	0	0.00	0		0.00
	Ft3	2.80	28.57	395	38.88	7		0.62
	Ft4	0.10	1.02	20	1.97	5		0.07
	EFB	1.70	17.35					0.00
	Total	**9.80**	**100.00**	**1016**	**100.00**			**0.69**

TABLE III. ANALYSIS OF TWO BUNCHES FROM A PALM WITH A DIFFERENT BUNCH STRUCTURE

Bunch No.	Classification	Wt. (kg)	% wt.	No. of fruit	% fruit	Av fruit wt. (g)	No. spikelets	Potential yield increase(kg)
B5	Ft1	3.30	39.76	220	39.43	15	18	0.00
	Ft2	2.50	30.12	202	36.20	12		0.53
	Ft3	1.20	14.46	134	24.01	9		0.81
	Ft4	0.01	0.12	2	0.36	5		0.02
	EFB	1.29	15.54					0.00
	Total	**8.30**	**100.00**	**558**	**100.00**		**31.0 fruit/spikelet**	**1.36**
B6	Ft1	2.10	38.18	127	33.51	17	7	0.00
	Ft2	1.50	27.27	156	41.16	10		1.08
	Ft3	0.70	12.73	89	23.48	8		0.77
	Ft4	0.03	0.55	7	1.85	4		0.09
	EFB	1.17	21.27					0.00
	Total	**5.50**	**100.00**	**379**	**100.00**		**54.1 fruit/spikelet**	**1.94**

The fruit bunch appeared more like a bunch of flowers rather than the normal bunch structure. Bunch weight and total fruit numbers are substantially different, very likely related to the low spikelet numbers. Bunch B5 is the larger of the two, with a bunch weight of 8.30kg while B6 weighs just 5.50kg. Individual fruit numbers and EFB weight are higher in bunch B5. Pollination in both bunches is very good, however fruit development is relatively uniform for stages Ft1, Ft2 and Ft3. Average fruit weight is higher than all other bunches except bunch B3. Potential yield is very low as would be expected given the openness of the bunch structure; 1.36kg for bunch B5 and 1.94kg for bunch B6. Fruit to spikelet ratio is very high at 31 and 54.1 for bunches B5 and B6 respectively. EFB to total fruit ratio is also very high at 263g per fruit. While overall bunch weights are low, potential yield is commercially very desirable. The high numbers of fruit at Ft1, Ft2 and Ft3 were surprising given the more open bunch structure.

Oil palm has been observed to preferentially allocate resources to younger bunches during periods of stress. Development of older bunches is delayed until favourable conditions return, and in some cases even stop never to start again. Even though bunch development may have stopped they can remain in this dormant state for quite some time. It is therefore possible that fruit development within the bunch is being delayed or stopped in a similar manner, relative to developmental stage. Once the outer fruit have matured and abscised then resources are available for allocation to the delayed fruit.

Despite the different structure and reduced numbers of spikelets, percentage fruit at Ft1 was not as high as expected. Dissection of the abnormal bunch shows some very interesting structural developments and highlights possible reasons for the low efficiency. The peduncle appears to be normal; however the rachis is very short and clearly shows some developmental irregularities. This accounts for the reduced numbers of spikelets. Several smaller spikelets were present on the rachis and had good fruit development, although the spikelets are clearly abnormal. From this short rachis a single terminal spikelet developed and eventually bifurcated before ceasing development. This terminal spikelet is larger than the others, and normal bunch spikelets. This aspect alone highlights the degree of developmental confusion that exists within this bunch structure. The fact that fruit were observed growing directly on the spikelet supports the structural development as spikelets and not separate rachises. A similar situation was observed in bunch B6 with a larger terminal and smaller lateral spikelets (Figure 3).

Fig. 3. Spikelets from the abnormal bunch (B6) showing the unusual developmental structure compared to Figure 2

Further inspection of the palm revealed that the fruit do not easily abscise from the bunch. These bunches are expressing delayed abscission which is a commercially beneficial trait when combined with virescens fruit, provided it does not interfere with the milling process. While hard bunch is a well known delayed abscission trait that causes milling problems, palms have been identified that have the delayed abscission trait (no loose fruit), but do not cause any milling problems (unpublished). The bunch structure shown in Figure 2 should not be confused with bunches that produce fruit on male spikelets (Figure 4).

Fig. 4. Bunch structure where female flowers have been produced on male spikelets and fruit have developed – in this case 100% of flowers are female

While the bunch structure appears very similar the cause is fundamentally very different. The basic inflorescence is male however a large proportion of the flowers are female. These bunches are in effect hermaphrodites (Figure 5). No bunch assessment was performed as fruit developmental was not suitable from a commercial perspective.

Fig. 5. Another example of a hermaphrodite inflorescence where fruit development has occurred on male spikelets – note the variation in fruit development

While it is not proposed to develop palms with this type of bunch structure, it does provide an ideal opportunity to assess a structure that is significantly more open than normal. Stability however might be a problem. Two abnormal bunches which developed prior to B5 and B6 were much smaller (Figure 6). These bunches were not harvested possibly due to the fact that there were no loose fruit to alert the harvester that these bunches were ready, or simply because they were abnormal. The presence of, and structure of, the rotten bunches supports the belief that the basic trait is stable in this palm, however it can also be seen that bunch development is not consistent as there exists variation in bunch size and fruit abortion.

Fig. 6. Bunches of rotted fruit with the different bunch structure

Interestingly fruit from bunches B5 and B6 contained no shell or endosperm (Figure 7). Fruit development is good and there is evidence of shell fibres and aborted ovules, consistent with a pisifera palm. Although technically possible, it is highly unlikely that these fruit are parthenocarpic; they may in fact be stenospermocarpic. Parthenocarpy is the development of seedless fruit without fertilization; stenospermocarpy produces seedless fruit through ovule abortion. While the actual cause of these seedless fruit is not known the latter is a distinct possibility given that pisifera is the paternal parent and is very likely a mutation itself.

If the large numbers of fruit that are constantly being recorded as parthenocarpic are truly seedless then it would be expected that a certain percentage would progress through to Ft1 stage, producing a mix of seeded and seedless fruit. Instances of seedless Ft1 fruit have been observed (unpublished), but not tested, and albeit only on one occasion.

Fig. 7. Dissected fruit from bunch B5 showing fruit with shell fibres and aborted ovules

While seedless fruit is considered a commercial trait in species such as citrus and water melon, this is not the case for oil palm where the kernel oil is a commercial product. Seedless fruit may however have some applications in locations where seasonal stresses limit yield. Fruit that only produce mesocarp may reduce resource demand, allowing resources that would otherwise be allocated to the endosperm and embryo, to be redirected towards mesocarp. In this way higher quantities of crude palm oil (CPO) might be possible, however it would be at the expense of kernel palm oil (KPO).

The results highlight the extent of the variation that exists within bunches in some commercial field plantings. If yields are to be increased then it is crucial to ensure that every fruit produced achieves its maximum potential, and for this reason efforts must be made to not only identify palms with more efficient bunch structures, but palms that are capable of efficient resource allocation, especially during periods of stress. Not only is it important to identify improved bunch structures within the *Elaeis* genus, but also to investigate other palm species.

Two palms that have bunch structures that might prove beneficial are date palm (*Phoenix dactylifera* L.) and sugar palm (*Arenga pinnata* (Wurmb) Merr.) (Figure 8). Both have bunch structures that provide significant improvements in developmental space for the fruit through their elongated peduncles, rachises and spikelets.

Fig 8 - Different bunch structure – left - Date palm (Phoenix dactylifera L.) and right - Sugar palm (Arenga pinnata (Wurmb) Merr.) - [6].

Date palm is an economically important food crop and is now naturalized in many parts of the world. It is a medium-sized palm growing to 21-31m tall [5]. Significant breeding and biotechnology research has been conducted, including sequencing of the date palm genome. *Arenga pinnata* is a medium-sized palm of economical important palm to tropical Asia [6]. It is very doubtful that any molecular research at all has been conducted into Arenga palms. Both palms have bunch structure that has a single, elongated peduncle and rachis from which multiple, long and pendulous rachillae emerge. Individual fruit are present on rachillae in a manner that allows for full development. There are however some aspects of the bunch development that are of concern. The rachillae in some cases are very long and there is variation between bunches in overall size and fruit set. These aspects are already observed in oil palm and are possibly in response to environmental stresses.

Before change can be initiated, it is important to consider our expectations and to understand the two basic options available. The first is that we modify our expectations to suit the palm; the second is that we modify the palm to suit our expectations. The first is very easy, but not always commercially desirable, the second, while commercially more desirable is much more complex and time consuming. The first option is almost never considered in our quest for dominance of the plant kingdom, and as for the second we are still in the very early stages of understanding the complexity of oil palm. This is evident by the fact that oil palm yields have made limited progress over the last 20 to 30 years [1].

While the aim of this paper is to raise awareness of the issues relating to oil palm bunch structure and how it affects yield, it is up to each interested party to explore the efficiency of their current and future planting material. Once researchers and breeders understand the limitations imposed by bunch structure they are in a better position to explore each and every option for improving yield.

IV. Conclusion

Oil palm bunch structure is by its very design commercially inefficient. The existing bunch structure does not allow for full flower fertilisation and fruit development as is evident by the amount of immature and non fertilised fruit at the time of harvest. The comparison of large and small normal bunches with bunches that have a different structure shows that in this particular case the abnormal bunch structure, while having less variation, is not more efficient in fruit development and maturation.

It is possible that the developmental variation is the result of preferential allocation of resources within the bunch. This produces an evolutionary maturation gradient and while this might suit oil palm very well it does constrain commercial development. The fact that elongation of the inflorescence peduncle has been observed in palms provides encouragement that the factors responsible can be developed within the inflorescence rachis and spikelet. By increasing the amount of developmental space available within the inflorescence, the potential exists to significantly increase bunch weight and oil yield, especially when compared to species such as *Phoenix dactylifera* and *Arenga pinnata*.

Without a major change in bunch structure and fruit maturation there appears little hope of really pushing yields beyond the current levels.

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