Development and maturation of fruits of two Indupalma OxG hybrids (*Elaeis oleifera* x *Elaeis guineensis*)

Desarrollo y maduración de frutos de dos híbridos OxG Indupalma (*Elaeis oleifera* x *Elaeis guineensis)*

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ABSTRACT

OxG hybrids are materials with characteristics notable for tolerance to pests and diseases, high quality oil and acceptable bunch production, but the physiological processes of growth and maturation of the fruits are not well known. For the two hybrid materials (Coarí x La Mé and Sinú-Coarí x La Mé), the physiological and biochemical changes during the growth and maturation of the bunches were studied in San Alberto, Cesar (Colombia) with a climate of 2,497 mm/year precipitation and 27°C. Female inflorescences in anthesis were selected and the changes in size, color, and oil content of the external, internal and red parthenocarpic fruits of the bunches were recorded from 98 days after anthesis (DAA). A completely random experimental design was used with five replications and 13 sample dates. In hybrid Coarí x La Mé, 70% of the oil in the fruits accumulated between 98 and 126 DAA and reached the maximum at 168 DAA, while in hybrid Sinú-Coarí x La Mé, more than 90% of the oil accumulated between 98 and 140 DAA, also reaching the maximum at 168 DAA. The external, internal and red parthenocarpic fruits of the bunches reached the maximum percentages of oil/dry mesocarp at the same time (day). It is possible to estimate the percentage of oil/moist mesocarp based on the moisture percentage of fresh fruits.

Key words: oil palm, plant physiology, oil synthesis, harvest criteria.

RESUMEN

Los híbridos OxG son materiales con características notables de tolerancia a plagas y enfermedades, mejor calidad del aceite y aceptable producción de racimos, pero no se conoce muy bien el proceso fisiológico de crecimiento y maduración de los frutos. En dos materiales híbridos (Coarí x La Mé y Sinú-Coarí x La Mé) se estudiaron en San Alberto, Cesar (Colombia) en un clima de 2.497 mm/año y 27°C, los cambios fisiológicos y bioquímicos durante el crecimiento y maduración de los racimos. Se seleccionaron inflorescencias femeninas en antesis y se registraron los cambios en tamaño, color y contenido de aceite de los frutos externos, internos y partenocárpicos rojos del racimo desde 98 días después de la antesis (DDA). Se utilizó un diseño experimental completamente al azar, cinco repeticiones y 13 fechas de muestreo. En el hibrido Coarí x La Mé, el 70% del aceite en los frutos se acumuló entre 98 y 126 DDA y alcanzó el máximo 168 DDA, mientras que en el híbrido Sinú-Coarí x La Mé más del 90% del aceite se acumuló entre 98 y 140 DDA alcanzando también el máximo 168 DDA. Los frutos externos, internos y partenocárpicos rojos del racimo alcanzaron al mismo tiempo el máximo porcentaje de aceite/mesocarpio seco. Es posible estimar el % de aceite/mesocarpio húmedo con base en el % de humedad de los frutos frescos.

Palabras clave: palma de aceite, fisiología de plantas, síntesis de aceite, criterios de cosecha.

Introduction

The OxG hybrids (*Elaeis oleifera* H.B.K. Cortes x *Elaeis guineensis* Jacq.) are a valuable alternative for the production of oil palm due to their tolerance to the pests and diseases that limit plantations, high bunch production and high quality oil (Peláez *et al*., 2010); due to the high content of unsaturated fatty acids and appreciable contents of carotenes and vitamin E (Le Guen *et al*., 1993; Rey *et al*., 2003; Rey *et al*., 2004; Rocha *et al*., 2006). One of the characteristics of OxG hybrid bunches is the presence of several parthenocarpic fruits in comparison to normal fruits. Red parthenocarpic fruits have oil and color that are similar to those in normal fruits, while the white or abortive parthenocarpic fruits do not have oil or kernels (Yáñez *et al*., 2006). The changes of the lipids during the growth, maturation, postharvest and senescence of the fruits are significant in the oleaginous species, due to the acidic phenomenon that can be generated by commercial oils and fats that these crops produce (Burton, 1982). In oil palm, the lipid content in the fruits changes considerably during maturation (Corley and Tinker, 2009), which means

Received for publication: 23 May, 2013. Accepted for publication: 1 November, 2013.

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that an understanding of the physiological and biochemical processes of maturation is of great importance to the improvement of harvested product quality and the prevention of high losses during production, storage, and commercialization of the bunches (Cayón, 1998). Considering that these processes are still not completely known for the OxG hybrids, the aim of this study was to analyze the growth, development and maturation of the internal, external, and parthenocarpic bunch fruits in the OxG hybrid materials developed for Indupalma's improvement program.

Materials and methods

This study was carried out in April and October of 2010 on the plantation of Indupalma (San Alberto, Cesar, Colombia), located at km 10 of the vía Panamericana, in the town of San Alberto (Cesar), at 125 m a.s.l., with a maximum temperature of 34°C and a minimum temperature of 22°C, 72.3% RH, annual precipitation of 2,497 mm, annual evaporation of 1,208 mm and 2,130 h of sunshine/year, and agroecological conditions that correspond to a Tropical Moist Forest (TMF, Espinal and Montenegro, 1963, Holdridge, 2000). Two Indupalma OxG hybrid materials were analyzed: 1) hybrid A (Coarí x La Mé), 3 years of age and 2) hybrid B (Sinú Coarí x La Mé), 4 years of age. Female inflorescences in anthesis were pollinated and marked in accordance with the available vegetative material, 65 for hybrid A (five replicates for 13 samples) and 39 for hybrid B (three replications for 13 samples) with a completely random experimental design. Every 14 d, from 14 to 175 days after anthesis (DAA), five marked bunches for hybrid A and three for hybrid B were collected for the respective analyses of growth and development.

Dry weight and oil

The accumulation of dry weight (DW) was evaluated in each of the bunch components, taking samples of the rachises, spikelets, and fruits from 14 to 84 DAA. From 98 DAA until 175 DAA, the fruits were classified as external, internal or red parthenocarpic. In the external and internal fruits, the mesocarp was separated from the kernel, the DW of each component of the fruit was determined and the percentage of oil/fresh mesocarp, the percentage of oil/dry mesocarp, and the percentage of mesocarp moisture were calculated according to the NIFOR method for the analysis of bunches (Corley and Tinker, 2009). Harvesting of the bunches was done according to age and, before cutting the bunch, the number of loose and cracked fruits was recorded. The harvest bunches were detached, the rachises were weighed, and then a random sample of 3,500 g of spikelets was taken; and finally the external, internal and parthenocarpic fruits were separated, counted and weighed. For each group of obtained fruits, a random sample of 30 fruits was taken according to the recommendation of Rao *et al.* (1983) and CIRAD (1980). In order to ensure that the fruit sample was representative, the following conditions of Yáñez *et al.* (2000, 2006) were followed:

$$\frac{\text{weight of sample fruits spikelets}}{\text{number of sample fruit spikelets}} - \frac{\text{weight of 30 fruit sample}}{30} \leq \pm 0.5\ \text{g} \quad (1)$$

The sample fruits were stripped to separate the mesocarp from the kernel, the kernels of each sample were weighed and the weight of the mesocarp was determined by the difference between the weight of the fruits and the weight of the kernels. Afterwards, samples of approximately 10 g were weighed out from the fresh mesocarp of external, internal and parthenocarpic fruits and dried in an electric oven at 105° C for more than 6 h until constant weight (Prada and Romero, 2012). Oil was extracted by the Soxhlet method from the dry mesocarp samples of external, internal and parthenocarpic fruits, using hexane as a solvent (Prada and Romero, 2012).

Oil acidity

To determine acidity, the method based on the AOCS Official Method was used, in which the free fatty acids are neutralized with sodium hydroxide and the quantity of sodium hydroxide used for the neutralization is proportioned to the percentage of free fatty acids (FFA) present in the oil (Prada and Romero, 2012).

Statistical analysis

For the quantitative variables, the percentage of oil in the mesocarp of external, internal, and parthenocarpic fruits and the percentage of oil in the bunches were determined with respect to an analysis of variance with a level of significance of $P \leq 0.05$. For the sample periods, the Tukey ($P \leq 0.05$) comparison of means test was used and, to analyze the ratio between the percentage of oil in moist and dry mesocarp and the percentage of moist mesocarp, a lineal regression test was used. For all the statistical procedures, the statistical software SAS® v9.2 (Sas Institute, Cary, NC) was employed.

Results and discussion

Dry weight and oil

In the two hybrids, the accumulation curves of oil and DW during the development of the bunch (Fig. 1) were adjusted

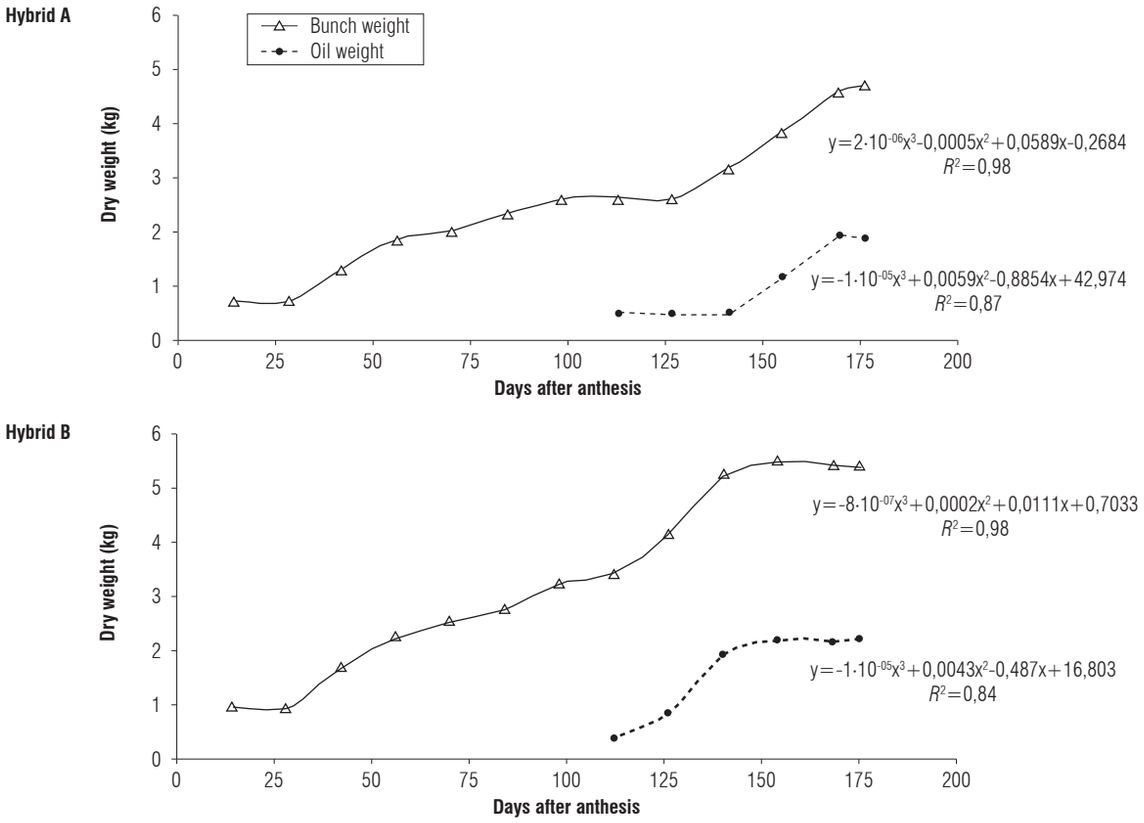

FIGURE 1. Accumulation of dry matter and oil during the development of bunches in two Indupalma OxG hybrids.

to a polynomial model of growth with a initial logarithmic of slow growth (15 to 30 DAA for bunches and 112 to 140 DAA for oil) followed by a exponential phase of progressive growth of dry weight (30 to 125 DAA for bunches and 140 to 150 DAA for oil) evidenced by the slope of the curve and finally a lineal phase of accelerated and constant growth with stability in the slope of the curve (126 to 168 DAA for bunches and 140 to 178 DAA for oil) and a final initial phase of the senescence (175 DAA for bunches and 175 DAA for oil). The physiological maturity of bunches occurs with the maximum accumulation of DW. In Hybrid A, the dry weight of bunches reached the maximum at 175 DAA, the rapid accumulation of oil in the fruits of the bunches started at 140 DAA and reached the maximum at 175 DAA, while in Hybrid B, the maximum dry weight of bunches was reached at 154 DAA, the rapid accumulation of oil in the fruits of the bunches started earlier (112 DAA) and also reached the maximum at 175 DDA. This growth model of the bunches also showed that the *E. guineensis* Ténera material and some OxG hybrids presented a higher DW of the bunches at 112 DAA and a higher accumulation of oil in the bunches between 170 and 180 DAA (Ruiz, 2005; Suárez *et al*., Preciado *et al*., 2011a, 2012).

Accumulation of oil in the fruits

Figure 2 shows that, in both materials, between 98 and 126 DAA, the percentage of oil/dry mesocarp (ODM) was higher in the internal fruits than in the external and parthenocarpic fruits, but from 140 DAA until 175 DAA, the ODM of the internal, external and parthenocarpic fruits did not differ significantly between the two hybrids. These results agree with other studies on oil palm (Bealing, 1987; Durán *et al*., 2004) and OxG hybrids (Preciado *et al*., 2011a), where significant differences in the ODM of internal and external fruits of bunches were not found. The advantage of parthenocarpic fruits of the OxG hybrids is that they develop and mature like normal, fertile fruits but contain more oil due to their higher proportion of mesocarp which can reach 98% (Bastidas *et al*., 2007; Preciado *et al*., 2011a). The fruits of the OxG Corpoica Elmira hybrids have ODMs from 52.3 to 75.8% when they are harvested between 150 and 190 d after pollination (Preciado *et al*., 2011b).

The color change of the fruits during the final stages of

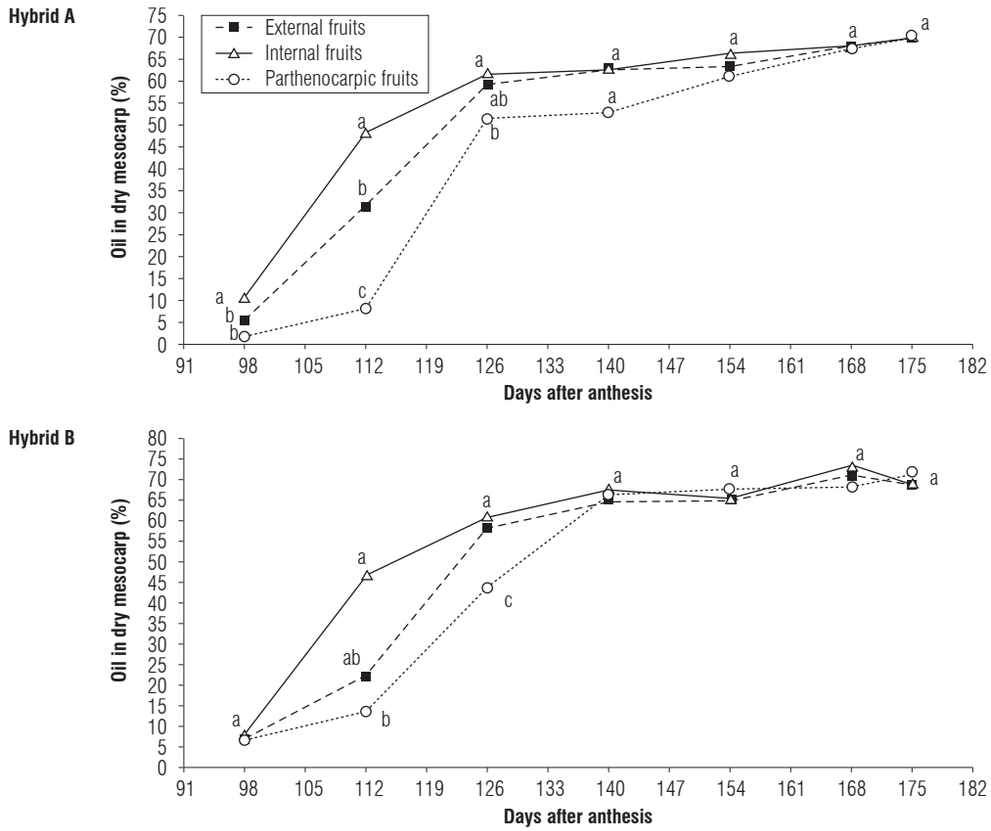

FIGURE 2. Accumulation of oil during the growth of external, internal and red parthenocarpic fruits of the bunches of two Indupalma OxG hybrids. Means with different letters indicate significant differences according to Tukey test ($P \leq 0.05$).

Days after anthesis	External fruits	Internal fruits	Parthenocarpic fruits
98			
112			
154			

FIGURE 3. Pigmentation changes during maturation of external, internal and red parthenocarpic fruits in Indupalma OxG hybrids.

maturation began between 98 and 112 DAA (Fig. 3). The reddish-orange pigmentation due to the carotenes present in the oil became apparent in both materials from 112 DAA in the internal fruits and from 126 DAA in the external and parthenocarpic fruits. Suárez *et al.* (2012) also observed changes in the reddish-orange pigmentation in OxG hybrid fruits from 112 DAA, starting with the normal, internal fruits. Rincón *et al.* (2013) observed that the dark orange color at ripening was homogeneous on the exocarp of all fruits. Hormaza *et al.* (2011) reported that the progress of maturation of the fruits in the spikelets of OxG hybrids presented acropetal forms while, in *E. guineensis* materials, they were basipetal.

Figure 4 demonstrates that the parthenocarpic fruits of the bunches contained a higher percentage of oil than the normal fruits (internal and external). Based on this, Fig. 5 highlights the contribution of red parthenocarpic fruits to the percentage of oil in the bunches of the two hybrids. In the bunches of these hybrids, the parthenocarpic fruits had a higher quality than the external and internal fruits (considered normal fruit) and so contributed more oil to

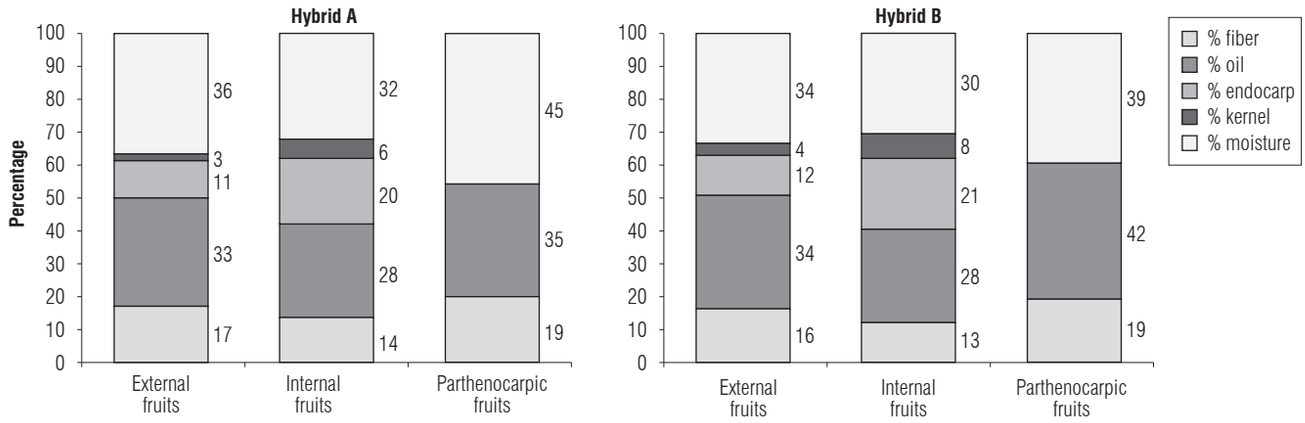

FIGURE 4. Distribution (%) of the moisture, fiber, kernel, oil and endocarp in external, internal and red parthenocarpic fruits in two Indupalma OxG hybrids.

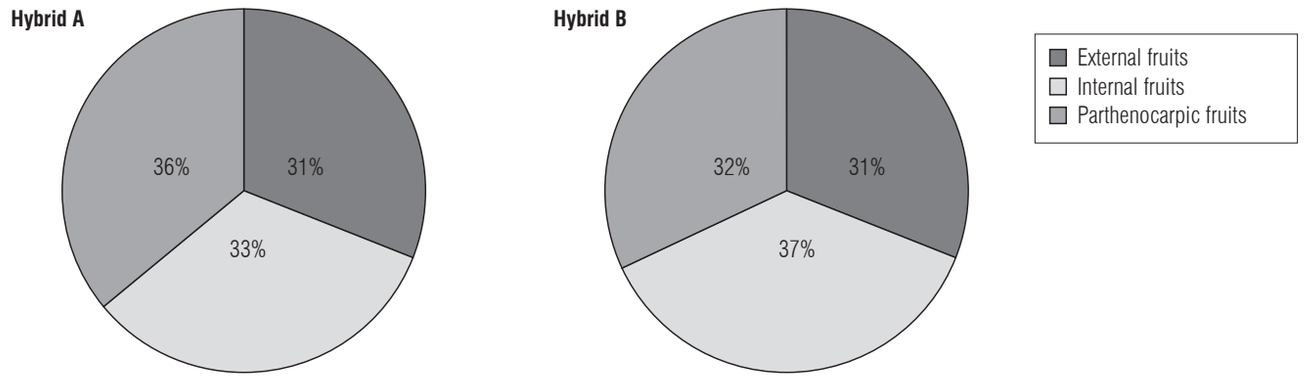

FIGURE 5. Oil contribution (%) of external, internal and red parthenocarpic fruits to the bunches in two Indupalma OxG hybrids.

the bunches than normal, external and internal fruits (35% in hybrid A and 42% in hybrid B). Bealing (1987) demonstrated that the oil content of external and internal fruits of the spikelets of mature bunches is similar and that all fruits reached physiological maturity (maximum oil content) at the same time.

Oil/bunch, loose and cracked fruits

Figure 6 presents the ratio between the total oil content in the bunches, expressed as the weighted average of the percentage of oil/dry mesocarp of the bunches, in the dry mesocarp of the external, internal, and parthenocarpic fruits and the average number of loose and cracked fruits during the final maturation period of the bunches. In both hybrids, the oil/bunch content increased at a high rate between 98 and 126 DAA and at a moderate rate between 126 and 175 DAA when the bunches reached physiological maturity. The phenomenon of fruit cracking in the bunches was seen from 140 DAA in Hybrid B and from 168 DAA in Hybrid A, and increased at a constant rate until 175 DAA when more than 15 cracked fruits per bunch were observed. The detachment or natural abscission of the fruits started towards 154 DAA and increased to more than 20 loose fruits per bunch at 175 DAA. At the time of harvest of the bunches (175 DAA), no significant differences were registered between the two hybrids for the number of loose fruits (24 and 27) or for the number of cracked fruits (17 and 20). In the two hybrids, there were no significant differences in the percentage of oil/dry mesocarp of the bunches between 168 and 175 DAA, however, the number of loose fruits was considerably higher in this last period. Prada *et al.* (2011), in *E. guineensis,* found that it takes between 140 and 154 DAA to have bunches ready to harvest, while Rincón *et al.* (2013) found it takes 191 DAA to harvest *E. oleifera* x *E. guineensis* in Colombia. Therefore, the interspecific hybrid OxG takes longer to have bunches ready to harvest, an important criterion for an oil palm OxG commercial plantation. In *E. guineensis,* the change in color from black to orange on the fruits and the number of loose fruits were observed as indicators of maturation, so these two criteria are used as harvest criteria (Taillez *et al.*, 1993; Corley and Tinker, 2009). OxG hybrid Recently, in OxG hybrids, it was observed that the fruits in early stages exhibited an intense green color and then turned

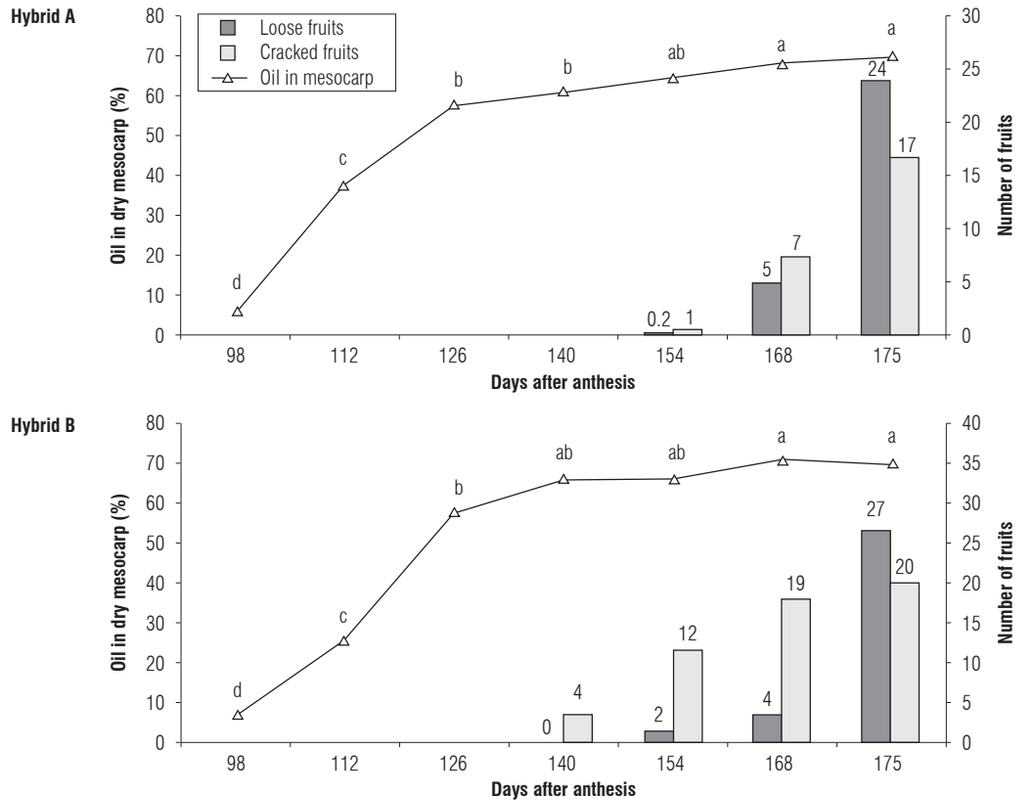

FIGURE 6. Ratio between oil in the mesocarp (%) and the number of loosed and cracked fruits of the bunches in two Indupalma OxG hybrids. Means with different letters indicate significant differences according to Tukey test ($P \leq 0.05$).

from a yellow-light orange to dark orange (Rincón *et al*., 2013). However, in the OxG hybrids, fruit detachment is not always an indicator of bunch maturation, however, fruit cracking has been observed to coincide with maturation (Gómez and Silva, 2010; Suárez *et al*., 2012).

Oil acidity

Oil acidity (FFA) of the two hybrids was low from 140 until 168 DAA and although it slightly increased to 175 DAA (1.35 in hybrid A and 1.2 in hybrid B), the values were below that required by plant extractors (Fig. 7). Since the fruits of the OxG hybrids remain attached to the bunch spines for a longer time and because the more unsaturated oil has less acidity, the bunches can maintain longer after being cut, which permits the establishment of harvest cycles of 21 d year round (Amblard *et al*., 2000). Therefore, it would be more convenient to apply to the hybrids, as the harvest criteria, the presence of cracked fruits per bunch rather than their detachment, as proposed by Gómez and Silva (2010). Nevertheless, it is important to take into account that one standard of maturation does not exist for all circumstances and, even on a single farm, it is necessary to make adjustments in accordance with the topography and climatic conditions (Toong and Yeang, 1993).

Correlation between moisture and oil in the mesocarp of the fruit

High coefficients of determination (R^2>0.95) were found for the correlation between the percentage of moisture in the mesocarp and the percentage of oil in moist mesocarp, both for hybrid A and hybrid B (Fig. 8). Since a lineal relationship exists between the content of moisture and oil in the mesocarp of the fruits and because one can assume that the amount of fiber in the mesocarp is constant for each genotype, it is possible to estimate the content of oil/moist mesocarp indirectly based on the content of moisture of the fresh fruits. With the lineal regression equations generated for the two hybrids in this study, one can estimate the content of oil in the mesocarp using the following formula:

$$\%\ \text{of oil in moist mesocarp} = -0.95 \times \%\ \text{mesocarp moisture} + 82.4 \quad (2)$$

Yañez *et al*. (2000) proposed the use of an indirect method for estimating the content of oil in the fruits for monitoring

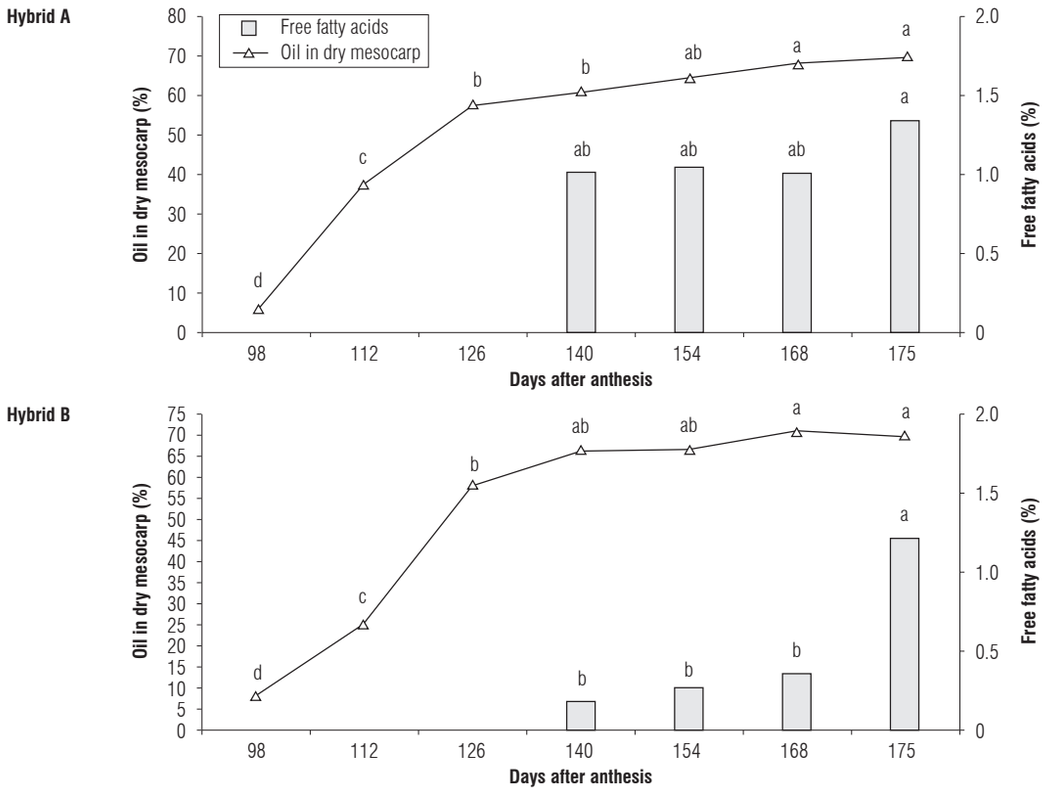

FIGURE 7. Ratio between oil in mesocarp (%) and acidity (FFA) in two Indupalma OxG hybrids. Means with different letters indicate significant differences according to Tukey test ($P \leq 0.05$).

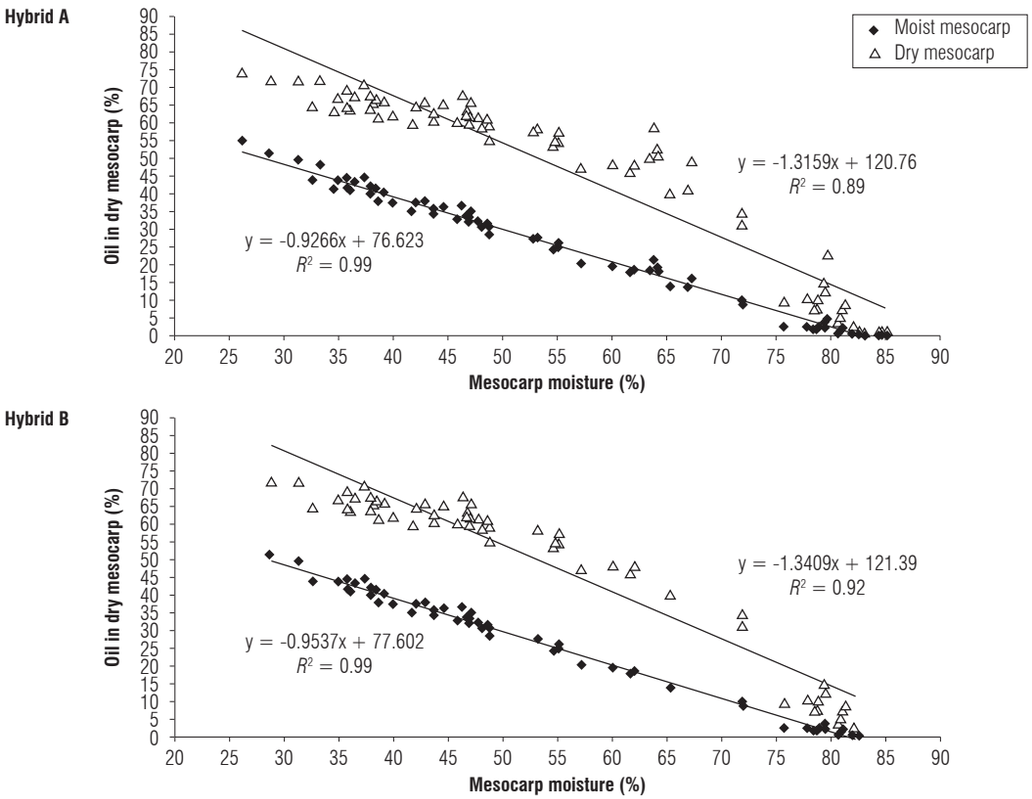

FIGURE 8. Lineal regression between moisture and oil of the mesocarp of the fruits of two Indupalma OxG hybrids.

the maturation state of the bunches at the entrance of plant extractors, with which Soxhlet extraction in a laboratory would not be necessary.

Conclusions

The harvest criterion for Hybrid A is the presence of at least 5 loose fruits or 7 cracked fruits when the bunch has around 168 DAA.

The harvest criterion for hybrid B is the presence of at least 4 loose fruits or 18 cracked fruits when the bunch has approximately 168 DAA.

It is possible to estimate the percentage of oil/moist mesocarp based on the percentage of moisture of the fresh fruits.

Acknowledgements

The authors wish to thank the managing, technical and operating personnel of Indupalma for the financial and technical support given in the development of this study.

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