http://journal.unoeste.br/index.php/ca/index
DOI: 10.5747/ca.2021.v17.n1.a422
ISSN on-line 1809-8215

Colloquium Agrariae

Submetido: 28/07/2020 Revisado: 01/12/2020 Aceito: 23/02/2021

Genotypic values and genetic correlations for components and oil content of bunch of hybrids between caiaué and dendê

Alessandra Ferraiolo de Freitas[1], Ricardo Lopes[2], Raimundo Nonato Vieira da Cunha[2], Antônio José de Abreu Pina[3], Marcos Deon Vilela Resende[4], Rui Alberto Gomes Júnior[1]

[1]Embrapa Amazônia Oriental, Belém PA.[2]Embrapa Amazônia Ocidental, Manaus, AM. [3]Grupo Marborges, Moju, PA. [4]Embrapa Café, Brasília, DF. E-mail: alessandra.ferraiolo@embrapa.br

Abstract

Interspecific hybridization between *Elaeis oleifera* and *Elaeis guineensis* (HIE OxG) is explored in plant breeding programs to meet the demand for resistant cultivars to fatal yellowing, which is the biggest phytosanitary problem in *E. guineensis* plants in South America, including Brazil. In addition to resistance to fatal yellowing, cultivars should have high oil yield, which depends directly on bunch production and oil content in the bunches (O/FFB). The obtaining of genetic gains in O/FFB for OxG requires information on the genotypic values of the breeding population and the understanding of how the components of the bunch are related to this characteristic in this type of material. Thus, the objective of this work was to estimate genotypic values and genetic correlations for bunch components and analyze the potential of using these components in the selection of gains for O/FFB. The physical composition and oil content in mesocarp of 840 bunches from 39 HIE OxG F1 progenies were analyzed. Genotypic values for bunch components were estimated using the procedure REML/BLUP and were obtained from genetic correlations between them. All evaluated components presented genetic variation with possibility of gains through selection, especially the oil content in the bunch (O/FFB), which presented variability above 23%. The selection for O/FFB will mainly result in bunches with a higher fruit proportion over the weight of the bunch (TF/FFB), greater oil contents in mesocarp of normal and parthenocarpic fruits, and lower proportion of empty spikelets. Considering the high and positive correlations between O/FFB and the evaluated characteristics and the practicality of evaluation, the characteristics with higher potential for indirect selection to increase O/FFB are TF/FFB and proportion of mesocarp in normal fruits.

Keywords: *Elaeis guineenses*; *Elaeis oleifera*; plant breeding; REML/BLUP.

Valores genotípicos e correlações genéticas para componentes e teor de óleo do cacho de híbridos entre caiaué e dendê

Resumo

A hibridação interespecífica entre caiaué e dendê (HIE OxG) é explorada no melhoramento genético para atender a demanda de cultivares resistentes ao amarelecimento fatal (AF), maior problema fitossanitário do dendê na América do Sul, incluindo o Brasil. Além da resistência ao AF, as cultivares devem apresentar alta produtividade em óleo, que depende diretamente da produção de cachos e do teor de óleo nos cachos (O/CFF). Para obter ganhos genéticos em O/CFF de HIE OxG é necessário conhecer os valores genotípicos da população de melhoramento e como os componentes do cacho estão relacionados a esta característica neste tipo de material. O objetivo deste estudo foi estimar valores genotípicos e correlações genéticas para componentes de cacho e analisar o potencial de uso desses componentes na seleção para ganho em O/CFF. Análises de composição física e do teor de óleo no mesocarpo foram realizadas em 840 cachos de 39 progênies HIE OxG F1. Valores genotípicos para os componentes de cacho foram estimados por procedimento REML/BLUP e obtidas às correlações genéticas entre eles. Todos os componentes avaliados apresentaram variação genética com possibilidade de ganhos por seleção, com destaque para valores do teor de óleo no cacho (O/CFF) superiores a 23%. A seleção para O/CFF resultará, principalmente, em cachos com maior proporção de frutos sobre o peso do cacho (F/CFF) e maiores teores de óleo no mesocarpo de frutos normais e partenocárpicos, bem como, com menor proporção de espiguetas vazias. Devido as correlações altas e positivas com O/CFF e pela praticidade de avaliação, as características com maior potencial para seleção indireta para aumento de O/CFF são F/CFF e proporção de mesocarpo nos frutos normais.

Palavras-chave: *Elaeis guineenses*; *Elaeis oleifera*; melhoramento genético; REML/BLUP.

Introduction

Oil palm (*Elaeis guineensis* Jacq.), has an African origin, and is responsible for 40.24% of world production of vegetable oil, with approximately 82 million tons (73.5 palm pulp (mesocarp) oil and 8.6 palm nut oil) (USDA, 2019). Caiaué (*Elaeis oleifera* HBK Cortés), is a semi-domesticated species native to the American continent, but which is not exploited in commercial plantations, mainly due to its low oil productivity (RIOS *et al.*, 2015), which is due, (i) to the lower proportion of mesocarp in the fruit, and (ii) lower oil content of the mesocarp when compared to oil palm fruits (LIEB *et al.*, 2017). However, caiaué is of great importance in interspecific genetic improvement of oil palm, principally due to its resistance to Fatal Yellowing (FY), a characteristic that is transmitted to (HIE) F1 interspecific hybrids (LOPES *et al.*, 2012). FY is a currently unclassified an etiological anomaly which has already decimated tens of thousands of hectares of oil palm in Latin America, including Brazil. It is considered the main phytosanitary problem facing oil palm culture in Latin America. There is no method of controlling FY other than genetic resistance, which has only been found so far in caiaué. Consequently, interspecific hybrids of caiaué and oil palm have become the only option for commercial oil palm in areas where the anomaly is present.

Palm oil, extracted from the mesocarp of the fruit, is the main commercial product of oil palm culture, and palm oil productivity directly depends on the productivity of fresh fruit bunch (FFB) and their palm oil content. Bunch palm oil content depends on bunch physical composition and the oil content in the mesocarp (RAO *et al.*, 1983; DURÁN *et al.*, 2004; BABU, 2008; ISA *et al.*, 2011; KESHVADI *et al.*, 2011; RAFII *et al.*, 2013), components that are determined by plant genotype, and also by environmental factors. Accordingly, in interspecific genetic improvement it is essential that the genotypic components of fruit bunch characteristics and oil composition are evaluated, genotypic values are estimated and genetic correlations between these components are obtained. Such information is essential for test the population's oil production potential, and also because the selection will affect the main components that determine the fresh fruit bunch palm oil content.

The genetic correlations between bunch components permits inference of how bunch composition would be altered in an improved population, and thus predict which should be the target of positive (increase in value) or negative (decrease in value) selection. When the genetic correlation between two characteristics is high, the possibility of indirect selection can be assessed, which also requires considering the costs, logistics and infrastructure, complexity and time required to evaluate the characteristics. This is important, especially when there are a large number of genotypes to be evaluated and it is necessary to make a preliminary selection tests for progeny. In the oil palm variety *tenera* (Dura x Pisifera), Krualee *et al.* (2013) identified a positive genetic correlation between palm oil productivity and the characteristics fresh fruit bunch weight (r^2 = 0.56), palm oil content per fresh fruit bunch (r^2 = 0.46), proportion of fruits in bunch weight (r^2 = 0.34) and proportion of mesocarp in fruit weight (r^2 = 0.32), indicating the potential of these characteristics for genetic gains in palm oil productivity via indirect selection. Studies of genetic correlations, similar to those carried out in oil palm, are also necessary in improvement studies using progenies inter-specific hybrids of caiaué with oil palm. This will generate information that helps to define interspecific genetic improvement strategies.

In a study by Chaves *et al.* (2018) to evaluate HIE OxG fruit bunch components obtained from the crossing of different sources of caiaué and palm oil, a wide variation was found for characteristics such as the proportion of mesocarp in normal and parthenocarpic fruits, oil content in the mesocarp and in the bunch. Other authors have also observed variations of genetic origin for bunch components or mesocarp and bunch oil contents in the HIE OxG (CADENA *et al.*, 2013; GONZÁLEZ *et al.*, 2013; PINTO *et al.*, 2019).

The genotypic values for HIE OxG bunch physicochemical characteristics, and the genetic correlations between these characteristics, are properties of the population and can be altered with selection, if there is appropriate genetic variability. In such cases, it is important that studies are carried out specifically on the populations of interest for use in genetic improvement, and with awareness of the palm oil content selection potential of the specific population. This is because selection can alter bunch components, so that if becomes necessary to establish the potential of these components for indirect selection to increase fresh fruit bunch oil content. The population whose potential for genetic improvement the current study investigated has high genetic variability (GOMES JÚNIOR *et al.*, 2019), and was obtained from interspecific crosses using female caiaué plants from the population Manicoré (Amazonas, Brazil), and male plants from oil palm from improved lines of the La Mé population (Côte d'Ivoire, Africa), both used in the development of the first Brazilian HIE cultivar of caiaué x oil palm (CUNHA; LOPES, 2010). The genetic origin of this hydrid population means high variability for bunch components can be safely inferred. This makes it necessary to evaluate the physico-chemical composition of hybrid progenies fresh fruit bunches to estimate genotypic values of the most important components, so as to obtain the oil content in a fresh fruit bunch, as well as to analyze how such components are genetically associated. This can be done by studying genetic correlation.

The objective of the current study, therefore, was to estimate genotypic values for components and oil content in fresh fruit bunches of interspecific hybrid of caiaué with oil palm, to obtain the genetic correlations between these components, to analyze how selection can change the physico-chemical composition of fresh fruit bunches in the population, and the feasibility of indirect selection.

Materials and Methods

Three experiments were set-up in February 2007, in a contiguous area of 17.6 hectares on the Grupo Marborges property, in Moju Municipality, Pará State, Brazil (coordinates 1°58’42”S, 48°36’50”W). The soil is of the dystrophic Latosol type (EMBRAPA, 2013). According to Köppen's classification, the local climate is Af (ALVARES *et al.*, 2013), with an average rainfall of 2,786 mm (2007 to 2016), and a concentration of rainfall in the first third of the year. The locality is classified as preferred oil palm cultivation, according to ZAE Oil Palm (RAMALHO FILHO *et al.*, 2010).

Thirty-nine full sibs progenies obtained from controlled crosses involving 32 female caiaué genitors of Manicoré origin, from 18 families, and 13 male oil palm genitors of La Mé origin, were evaluated, seven from three families of LM10T descent, and six from four families of LM2T descent (Table 1). Two experiments included one with 14 and one with 15 progenies, with two progenies common to the three experiments (RUB 1195 and RUB 1213). The caiaué and oil palm genitors used in the crossings came from the populations that gave rise to the first interspecific caiaué x oil palm cultivar (HIE OxG), known as BRS Manicoré (RNC 26031) (CUNHA; LOPES, 2010).

The experiments were conducted using a randomized block design with four replications and 12 plants per plot (four lines of three plants); as a border, one line was used at each end of the experiment and one plant at the end of each line. Planting occurred at a density of 143 plants ha^{-1}, and was conducted in accordance with the management practices adopted by the Marborges Group (PINA, 2010), where assisted pollination is an main differential of the oil palm production system. Bunches were collected between January 2015 (seventh year after planting) and October 2016 (eighth year after planting), in individuals randomly sampled from the aforementioned experiments. Harvesting occurred the point of maturation when at least one fruit per bunch was loose. In total, 840 bunches were analyzed, from seven to 37 bunches per progeny, and 64 and 82 bunches in the two progenies used as common controls for the three experiments.

Analyzes were carried out with fresh fruits bunches (FFB), in the field and immediately post-harvest, and determined 15 bunch components: bunch weight (FFBW), in kg; proportion of stalk in the bunch (S/FFB); proportion of empty spikelets in the bunch (ES/FFB); proportion of total fruits in the bunch (TF/FFB); proportion of normal fruits in the bunch (NF/FFB); proportion of parthenocarpic fruits in the bunch (PF/FFB); total number of fruits per bunch (T_{NF}/FFB); number of normal fruits per bunch (N_{NF}/FFB); number of parthenocarpic fruits per bunch (N_{PF}/FFB); mean weight of normal fruits (MW_{NF}), in grams, mean weight of parthenocarpic fruits (MW_{PF}), in grams; proportion of mesocarp in the weight of normal fruits (M/NF); oil content of the mesocarp of normal fruits (O/M_{NF}), as a percentage; oil content in mesocarp of parthenocarpic fruits (O/M_{PF}), as a percentage; and oil content per bunch (O/FFB), as a percentage.

The methodology used to analysis bunches was developed by the Nigerian Institute for Oil Palm Research (RAO *et al.*, 1983). Immediately after the harvest, by weighing on a scale, the weight per fresh fruit bunch (FFB) was obtained. Then, the spikelets with fruits were separated from the stalk (S), which was weighed. Fruits were manually removed from the spikelets, classified as either normal (NF) or parthenocarpic (PF), and these then counted and weighed separately. Empty spikelets (ES) were also weighed. In bunches weighing less than 14 kg, all spikelets were sampled, while for those weighing more than this value half of the spikelets were sampled. Aborted fruits and normal and parthenocarpic fruits with injuries to the pericarp/mesocarp were discarded. A random sample of 50 NF and 50 PF was taken, and then used to determine the proportion of mesocarp in the fruit weight, and to obtain samples for determining mesocarp oil content. Extraction of the mesocarp from fruits was performed manually, with the aid of a stainless-steel knife. Fresh mesocarp was dried at 105 °C for 24 h in an oven with air circulation and renovation. After drying, the mesocarp was cooled in a desiccator at room temperature, weighed and crushed in a domestic processor (Arno brand, model LN 73) until particles of approximately 2.0 mm were obtained. The extraction of oil from the samples was carried out with Soxhlet, using petroleum ether as a solvent, and a 5 g sample of dry mesocarp.

The palm oil content per bunch (O/FFB) (Equation 1) was determined by the sum between the percentage of oil in the NF (Equation 2), and the percentage of oil in the PF (Equation 3).

$$\frac{O}{FFB}(\%) = \frac{O_{NF}}{FFB}(\%) + \frac{O_{PF}}{FFB}(\%) \quad (1)$$

$$\frac{O_{NF}}{FFB}(\%) = \frac{1}{10.000}\left[\left(\frac{NF}{FFB}(\%)\right)\left(\frac{M}{NF}(\%)\right)\left(\frac{O}{M_{NF}}\right)(\%)\right] \quad (2)$$

$$\frac{O_{PF}}{FFB}(\%) = \frac{1}{10.000}\left[\left(\frac{PF}{FFB}(\%)\right)\left(\frac{M}{PF}(\%)\right)\left(\frac{O}{M_{PF}}\right)(\%)\right] \quad (3)$$

where $\left(\frac{NF\ or\ PF}{FFB}\right)$ is the percentage of NF or PF per bunch (Equation 4), $\left(\frac{M}{NF\ or\ PF}\right)$ is the percentage of mesocarp for NF or PF (Equation 5) and $\left(\frac{O}{M_{NF\ or\ PF}}\right)$ is the percentage of oil in the mesocarp of NF or PF (Equation 6).

$$\frac{NF\ or\ PF}{FFB}(\%) = 100\left[\left(\frac{NF\ or\ PF}{spikelets\ with\ fruits}\right)\left(\frac{FFB-S}{FFB}\right)\right] \quad (4)$$

$$\frac{M}{NF\ or\ PF}(\%) = 100\left(\frac{(NF\ or\ PF)_{subsample} - Endocarp}{(NF\ or\ PF)_{subsample}}\right) \quad (5)$$

$$\frac{O}{M_{NF\ or\ PF}}(\%) = \frac{1}{100}\left[(100 - mesocarp\ moisture\ content_{NF\ or\ PF}(\%))\left(\frac{O}{M_{NF\ or\ PF(dry)}}(\%)\right)\right] \quad (6)$$

Table 1. Genealogy of the 39 progenies of the F1 interespecific hybrids between caiaué and oil palm (HIE OxG F1).

Progeny	Caiaué (female genitor)		Oil palm (male genitor)			Trial
	Family	Genitor code	Descendents	Family	Genitor code	
RUB 1198	RUC 107	RU 2842 D	LM 2 T	LM 12437	RU 2707 P	3
RUB 1226	RUC 102	RU 78 D	LM 2 T	LM 12785	RU 53 P	1
RUB 1271	RUC 224	RU 1578 D	LM 2 T	LM 13582	RU 2691 P	1
RUB 1210	RUC 76	RU 3308 D	LM 2 T	LM 13582	RU 2691 P	2
RUB 1227	RUC 102	RU 2846 D	LM 2 T	LM 13582	RU 2692 P	1
RUB 1283	RUC 103	RU 92 D	LM 2 T	LM 13582	RU 2692 P	1
RUB 1196	RUC 107	RU 2841 D	LM 2 T	LM 13582	RU 2692 P	3
RUB 1274	RUC 224	RU 1578 D	LM 2 T	LM 13582	RU 2692 P	1
RUB 1199	RUC 109	RU 3099 D	LM 2 T	LM 13582	RU 2693 P	3
RUB 1211	RUC 76	RU 3111 D	LM 2 T	LM 13582	RU 2693 P	2
RUB 1218	RUC 79	RU 2900 D	LM 2 T	LM 13582	RU 2693 P	2
RUB 1219	RUC 79	RU 2901 D	LM 2 T	LM 13582	RU 2693 P	2
RUB 1208	RUC 80	RU 2905 D	LM 2 T	LM 13582	RU 2693 P	3
RUB 1232	RUC 104	RU 3079 D	LM 2 T	LM 13582	RU 2749 P	1
RUB 1202	RUC 93	RU 1608 D	LM 2 T	LM 13582	RU 2749 P	3
RUB 1234	RUC 105	RU 3189 D	LM 10 T	LM 12011	RU 2710 P	1
RUB 1201	RUC 109	RU 3089 D	LM 10 T	LM 12011	RU 2710 P	3
RUB 1221	RUC 114	RU 101 D	LM 10 T	LM 12011	RU 2710 P	2
RUB 1223	RUC 224	RU 1578 D	LM 10 T	LM 12011	RU 2710 P	2
RUB 1213	RUC 76	RU 1724 D	LM 10 T	LM 12011	RU 2710 P	1, 2, 3
RUB 1204	RUC 96	RU 3170 D	LM 10 T	LM 12011	RU 2710 P	3
RUB 1225	RUC 102	RU 2839 D	LM 10 T	LM 12011	RU 56 P	1
RUB 1231	RUC 103	RU 92 D	LM 10 T	LM 12011	RU 56 P	1
RUB 1233	RUC 104	RU 3101 D	LM 10 T	LM 12011	RU 56 P	1
RUB 1195	RUC 107	RU 1604 D	LM 10 T	LM 12011	RU 56 P	1, 2, 3
RUB 1203	RUC 95	RU 1778 D	LM 10 T	LM 12252	RU 2698 P	3
RUB 1212	RUC 76	RU 3111 D	LM 10 T	LM 12252	RU 2700 P	2
RUB 1214	RUC 77	RU 2914 D	LM 10 T	LM 12252	RU 2700 P	2
RUB 1215	RUC 78	RU 3359 D	LM 10 T	LM 12252	RU 2700 P	2
RUB 1205	RUC 96	RU 3123 D	LM 10 T	LM 12252	RU 2700 P	3
RUB 1206	RUC 96	RU 3169 D	LM 10 T	LM 12252	RU 2700 P	3
RUB 1209	RUC 43	RU 2787 D	LM 10 T	LM 12252	RU 2733 P	2
RUB 1224	RUC 102	RU 2845 D	LM 10 T	LM 13751	RU 2729 P	2
RUB 1197	RUC 107	RU 2842 D	LM 10 T	LM 13751	RU 2730 P	3
RUB 1200	RUC 109	RU 3089 D	LM 10 T	LM 13751	RU 2730 P	3
RUB 1217	RUC 224	RU 1578 D	LM 10 T	LM 13751	RU 2730 P	2
RUB 1220	RUC 79	RU 1588 D	LM 10 T	LM 13751	RU 2730 P	2
RUB 1277	RUC 79	RU 1586 D	LM 10 T	LM 13751	RU 2730 P	1
RUB 1250	RUC 97	RU 1605 D	LM 10 T	LM 13751	RU 2730 P	1

The phenotypic values obtained during bunch analyzes were used to estimate the progeny genotypic values for each component. These were then used in the calculation of the genetic correlations between the bunch components. Genotypic values were obtained via mixed linear models using the REML/BLUP procedure, and Selegen-Reml/Blup software (RESENDE, 2016), according to the statistical model $y = Xr + Zg + Wp + Tb + e$, where *y* is the data vector; *r* is the population effects vector (assumed to be fixed), plus the general average (includes the population and sub-sample average); *g* is the genotypic effects vector (assumed to be random) ; *p* is the parcel effects vector (random); *b* is the block effects vector (assumed to be random) and *e* is the errors or residuals vector (random). The capital letters *X, Z, W* and *T* represent, respectively, the incidence matrices for the effects *r, g, p* and *b*.

Results and Discussion

Ripeness influences the results of bunch physico-chemical analysis. Accordingly, so that physico-chemical analysis results represent the real genotypic values of the evaluated progenies, it is key that bunches to be analysed are harvested at the appropriate maturation point. In the final stages of palm fruit maturation oil accumulation in the mesocarp is accompanied by loss of water, but without an increase in non-oily solids content. Consequently, a low proportion of oil in the mesocarp of normal (O/M_{NF}) or parthenocarpic (O/M_{FP}) fruits implies either a high content of non-oily solids or a high water content, which indicates an immature bunch (HENSON, 2001). In the current study, negligible genetic correlations were observed between normal fruit mesocarp moisture content (O/M_{NF}, r^2 = 0.04), and parthenocarpic fruit mesocarp moisture content ($O/M_{PF,}$ r^2 = 0.04), indicating that the assayed bunches were harvested at the appropriate maturation, and this point was standardized for progeny evaluation.

Variation for progeny genotypic values was assayed for all physico-chemical components of each evaluated bunch (Table 2). Overall mean bunch weight (FFBW) for all progenies was 16.1 kg, with a range of 14.2 kg and 18.4 kg, a result similar to those obtained for FFBWs of HIE OxG in a variety of locations and with genitors of other origins. In the municipality of Rio Preto da Eva, AM, Brazil, for HIE OxG hybrids obtained from different origins, Lopes *et al.* (2012) reported an average FFBW of 13.5 kg, and 16.2 kg for the best FFBW for caiaué progeny of Manicoré origin. In the municipality of Una, Bahia, Brazil, Pinto *et al.* (2019) evaluated HIE OxG progenies of the same origin as those evaluated in the current study, and obtained a mean FFBW of 16 kg. In the municipality of Barranca de Upía, Colombia, Rincón *et al.* (2013) evaluated HIE OxG progenies from crosses between caiaué of Coari origin and oil palm of La Mé origin, and recorded a mean FFBW of 17.0 kg. The results indicate that current FFBW values are similar to those from other interspecific hybrids populations, but with genetic variation and, therefore, the possibility of altering the FFBW via selection. It should be noted that it is not desirable that oil palm bunches are too heavy since, as the harvest is manual, very heavy bunches would overload the harvester during the process of harvesting and loading the bunches.

The overall progeny mean for genotypic value of bunch oil content (O/FFB), the main characteristic of bunch analysis, was 22.56%, with a minimum of 19.81% and a maximum of 24.86%. The five top ranked progenies had O/FFB values close to or above 23% (Table 2). The average populational genotypic value for O/FFB (22.56%) was higher than the maximum phenotypic value reported by Rincón *et al.* (2013) (21.6%) for HIE OxG (Coari x La Mé) (phenological stage 807). Genetic improvement programs seek to increase O/FFB to the maximum possible. The higher the oil extraction rate, the greater the amount of oil obtained per ton of bunch produced (CORREDOR *et al.*, 2017). Thus, an increase in O/FFB results not only in greater palm oil productivity, but in a greater amount of oil produced per ton of bunch transported and processed, thus contributing to a reduction in palm oil production costs. The O/FFB values obtained for the HIE OxG progenies appear high when compared to those obtained in international palm genetic improvement programs (between 17 and 24%: CORLEY; TINKER, 2016), which indicates high population potential for gain with genetic selection to increase bunch palm oil content.

The average progeny normal fruit mesocarp oil content genotypic value (O/M_{NF}) was 45.02% (min. 42.87% and max. 46.91%), with oil content for parthenocarpic fruits (O/ M_{PF}) being 43.52% (min. 41.04% and max. 45.25%). In HIE OxG breeding experiments from Colombia, the upper reported O/M_{NF} limit was 47% (CORLEY; TINKER, 2016), a value similar to the 46.91% found in the current study. Therefore, the values found here are similar to those obtained in populations of interspecific breeding programs in other countries, confirming the population's potential for genetic improvement of increasing palm oil production.

Table 2. Genotypic values for the main characteristics of the HIE OxG bunches.

PROGENY	O/FFB	FFBW	S/FFB	ES/FFB	TF/FFB	NF/FFB	M/NF	O/M_{NF}	PF/FFB	O/M_{FP}
RUB 1211	24.23^{1}	15251^{29}	8.58^{33}	21.33^{37}	65.94^{3}	45.79^{11}	72.46^{2}	45.95^{3}	20.50^{24}	44.82^{2}
RUB 1208	23.91^{2}	16051^{23}	8.80^{25}	21.11^{38}	65.16^{6}	41.01^{24}	70.92^{7}	45.09^{11}	24.35^{12}	45.73^{1}
RUB 1199	23.38^{3}	17452^{6}	8.54^{35}	21.46^{36}	66.11^{2}	41.92^{21}	69.83^{15}	45.39^{8}	24.61^{9}	43.23^{12}
RUB 1250	22.91^{4}	15792^{25}	9.45^{5}	22.77^{32}	62.97^{25}	37.47^{30}	70.55^{9}	45.14^{10}	25.42^{6}	43.46^{6}
RUB 1274	22.89^{5}	18069^{3}	8.56^{34}	20.88^{39}	66.59^{1}	51.42^{2}	68.55^{28}	45.89^{4}	15.83^{36}	43.23^{11}
RUB 1204	22.70^{6}	14359^{38}	9.32^{7}	25.96^{5}	60.37^{34}	28.79^{38}	71.32^{5}	43.61^{20}	31.15^{3}	44.59^{3}
RUB 1196	22.58^{7}	16776^{12}	8.99^{11}	22.77^{33}	63.91^{14}	46.16^{9}	69.18^{22}	45.77^{5}	18.05^{30}	44.45^{4}
RUB 1227	22.47^{8}	16415^{17}	9.14^{8}	23.27^{23}	63.12^{21}	44.61^{14}	68.80^{25}	46.51^{2}	18.62^{28}	42.89^{13}
RUB 1220	22.44^{9}	14328^{39}	8.76^{26}	23.03^{26}	63.68^{16}	39.59^{27}	71.49^{4}	43.18^{24}	24.11^{13}	42.61^{18}
RUB 1218	22.27^{10}	16428^{16}	8.69^{29}	22.80^{31}	65.00^{7}	43.09^{17}	69.41^{21}	43.78^{17}	22.30^{16}	41.96^{25}
RUB 1203	22.26^{11}	15245^{30}	9.56^{2}	25.82^{6}	61.16^{32}	29.00^{37}	71.04^{6}	41.72^{35}	31.52^{2}	43.45^{7}
RUB 1210	22.25^{12}	18453^{1}	8.65^{31}	24.16^{15}	62.77^{26}	46.68^{7}	69.14^{33}	46.55^{1}	16.15^{35}	42.68^{16}
RUB 1219	22.13^{13}	16563^{14}	8.60^{32}	23.42^{22}	64.54^{9}	46.25^{8}	67.88^{35}	45.21^{9}	18.58^{29}	42.67^{17}
RUB 1215	22.11^{14}	16078^{22}	8.98^{12}	24.67^{11}	61.93^{28}	37.05^{31}	71.99^{2}	42.61^{31}	24.63^{8}	42.42^{22}
RUB 1200	22.11^{15}	15397^{28}	8.26^{39}	22.82^{30}	65.86^{4}	45.21^{12}	67.80^{37}	44.34^{15}	21.05^{20}	41.78^{31}
RUB 1232	22.10^{16}	17622^{5}	8.93^{14}	22.12^{34}	64.79^{8}	42.63^{18}	68.25^{31}	43.59^{21}	22.51^{15}	42.11^{24}
RUB 1283	22.00^{17}	16828^{11}	9.01^{10}	22.85^{29}	64.09^{11}	49.39^{3}	69.55^{18}	44.78^{14}	15.07^{38}	42.46^{19}
RUB 1213	21.93^{18}	16185^{20}	8.91^{16}	23.89^{20}	63.06^{22}	41.48^{22}	69.49^{20}	43.76^{19}	21.61^{19}	42.45^{20}
RUB 1195	21.93^{19}	16185^{19}	8.91^{17}	23.89^{19}	63.06^{23}	41.48^{23}	69.49^{19}	43.76^{18}	21.61^{18}	42.45^{21}
RUB 1271	21.92^{20}	18347^{2}	8.54^{36}	22.93^{27}	64.23^{10}	46.86^{6}	68.24^{32}	44.93^{12}	17.67^{31}	41.75^{32}
RUB 1198	21.91^{21}	15954^{24}	8.51^{37}	24.03^{17}	63.06^{24}	42.44^{19}	72.88^{1}	44.89^{13}	20.68^{23}	38.42^{39}
RUB 1217	21.79^{22}	14708^{36}	8.91^{15}	23.12^{24}	63.81^{15}	47.41^{5}	69.61^{16}	43.51^{23}	16.80^{34}	42.73^{14}
RUB 1277	21.72^{23}	14839^{35}	8.84^{22}	24.22^{14}	63.13^{10}	40.33^{26}	70.12^{13}	42.88^{26}	22.77^{14}	41.43^{33}
RUB 1205	21.68^{24}	16340^{18}	8.82^{24}	23.05^{25}	63.52^{27}	28.12^{39}	68.16^{33}	40.62^{39}	34.92^{1}	41.11^{35}
RUB 1234	21.64^{25}	15497^{27}	9.46^{4}	26.97^{2}	60.36^{35}	33.19^{36}	68.61^{27}	42.63^{30}	26.14^{5}	43.44^{8}
RUB 1233	21.61^{26}	16615^{13}	8.73^{28}	24.23^{13}	61.83^{30}	36.97^{32}	69.57^{17}	42.80^{28}	24.76^{7}	42.14^{23}
RUB 1224	21.55^{27}	15136^{31}	8.76^{27}	24.02^{18}	64.06^{12}	52.75^{1}	67.83^{36}	45.49^{7}	11.53^{39}	43.30^{9}
RUB 1223	21.47^{28}	17013^{10}	8.90^{19}	23.76^{21}	63.38^{18}	43.59^{16}	68.10^{34}	43.10^{25}	20.06^{27}	42.72^{15}
RUB 1221	21.37^{29}	16479^{15}	9.33^{6}	25.77^{7}	59.92^{38}	35.02^{34}	68.51^{30}	42.82^{27}	24.40^{11}	44.06^{5}
RUB 1202	21.35^{30}	16134^{21}	8.35^{38}	21.97^{35}	65.49^{5}	46.05^{10}	68.53^{29}	41.91^{34}	20.50^{25}	40.92^{36}
RUB 1226	21.32^{31}	17261^{7}	8.94^{13}	25.70^{8}	60.55^{33}	45.18^{13}	68.88^{24}	45.75^{6}	15.30^{37}	41.84^{28}
RUB 1206	21.27^{32}	15075^{32}	8.88^{21}	26.66^{4}	60.25^{36}	33.29^{35}	70.09^{14}	41.05^{38}	26.3^{14}	43.25^{10}
RUB 1209	21.22^{33}	17153^{9}	9.53^{3}	22.87^{28}	63.99^{13}	47.56^{4}	67.35^{38}	43.84^{16}	16.82^{33}	41.24^{34}
RUB 1225	21.21^{34}	15744^{26}	8.83^{23}	26.95^{3}	60.25^{37}	38.83^{28}	70.45^{10}	43.56^{22}	21.03^{21}	41.79^{30}
RUB 1214	21.15^{35}	14898^{34}	8.89^{20}	24.92^{10}	62.30^{27}	37.66^{29}	68.70^{26}	41.65^{36}	24.55^{10}	41.80^{29}
RUB 1197	21.08^{36}	14567^{37}	8.68^{30}	24.67^{12}	63.20^{19}	42.38^{20}	70.34^{11}	42.22^{32}	20.95^{22}	40.11^{38}
RUB 1231	20.92^{37}	17776^{4}	9.13^{9}	24.10^{16}	61.85^{29}	44.21^{15}	70.79^{8}	41.56^{37}	17.62^{32}	41.92^{26}
RUB 1212	20.66^{38}	14940^{33}	9.80^{1}	27.42^{1}	58.75^{39}	36.22^{33}	70.19^{12}	42.64^{29}	21.92^{17}	41.89^{27}
RUB 1201	19.81^{39}	17245^{8}	8.90^{18}	25.38^{9}	61.28^{31}	40.73^{25}	66.18^{39}	42.00^{33}	20.44^{26}	40.15^{37}
Mean	22.56	16.1	8.76	24.12	62.95	39.91	68.07	45.02	23.08	43.52
Maximum	24.86	18.4	9.56	27.611	66.43	51.15	72.08	46.91	36.39	45.25
Minimum	19.81	14.2	8.14	21.2039	58.78	26.45	64.18	42.87	13.16	41.04

O/FFB - Oil content in the bunch (%), FFBW - Bunch weight (kg), S/FFB - Ratio of stalk to bunch (%), ES/FFB - proportion of empty spikelets in bunch (%), TF/FFB - Proportion of total fruits in bunch (%), NF/FFB - Proportion of normal fruits in bunch (%), M/NF - Proportion of mesocarp in normal fruits (%), O/M_{NF} - Oil content of normal fruits mesocarp (%), PF/FFB - proportion of parthenocarpic fruits in bunch (%), and O/M_{PF} - oil content of parthenocarpic fruits mesocarp (%). Superscript numbers indicate the progeny classification according to the decreasing value of the variable (column).

For the proportion of fruits per bunch (TF/FFB), the mean progeny genotypic value was 62.95% (range 58.78 to 66.43%). Such values are higher than those observed in HIE OxG progenies of the same origin evaluated by Pinto *et al.* (2019), who found a mean TF/FFB of 51.3% (between- progeny range, 44.4 to 56.1%). In the study by Pinto *et al.* (2019) assisted pollination was not performed, which explains why TF/FFB value were lower than in the current study, which deployed assisted pollination, a practice that increases fruiting rates in both normal and parthenocarpic fruits (SOCHA *et al.*, 2019). The mean TF/FFB observed in HIE OxG was lower than the 60% and 65% normally found in oil palm (CORLEY; TINKER, 2016), which supports the data in González *et al.* (2013) that HIE OxG bunches have a higher proportion of parthenocarpic fruits compared to those of oil palm. The rate of fruit fixation in the HIE OxG bunches is influenced by the genotype, and also the pollination (SOCHA *et al.*, 2019). Therefore, regardless of genetic selection, assisted pollination will increase the proportion of fruits in the weight per bunch. The observed results indicate that there is genetic variability for TF/FFB in the evaluated population. Thus, it would be possible to select progeny genotypes to increase the average population values for these characters.

The mean progeny genotypic value for the proportion of normal fruits per bunch (NF/FFB) was 39.91% (min. 26.45%, max. 51.15%), and 23.08% (min. 13.16% and max. 36.39%) for the proportion of parthenocarpic fruits per bunch (PF/FFB). In an evaluation of 12 HIE OxG progenies of the same origin as the current study, conducted in Una municipality, Bahia, Brazil, Pinto *et al.* (2019) reported an average of 51.3% (min. 46.3%, max 56.1%) for NF/FFB and 35.5% (min. 29.7% and max. 43.3%) for PF/FFB. The differences in results between progenies of the same genetic origin can be explained by reduced genetic representativeness, since Pinto *et al.* (2019) evaluated 12 only progenies, against the 39 used in the current study. In addition, the authors did not use assisted pollination, and there may also be environmental differences between the evaluation sites. In HIE OxG with assisted pollination, Rincón *et al.* (2013) reported an average of 45.8% for NF/FFB and 18.6% for PF/FFB, higher and lower values, respectively, than those observed in the current study. For progenies to have a higher proportion of normal fruits in the bunch is desirable since existing palm oil extracting presses are optimized for normal fruits, which have a seed. They are less efficient at extracting palm oil from parthenocarpic fruits, which are seedless. The results observed indicate that, although the population analyzed in the current study showed good fruit production, it is necessary to exploit existing genetic variability to increase the NF/FFB ratio and reduce that of PF/FFB. This should contribute to an overall increase in bunch oil content yield.

In the current study, the mean for the proportion of mesocarp in normal fruits (M/NF) was 68.07% (range 64.18 to 72.08%), less than the 70.5% reported by Pinto *et al.* (2019) for progenies of the same origin. As previously discussed, this difference can be attributed to genetic representativeness and environmental conditions, plus variations in studied characteristic evaluation procedures. According to Corley and Tinker (2016), in HIE OxG, M/NF is influenced by the oil palm genitor used in interspecific crossing, particularly by its endocarp classification category (dura, thick endocarp; tenera, thin; pisifera, lacking endocarp or with only traces present). According to the authors, when dura oil palm genitors were used to obtain HIE OxG, the M/FN values were lower values than when tenera and pisifera forms were used (40% to 50%, and 58% to 74%, respectively). In caiaué, there are no pisifera and tenera types, so fruits endocarp is always thick, similar to the oil palm dura form. In the current study, the oil palm form pisifera were used, so contributing to the high genotypic values for M/FN in the progeny, which are within the range of the values reported for oil palm (CORLEY; TINKER, 2016). Considering the high average M/FN value, and the presence of genetic variation in the population for this trait, it will be possible to obtain genetic progress via selection for this characteristic, so increasing of the population mean for bunch oil content.

By classifying the genotypic values of the progenies (Table 2), classifying each bunch component by using the five best progenies as reference points, it can be inferred that selection for higher O/FFB would result different responses in the various bunch components analyzed. For PF/FFB, for example, genotypic values classifications show there is no coincidence with progeny classified among the five best by O/FFB genotypic value. For other components, the number of progenies coinciding with the five best genotypic values for O/FFB, varied from one progeny (FFBW, S/FFB, NF/FFB, M/FFB, M/NF), two progenies (O/M_{NF} and O/M_{PF}), and three progenies (TF/FFB) to progenies (ES/FFB). Variation in results is explained by different between characteristics of estimates of genetic correlation (Table 3).

High and positive genetic correlations ($0.50 \leq r^2 \leq 0.79$) were observed for oil content per bunch (O/FFB), and such characteristics as proportion of total fruits in bunch (TF/FFB, r^2 = 0.58), normal fruit mesocarp oil content (O/M_{FN}, r^2=0.52) and parthenocarpic fruit mesocarp oil content (O/M_{FP}, r^2 = 0.63). High negative genetic correlation (r^2 = -0.64) was recorded for the proportion of empty spikelets per bunch (ES/FFB) (Table 3). The observed correlation values indicate that with the selection for O/FFB, values for FT/FFB, O/M_{NF}, O/M_{PF} would also be elevated, and the ES/FFB ratio reduced. This is a favorable situation for improvement because, with a higher proportion of fruits for a given bunch weight, and a higher mesocarp oil content, more oil would be produced per ton of fresh fruit bunch. TF/FFB has a high and negative correlation with ES/FFB (r^2= -0.94), and also with the proportion of stalk in the bunch (S/FFB, r^2= -0.66), which indicates that an increase in TF/FFB is strongly associated to the reduction in ES/FFB and in S/FFB, which have a high and positive correlation (r^2= 0.52). As for the potential for indirect selection, TF/FFB and ES/FFB are notable among those characteristics with higher correlations with O/FFB, for the simplicity of their evaluation methods which do not require laboratory infrastructure. Krualee *et al.* (2013) found both fruit mesocarp content and TF/FFB showed a high and positive correlation with oil production, with high potential for preliminary indirect palm oil selection, results similar to those obtained in the current study with HIE OxG.

Because it is easily and speedily measured, it is usual to check the amount of mesocarp in normal fruits (M/NF) as an indirect selection assessment of bunch oil content (O/FFB) when making a preliminary selection of oil palm genotypes. This is based on the strong and positive correlation between these characteristics. A swift visual assessment of the proportion of mesocarp in normal fruits is a widely adopted practice, especially when collecting individuals from natural populations or areas of commercial crops for oil palm genetic improvement (CORLEY; TINKER, 2016). In the current study, M/NF showed a medium-level and positive correlation with O/FFB (r^2 = 0.41). Although this is a magnitude lower than the characteristic proportion of fruits per bunch (TF/FFB), it also has potential for use in selection during preliminary analysis of genotypes to increase O/FFB.

The proportion of normal fruits (NF/FFB) showed a positive genetic correlation, one greater than all other characteristics, with weight per bunch (r^2 = 0.70), and a very high and negative genetic correlation with the proportion of parthenocarpic fruits with bunch weight (PF/FFB). According to Corley and Tinker (2016), the formation of normal fruits is directly correlated with bunch weight and oil content, as well as with bunch production and oil yield per plant. Additionally, they report that a minimum, but varied, number of normal fruits is needed to prevent abortion of each oil palm bunch. Genetic correlation results indicate that, with the increase in NF/FFB, which is desirable, there will be a reduction in PF/FFB. Parthenocarpy is a characteristic that occurs more frequently in caiaué than either oil palm or the interspecific hybrids (GONZÁLEZ *et al.*, 2013, RIOS *et al.*, 2015; TELES *et al.*, 2015). A review by Rios *et al.* (2015) reported that the by-weight percentage of parthenocarpic fruits in caiaué bunches from different Brazilian origins varied from 0 to 45.7%. Meanwhile, Teles *et al.* (2015) reported values from 26.0 to 70% for oil palm cultivars grown in Brasília, DF, Brazil – these were produced with male genitors of the same origin (La Mé) as those used to obtain the hybrids evaluated in the current study. Parthenocarpy can occur pre-anthesis or be stimulated by the lack of pollination. When parthenocarpy is initiated pre-anthesis, any subsequent pollination is unable to promote the formation of normal fruits. On the other hand, flowers destined to the formation of normal fruits, if they remain unpollinated, may form parthenocarpic fruits (CORLEY; TINKER, 2016).

The proportion of total fruits per bunch (TF/FFB) showed a high correlation with the proportion of normal fruits per bunch (r^2 = 0.62), and a median correlation with number of normal fruits in the bunch (N_{NF}/FFB) (r^2 = 0.42). On the other hand, TF/FFB had a median and negative correlation with the proportion of parthenocarpic fruits per bunch (PF/FFB) (r_2 = -0.3), and with the number of parthenocarpic fruits in the bunch

(N_{PF}/FFB) (r^2 = -0.41). Considering these results, and the very strong negative correlation between NF/FFB and PF/FFB (r^2 = -0.94), practicing indirect selection on TF/FFB to increase the oil content per bunch should promote the increase of normal fruits and a reduction in parthenocarpic fruits.

Results indicate that, with the selection for higher oil content per bunch, as well as for a higher proportion of normal fruits per bunch, and a higher proportion of total fruits per bunch weight, the occurrence of genetically-based parthenocarpy in the population should decline. This will also help increase the rate of industrial oil extraction, which is more efficient when using normal fruits. However, it should be noted that, in the case of HIE OxG, even with advances in genetic selection for greater NF/FFB, pollination quality is still essential to reduce PF/FFB. An improvement strategy to reduce the proportion of PF/FFB may be to perform backcrosses with oil palm, which has a lower natural incidence of parthenocarpy compared to caiaué. However, such a strategy is only viable if, after doing so, it is still possible to retain the genetic resistance to FY shown by HIE OxG F1 - the characteristic currently justifying the cultivation of this material. Another advantage of backcross improvement would be the possibility of increasing HIE OxG natural fertility, which could eliminate the need for the assisted pollination currently required when planting this type of material.

Table 3. Genetic correlations between bunch characteristics of caiaué/dendê interspecific hybrids.

	O/FFB	FFBW	S/FFB	ES/FFB	TF/FFB	NF/FFB	M/NF	O/M_{NF}	PF/FFF	O/M_{PF}	MW_{PF}	MW_{NF}	N_{NF}/FFB	NPF/FFB
FFBW	0.00^{ns}													
S/FFB	-0.22^{**}	-0.18^{**}												
ES/FFB	-0.63^{**}	-0.35^{**}	0.52^{**}											
TF/FFB	0.57^{**}	0.26^{**}	-0.66^{**}	-0.94^{**}										
NF/FFB	0.10^{**}	0.42^{**}	-0.47^{**}	-0.56^{**}	0.62^{**}									
M/NF	0.44^{**}	-0.42^{**}	0.06^{ns}	0.06^{ns}	-0.13^{**}	-0.29^{**}								
O/M_{NF}	0.60^{**}	0.35^{**}	-0.24^{**}	-0.46^{**}	0.45^{**}	0.63^{**}	0.02^{ns}							
PF/FFB	0.12^{**}	-0.39^{**}	0.26^{**}	0.25^{**}	-0.30^{**}	-0.93^{**}	0.29^{**}	-0.57^{**}						
O/M_{PF}	0.64^{**}	-0.09^{*}	0.24^{**}	-0.15^{**}	0.06^{ns}	-0.10^{**}	0.16^{**}	0.32^{**}	0.13^{**}					
MW_{PF}	0.44^{**}	-0.13^{**}	-0.07^{*}	-0.18^{**}	0.18^{**}	-0.43^{**}	0.33^{**}	-0.08^{*}	0.61^{**}	0.05^{ns}				
MW_{NF}	0.17^{**}	0.11^{**}	-0.38^{**}	-0.25^{**}	0.33^{**}	-0.05^{ns}	-0.08^{*}	-0.06^{ns}	0.21^{**}	-0.14^{**}	0.41^{**}			
N_{NF}/FFB	0.00^{ns}	0.70^{**}	-0.25^{**}	-0.44^{**}	0.42^{**}	0.86^{**}	-0.37^{**}	0.57^{**}	-0.86^{**}	-0.05^{ns}	-0.48^{**}	-0.31^{**}		
N_{PF}/FFB	-0.15^{**}	0.09^{*}	0.31^{**}	0.27^{**}	-0.41^{**}	-0.65^{**}	-0.03^{ns}	-0.50^{**}	0.61^{**}	0.13^{**}	-0.08^{**}	-0.01^{ns}	-0.39^{**}	
N_{TF}/FFB	-0.17^{**}	0.54^{**}	0.18^{**}	0.01^{ns}	-0.17^{**}	-0.13^{**}	-0.27^{**}	-0.17^{**}	0.08^{*}	0.10^{**}	-0.41^{**}	-0.21^{**}	0.23^{**}	0.81^{**}

O/FFB - Oil content per fresh fruit bunch (%), FFBW – Fresh fruit bunch weight (kg), S/FFB - Stalk per fresh fruit bunch (%), ES/FFB - Empty spikelets per fresh fruit bunch (%), TF/FFB - Total fruits per fresh fruit bunch (%), NF/FFB - Normal fruits per fresh fruit bunch (%); M/NF - Mesocarp in normal fruits (%), O/M_{NF} - Oil content of normal fruits mesocarp (%), PF/FFB - Parthenocarpic fruits per fresh fruit bunch (%), O/M_{PF} - Oil content of parthenocarpic fruits mesocarp (%), MW_{PF} - Average weight of parthenocarpic fruits (g), MW_{NF} - Average weight of normal fruits (g), N_{NF}/FFB - Number of normal fruits per of fresh fruit bunch, N_{PF}/FFB - Number of parthenocarpic fruits per fresh fruit bunch, TF/FFB- Total number of fruits per fresh fruit bunch.

* e ** significant at 5% and 1% probability, respectively, e ^{ns} t test not significant

Conclusions

Progeny means and variation for genotypic values of bunch components indicate the possibility of gains with selection for increases in hybrid bunch oil content.

Due to the high and positive genetic correlations, selection for increased bunch oil content will result in bunches with a higher proportion of fruits per bunch weight, normal and parthenocarpic fruits with higher oil content in their mesocarps and, due to the negative genetic correlations, in a reduction of the proportion of empty spikelets per bunch weight.

Due to their high correlations with oil content and high evaluation practicality compared to other group components, the characteristics with the greatest potential for indirect selection to increase per bunch oil content are the total proportion of fruits and the proportion of empty spikelets.

Acknowledgements

The authors would like to thank Carlos Edmundo Quaresma (Group Marborges) for supervising the technical work related to the maintenance and evaluation of the HIE OxG experiments; the Conselho Nacional de Desenvolvimento Científico e Tecnológico-CNPq (Grants 404815/2013-8 and 482.500/2009-3); Embrapa (Grant 02.13.13.002.00.00); to Fundação de Amparo à Pesquisa do Estado do Pará-FAPESPA (Grant 141.308/2014) and the Group Marborges (Grant P25200.08/0837-2).

References

ALVARES, C. A.; STAPE, J. L.; SENTELHAS, P. C.; GONÇALVES, J. L. M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, v. 22, p. 711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507.

BABU, M. K. **Bunch analysis of oil palm**. [S.l.]: National Research Centre for Oil Palm, 2008. (Tecnical Bulletin, n. 8). Available from: http://dopr.gov.in/Reports/Bunch%20Analysis%20of%20 Oil%20Palm.pdf. Accessed: Dec 16, 2020.

CADENA, T.; PRADA, F.; PEREA, A.; ROMERO, H. M. Lipase activity, mesocarp oil content, and iodine value in oil palm fruits of *Elaeis guineensis*, *Elaeis oleifera*, and the interspecific hybrid O×G (*E. oleifera* × *E. guineensis*). **Journal of the Science of Food and Agriculture**, v. 93, n. 3, p. 674-680, 2013. https://doi.org/10.1002/jsfa.5940.

CHAVES, G., LIGARRETO-MORENO, G. A.; CAYON-SALINAS, D. G. Physicochemical characterization of bunches from American oil palm (*Elaeis oleifera* HBK Cortes) and their hybrids with African oil palm (*Elaeis guineensis* Jacq.). **Acta Agronómica**, v. 67, n. 1, p. 168-176, 2018. https://doi.org/10.15446/acag.v67n1.62028.

CORLEY, R. H. V.; TINKER, P. B. **The oil palm**. Oxford: Blackwell Science Ltd., 2016. 692 p. https://doi.org/10.1002/9781118953297.

CUNHA, R. N. V.; LOPES, R. **BRS Manicoré:** híbrido interespecífico entre o caiaué e o dendezeiro africano recomendado para áreas de incidência de amarelecimento-fatal. Manaus, AM: Embrapa Amazônia Ocidental, 2010. Available from: http://www.snt.embrapa.br/publico/usuarios/produtos/85-Anexo1.pdf. Accessed: Dec. 16, 2020.

DURÁN, Q.; SIERRA, G. A.; GARCÍA, J. A. Potencial de aceite en racimos de palma de aceite de diferente calidad y su influencia em el potencial y extracción de aceite em la planta de beneficio. **Palmas**, v. 25, p. 501-508, 2004. Available from: https://palma.webcindario.com/potencialaceite1.pdf. Accessed: Dec. 16, 2020.

CORREDOR, E. M.; GARCÍA, J. M.; RANGEL, C. A. D.; MENESES, H. M.; CONTRERAS, N. E. R.; NÚÑEZ, J. A. G. Optimización de la medición del potencial industrial de aceite. **Palmas**, n. 38, v.4, p. 98-107, 2017.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA (EMBRAPA). **Sistema brasileiro de classificação de solos**. Brasília: Embrapa, Brasília, 2013. 353 p. Available from: https://www.embrapa.br/solos/sibcs. Accessed: Dec. 16, 2020.

GOMES JÚNIOR, R. A.; LOPES, R.; CUNHA, R. N. V.; OINA, A. J. A. QUARESMA, C. E.; CAMPELO, R. D.; RESENDE, M. D. V. Selection gains for bunch production in interspecific hybrids between "caiaué" and oil palm. **Pesquisa Agropecuária Brasileira**, v. 54, e00819, 2019. https://doi.org/10.1590/s1678-3921.pab2019.v54.00819.

GONZÁLEZ, G. D. A.; CAYÓN S. G.; LÓPEZ, M. J. E.; ALARCÓN, W. H. Development and maturation of fruits of two Indupalma OxG (*Elaeis oleifera* x *Elaeis guineensis*). **Agronomía Colombiana**, v. 31, n. 3, p. 343-351, 2013.

HENSON, I. Marco analítico para identificar los factores que determinan lãs tasas de extracción de aceite. **Palmas**, v. 22, n. 3, p. 29-38, 2001. Available from: https://publicaciones.fedepalma.org/index.php/palmas/article/view/882. Accessed: Dec. 16, 2020.

ISA, Z. A.; KUSHAIRI, A.; MOHD DIN, A.; SUBOH, O.; JUNAIDAH, J.; NOH, A.; CHOO KIEN, W.; MUSA, B. A critical re-examination of the method of bunch analysis in oil palm breeding - an update. **International Seminar on Breeding for Sustainability in Oil Palm**, p. 19-42, 2011. Available from: http://isopb.mpob.gov.my/pdfFile/5th/P2_Paper%20ISA%20et%20al%20for%20ISOPB%202011.pdf. Accessed: Dec. 16, 2020.

KESHVADI, A.; ENDAN, J. B.; HARUN, H.; AHMAD, D.; SALEENA, F. Palm oil quality monitoring in the ripening process of fresh fruit bunches. **International Journal of Advanced Engineering Sciences and Technologies**, v. 4, n. 1, p. 26-52, 2011.

KRUALEE, S.; SDOODEE, S.; EKSOMTRAMAGE, T.; SEREEPRASERT, V. Correlation and Path Analysis of Palm Oil Yield Components in Oil Palm (*Elaeis guineensis* Jacq.). **Kasetsart Journal of Natural Science**, v. 47, n. 4, p. 528-533, 2013.

LIEB, V. M.; KERFERS, M. R.; KRONMÜLLER, A.; ESQUIVEL, P.; ALVARADO, A.; JIMÉNEZ, V. M.; SCHMARR, H-G.; CARLE, R.; SCHWEIGGERT, R. M.; STEINGASS, C. B. Characterization of mesocarp and kernel lipids from *Elaeis guineensis* Jacq., *Elaeis oleifera* [Kunth] Cortés, and their interspecific hybrids. **Journal of Agricultural and Food Chemistry**, n. 65, p. 3617-3626, 2017. https://doi.org/10.1021/acs.jafc.7b00604.

LOPES, R.; CUNHA, R. N. V.; RESENDE, M. D. V. Produção de cachos e parâmetros genéticos de híbridos de caiaué com dendezeiro. **Pesquisa Agropecuária Brasileira**, v. 10, n. 47, p. 1496-1503, 2012. https://doi.org/10.1590/S0100-204X2012001000012.

PINA, A. J. A. Experiências na produção para a cultura de palma de óleo na Amazônia: relato de experiências da Marborges Agroindústria S.A. (Moju – Pará). *In*: RAMALHO FILHO, A.; MOTTA, P. E. F.; FREITAS, P. L.; TEIXEIRA, W. G. T. **Zoneamento agroecológico, produção e manejo para a cultura do dendezeiro na Amazônia**. Rio de Janeiro: Embrapa Solos, 2010. p. 189-204.

PINTO, S. S.; LOPES, R.; CUNHA, R. N. V.; SANTOS FILHO, L. P.; MOURA, J. I. L. Produção e composição de cachos e incidência do anel vermelho em híbridos interespecíficos de caiaué com dendezeiro no sul da Bahia. **Agrotrópica**, v. 31, n. 1, p. 5-16, 2019. https://doi.org/10.21757/0103-3816.2019v31n1p5-16.

RAFII, M. Y.; ISA, Z. A.; KUSHAIRI, A.; SALEH, G. B.; LATIF, M. A. Variation in yield components and vegetative traits in Malaysian oil palm (*Elaeis guineensis* Jacq.) dura x psifera hybrids under various planting densities. **Industrial Crops and Products**, v. 46, p. 147-157, 2013. https://doi.org/10.1016/j.indcrop.2012.12.054.

RAMALHO FILHO, A.; MOTTA, P. E. F.; NAIME, U. J.; GONÇALVES, A. O.; TEIXEIRA, W. G. T. Zoneamento Agroecológico para a cultura da palma de óleo nas áreas desmatadas da Amazônia Legal. *In*: RAMALHO FILHO, A.; MOTTA, P. E. F.; FREITAS, P. L.; TEIXEIRA, W. G. T. **Zoneamento agroecológico, produção e manejo para a cultura do dendezeiro na Amazônia**. Rio de Janeiro: Embrapa Solos, 2010. p. 57-68.

RAO, V.; SOH, A. C.; CORLEY, R. H. V.; LEE, C. H.; RAJANAIDU, N.; TAN, Y. P.; CHIN, C. W.; LIM, K. C.; TAN, S. T.; LEE, T. P.; NGUI, M. **A critical reexamination of the method of bunch quality analysis in oil palm breeding**. India: Department of Agriculture, 1983.

RESENDE, M. D. V. Software Selegen-REML/BLUP: a useful tool for plant breeding. **Crop Breeding and Applied Biotechnology**, v. 16, p. 330-339, 2016. http://dx.doi.org/10.1590/1984-%2070332016v16n4a49.

RINCÓN, S. M.; HORMAZA, P. A.; MORENO, L. P.; PRADA, F.; PORTILLO, D. J.; GARCÍA, J. A.; ROMERO, H. M. Use of phenological stages of the fruits and physicochemical characteristics of the oil to determine the optimal harvest time of oil palm interspecific OxG hybrid fruits. **Industrial Crops and Products**, n. 49, p. 204-210, 2013. https://doi.org/10.1016/j.indcrop.2013.04.035.

RIOS, S. A.; CUNHA, R. N. V.; LOPES, R.; BABCELOS, E.; LIMA, W. A. A.; RODRIGUES, M. R. L.; KRUG, C.; BITTENCOURT, D. M.; QUISEN, R. Q.; GOMES JUNIOR, R. A.; ROCHA, R. N. C. Caiaué. *In:* LOPES, R.; OLIVEIRA, M. S. P.; CAVALLARI, M. M.; BARBIERI, R. L.; CONCEIÇÃO, L. D. H. C. (Org.). **Palmeiras Nativas do Brasil**. 1. ed. Brasília, DF: Empresa Brasileira de Pesquisa Agropecuária, v. 1, p. 211-246, 2015.

SOCHA, J.; CAYON, D.; LIGARRETO, G.; CHAVES, G. Effect of pollen doses on fruit formation and oil production in two hybrid palm genotypes (*Elaeis oleifera* H.B.K. Cortes x *Elaeis guineensis* Jacq.). **Agronomia Colombiana**, v. 37, n. 1, p. 12-17, 2019. http://dx.doi.org/10.15466/agron.colomb.v37n1.75313.

TELES, D. A. A.; BRAGA, M. F.; ANTONIASSI, R.; JUNQUEIRA, N. T. V.; PEIXOTO, J. R.; MALAQUIAS, J. V. Yield Analysis of Oil Palm Cultivated Under Irrigation in the Brazilian Savanna. **Journal of the American Oil Chemists Society**, v. 93, n. 2, p. 193-199, 2015. http://dx.doi.org/10.1007/s11746-015-2765-6.

UNITED STATES DEPARTAMENT OF AGRICULTURE (USDA). **Oil Seeds:** world markets and trade. EUA: United States Department of Agriculture, 2019. Available from: http://www.fas.usda.gov/psdonline/circulars/oilseeds.pdf. Accessed: Dec 16, 2020.