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Physicochemical characterization of bunches and oil composition in a backcross progeny (caiaué x oil palm) x oil palm

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Abstract

Hybrids between caiaué and oil palm (IEH OxG) are explored in genetic improvement with the main objective of associating the high palm oil productivity of oil palm with resistance of caiaué to Bud Rot disease. In addition, caiaué has better oil quality and greater resistance to some pests and diseases than oil palm and these characteristics are transmitted to the hybrid between species. Due to fertility problems, IEH OxG plantations require assisted pollination, which raises the production costs. Backcrossings using oil palm as recurrent parent (BC OGxG) are being evaluated as a solution to restore the fertility of IEH OxG, however, the species contrast to physicochemical characteristics of the bunch and to oil composition, therefore, there is a need to observe how these characteristics vary in BC OGxG. Physicochemical characteristics of the bunch and fatty acid composition of the oil produced by 90 plants from an BC OGxG progeny were analysed. A large variation was observed in the progeny, with mean values of 9.0 kg for bunch weight, 46.0% of parthenocarpic fruits in the bunch weight, 72.2% of mesocarp in normal fruit and 86.5% in parthenocarpic fruit, 37.6% of oil in the humid mesocarp of normal fruits and 35.9% in parthenocarpic fruits and 16.4% of oil content in the fresh fruits bunch (FFB). The unsaturated fatty acids oleic (52.5%) and linoleic (10.8%) and the saturated fatty acids palmitic (30.7%) and stearic (4.4 %) stood out in the oil composition. In the progeny BC OGxG is possible to select individuals for high OCB and for a greater or lesser percentage of saturated or unsaturated fatty acids in the oil composition.

Keywords: fatty acids; interspecific cross; *Elaeis guineensis*; *Elaeis oleifera*.

Caracterização físico-química dos cachos e composição do óleo em progênie do retrocruzamento (caiaué x dendezeiro) x dendezeiro

Resumo

Híbridos interespecíficos de caiaué com dendezeiro (HIE OxG) são explorados no melhoramento genético com objetivo principal de associar a alta produtividade em óleo de palma do dendezeiro com a resistência do caiaué a anomalia Amarelecimento Fatal. Além disso, o caiaué apresenta também melhor qualidade de óleo e maior resistência a algumas pragas e doenças do que a palma de óleo e que são transmitidas para o híbrido entre as espécies. Devido a problemas de fertilidade, os plantios do HIE OxG requerem polinização assistida, o que aumenta os custos de produção. Retrocruzamentos utilizando o dendezeiro como genitor recorrente (RC OGxG) estão sendo avaliados como solução para restaurar a fertilidade dos HIE OxG, contudo, as espécies contrastam para as características físico-químicas dos cachos e também na composição em ácidos graxos do óleo, sendo necessário verificar como essas características variam no RC OGxG. Foram avaliadas as características físico-químicas dos cachos e composição em ácidos graxos do óleo produzido por 90 plantas de uma progênie RC OGxG. Ampla variação foi observada na progênie, com valores médios de 9,0 kg para peso dos cachos, 46,0% de frutos partenocárpicos no peso dos cachos, 72,2% de mesocarpo no fruto normal e 86,5% no fruto partenocárpico, 37,6% de óleo no mesocarpo úmido de frutos normais e 35,9% nos frutos partenocárpicos e 16,4% para percentual de óleo nos cachos de frutos frescos. Na composição do óleo destacaram-se os ácidos graxos insaturados oleico (52,5%) e linoleico (10,8%) e os saturados palmítico (30,7%) e esteárico (4,4%). Na progênie RC OGxG é possível selecionar

indivíduos para alto percentual de óleo no cacho e para maior ou menor percentual de ácidos graxos saturados ou insaturados na composição do óleo.
Palavras-chave: ácidos graxos; cruzamento interespecífico; *Elaeis guineensis* Jacq.; *Elaeis oleifera* (Kunth) Cortés.

1 Introduction

The oil palm (*Elaeis guineensis* Jacq.) accounts for the majority of the vegetable oil produced in the world, 40.21% in total, of which 36.03% is palm oil, extracted from the fruit mesocarp, and 4.18% of palm kernel oil, extracted from the endosperm of the fruit (USDA, 2021). Of the same genus as palm oil, caiaué (*E. oleifera* HBK Cortes), a palm tree native to the American continent, produces an oil similar to palm oil in the mesocarp of its fruit, but with important differences, such as a higher concentration of antioxidants, low lipase enzyme activity and higher proportion of unsaturated fatty acids (CADENA *et al.*, 2012; LIEB *et al.*, 2017, CHAVES *et al.*, 2018). On the other hand, caiaué fruits have a lower proportion of mesocarp in the fruit and oil in the mesocarp than oil palm fruits (LIEB *et al.*, 2017), which partly explains their lower potential for exploitation in commercial production of oil.

The hybridization between caiaué and oil palm is explored in genetic improvement particularly for introducing in oil palm the resistance to the disease named Bud Rot (BR), shown by caiaué (BARBA, 2016). The interspecific hybrid between caiaué and palm (IEH O × G) is resistant to Bud Rot disease and the interspecific hybrid cultivars are the only option for palm cultivation in areas where the disease has occurred. Nevertheless, the fertility of these hybrids is partial, therefore, it is necessary to perform assisted pollination so that the plants express their productive potential (SOCHA *et al.*, 2019). Assisted pollination is an expensive activity. It requires the collection of pollen and its processing and 2 to 3-day pollination shifts, increasing the demand for field and supervisory labor, reducing the profitability of IEH OxG cultivation. The most promising solution for restoring the fertility of IEH OxG and maintaining the resistance to BR is through backcrossing using oil palm as recurrent parent (BARBA, 2016).

The palm oil produced by IEH OxG has characteristics intermediate to the oils of its parents, caiaué and oil palm (RIOS *et al.*, 2015), therefore, a great segregation for oil composition in backcross progenies is expected. The palm oil produced by IEH OxG has a lower amount of free fatty acids than that produced by oil palm, so it is an oil with less acidity and better quality, it is also more unsaturated and with a higher content of vitamin E and carotenes (CADENA *et al.*, 2012; MOZZON *et al.*, 2018; CHAVES *et al.*, 2018; ANTONIASSI *et al.*, 2018). Studies show that IEH OxG oil has the potential to prepare functional foods with antioxidant properties and a favorable impact on human plasma lipids, related to cardiovascular risk factors (LUCCI *et al.*, 2016; RODRIGUEZ *et al.*, 2016). Because the interest in the fractions or components of palm oil depends on the purpose of the use, one can, for example, have a greater interest in the olein, which is found in greater proportion in the palm oil of caiaué and IEH OxG, or in the stearin, in this case, found in greater proportion in palm oil produced by oil palm. As the fatty acid composition of palm oil produced by IEH OxG is different from that produced by oil palm, a specific identity pattern for this oil was proposed in Codex Alimentarus, in which the palm oil with higher oleic acid was recognized, which should have a percentage equal to a greater than 48% oleic acid in its composition (FAO, 2017).

Considering the importance of the composition of palm oil for the market and the variation found between caiaué and oil palm species, it is essential for breeding programs that explore interspecific hybridization to know the production, and composition of oil in these progenies. In this context, the objective of this study was to evaluate the physicochemical characterization of bunches and composition palm oil produced by plants from a backcross progeny (caiaué x oil palm) x oil palm.

2 Material and Methods

The progeny was planted in June 1993, at the Rio Urubu Experimental Field (CERU), owned by Embrapa Amazônia Ocidental, located in the municipality of Rio Preto da Eva, Amazonas, latitude 2°25'S, longitude 59°33'W. The climate in CERU is of the Ami type (Köppen's classification), hot and humid, temperature with average values of 31.2 ^{0}C and 23.5 ^{0}C for maximum and minimum, respectively, and rainfall around 2,200 mm/year, air relative humidity pressure of around 85%, average annual total sunshine of 1,940 hours and on a Yellow Latosol-type soil with a very clayey texture. The physicochemical characterization of the bunches and the composition of palm oil in fatty acids were evaluated in a progeny with 90 individuals of an interspecific backcross (caiaué x oil palm) x oil palm. The progeny was obtained by crossing using as a female parent a hybrid plant (ISH OxG) from the interspecific crossing between caiaué (parent CA 09 D originated from Caldeirão) with oil palm (parent 138 T, commercial material originating from IRHO) and as a male parent an oil palm plant (Genitor PO 2558 P, originated from IRHO). This genetic configuration represents the first generation of interspecific backcrossing (BC OGxG) between the species caiaué and oil palm, using oil palm as a recurrent parent.

The physicochemical analyses of the bunches were carried out in 2014 and 2015 at the Oil Palm and Agroenergy Laboratory of Embrapa Amazônia Ocidental. The optimal harvest time for both quantitative (i.e., extraction rate, industrial applications, etc.) and qualitative (i.e., nutritional properties) characteristics of the O×G interspecifics hybrids is 24 weeks after anthesis (LUCCI *et al.*, 2015). However, this time is variable between climatic stations and environmental conditions, for this reason, the bunches maturation point for harvesting was established based on the field criterion used in oil palm commercial plantations, which consists of the presence at least one loose fruit per bunch (FREITAS *et al.*, 2021). Two bunches were analyzed of each plant, one harvested in 2014 and the other in 2015. The methodology used to analysis bunches was adapted from the Nigerian Institute for Oil Palm Research (RAO *et al.*, 1983). Ripe bunches harvested in the field were immediately taken to the laboratory for evaluation of the bunch weight (BW), rachis weight (RW), spikelets with fruits weight (WS), normal fruits (NF) and parthenocarpic fruits (PF) weight in the fresh fruit bunch (FFB). Two samples with 50 fruits, one of NF and another of PF, were used to determine the percentage of mesocarp (M) in the weight of the fruit and percentage of diaspore (DIASP) in the weight of the fruit (Figure 1). To obtain the percentage of palm oil in the mesocarp of normal fruit (ONF) and parthenocarpic fruit (OPF) were used 40 g of fresh mesocarp from each fruit type. After drying at 105º C in an oven for 24 h two samples with 5 g of dry mesocarp from each type of fruit were analyzed by bunch. The oil was extracted in a Soxhlet system, using petroleum ether (30-60°C) as a solvent and an extraction-time of 16h (AOAC, 2005). The determination of the palm oil content in the FFB, expressed as a percentage of the weight of the bunches, was carried out as follows:

$$\text{POB}\ (\%) = \frac{ONF}{FFB}(\%) + \frac{OPF}{FFB}(\%) \quad (1)$$

$$\frac{ONF\ or\ OPF}{FFB}(\%) = \frac{1}{10{,}000}\left[\left(\frac{NF\ or\ PF}{FFB}(\%)\right)\left(\frac{M}{NF\ or\ PF}(\%)\right)\left(\frac{O}{MNF\ or\ MOF}(\%)\right)\right] \quad (2)$$

$$\frac{NF\ or\ PF}{FFB}(\%) = 100\left[\left(\frac{NF\ or\ PF}{spiklets\ with\ fruits}\right)\left(\frac{FFB - Rachis}{FFB}\right)\right] \quad (3)$$

$$\frac{M}{NF\ or\ PF}(\%) = 100\left(\frac{(NF\ or\ PF) - Diasspore}{(NF\ or\ PF)}\right) \quad (4)$$

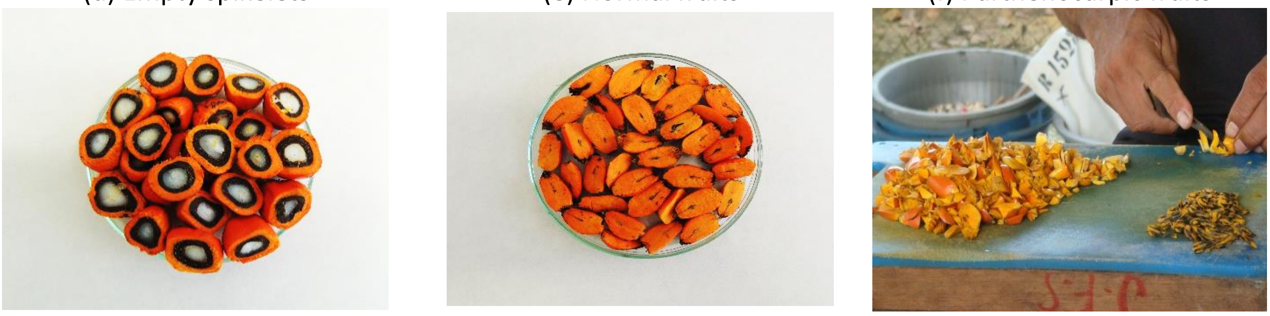
$$\frac{O}{MNF\ or\ MPF}(\%) = \frac{1}{100}\left[(100 - Mesocarp\ moisture\ \text{NF or PF}(\%))\left(\frac{O}{MNF\ or\ MPF_{(DRY)}}(\%)\right)\right] \quad (5)$$

Where:
POB = Palm oil content in the fresh fruit bunch
FFB = fresh fruit bunch
ONF = palm oil in the mesocarp of normal fruit
OPF = palm oil in the mesocarp of parthenocarpic fruit
NF = normal fruit
PF = parthenocarpic fruit
M = mesocarp
O = palm oil
MNF = mesocarp in the normal fruit
MPF = mesocarp in the parthenocarpic fruit

Figure 1. Oil palm Bunches components (Photos: Alessandra Ferraiolo N. Domingues).

(a) Bunche (b) Rachis (c) Spikelets with normal and parthenocarpic fruits

(d) Empty spikelets (e) Normal fruits (f) Parthenocarpic fruits



(g) Normal fruits with diaspore (h) Parthenocarpic fruits without diaspore (i) Manual removal of the mesocarp from the fruit

The analysis of the composition of palm oil in fatty acids was carried out at the Oil and Fats Laboratory of Embrapa Agroindústria de Alimentos, Rio de Janeiro, Rio de Janeiro State. It was analyzed two samples per plant, obtained from the same bunches used in physicochemical analyses, with three replicates of each sample. The oil samples were obtained from the dry mesocarp of the fruits of the same bunches after extraction with petroleum ether in Soxhlet Extractor. The solvent was removed in a rotary-evaporator and under nitrogen flow. For analysis of the oil composition in fatty acids, the methyl esters were prepared according to the Hartman and Lago (1973) method and analyzed through chromatography in the gas phase on an Agilent 7890 gadget, equipped with a flame ionization detector operated at 280 °C.

A capillary column of fused silica of nitroterephthalic acid modified polyethylene glycol film – FFAP (25 m x 0.32 mm x 0.25 µm) was used according to the following schedule: initial temperature of 150 °C for 1 min; from 150 °C to 180 °C with a ramp of 30 °C / min; from 180 to 200 °C with a ramp of 20 °C / min; from 200 to 230 °C with a ramp of 3 °C / min and at the final temperature of 230 °C for 10 min. 1 µL of sample was injected into an injector heated to 250 °C operated in the 1:50 flow division mode. Fatty acids were identified by comparing the retention times with the NU-CHEK Prep, Inc. (Elysian, MN) standards numbers 62, 79 and 87. The quantification was performed through internal normalization and the results were expressed as a percentage of the different fatty acids in the total fatty acids in the oil.

The data of the physicochemical composition of the bunches and the fatty acid composition of the palm oil of the progeny individuals were analyzed with descriptive statistics (mean, minimum value, maximum value, standard deviation and variation coefficient), frequency of classes and Pearson's correlation coefficient. The composition of the palm oil in fatty acids of the interspecific backcross progeny (BC OGxG) was compared with that produced by caiaué plant used with female parent to obtain the interspecific hybrid F1 (ISH OxG), female parent of the backcross progeny. The oil palm ancestors were not available, so they were not included in the study.

3 Results and Discussion

A wide variation was observed in the BC OGxG progeny for weight and composition of the bunch, according to the descriptive statistics (Table 1) and mean distribution of the individuals (Figure 2), which is expected because it is an interspecific backcross, with great divergence between the parent specie for bunches physicochemical characteristics. The largest variations were observed for the percentage of palm oil from parthenocarpic fruits in FFB weight (OBPF), CV = 85.3%, and percentage of parthenocarpic fruits in FFB weight (PFB), CV = 80.1%, while the smallest variations were observed for percentage of oil in dry mesocarp of normal fruits (ODMFN), CV = 11.7%, and percentage of mesocarp in normal fruits weight (MNF), CV = 13.4%. The other characteristics presented intermediate CV, between 23.0% (percentage of normal fruits in FFB weight - NFP) and 48.2% (percentage of diaspore in fruit weight - DIASP). The variable OBPF is derived from the components PFB, MPF and OMPF. That is why, the large variation observed in OBPF (85.3%) can be attributed mainly for variation observed in PFB (80.1%), since the variations in MPF (23,7%) and OMPF (30.9%) were smaller. In the oil palm fruiting process, normal and parthenocarpic fruits are formed. Under suitable pollination conditions, in oil palm normal fruits represent on average 58% of the bunch weight and parthenocarpic fruits 3% (CORLEY; TINKER, 2016), while in caiaué they may constitute up to 90% of the total fruits (NTSOMBOH-NTSEFONG *et al.*, 2016). Parthenocarpy has genetic basis (defined before anthesis), which is more evident in caiaué, but is also influenced by pollination (defined after anthesis). In the same bunch the variation in the weight of parthenocarpic fruits is greater than that observed in normal fruits. Among the fruits classified as parthenocarpics sometimes occurs fruits with formation of endocarp, but without the formation of almond, which are classified as false parthenocarpic and these are heavier than the trues parthenocarpics. Due to these factors, in backcross progenies (OxG)xG large variation is expected for the percentage of parthenocarp fruits on the bunche weight.

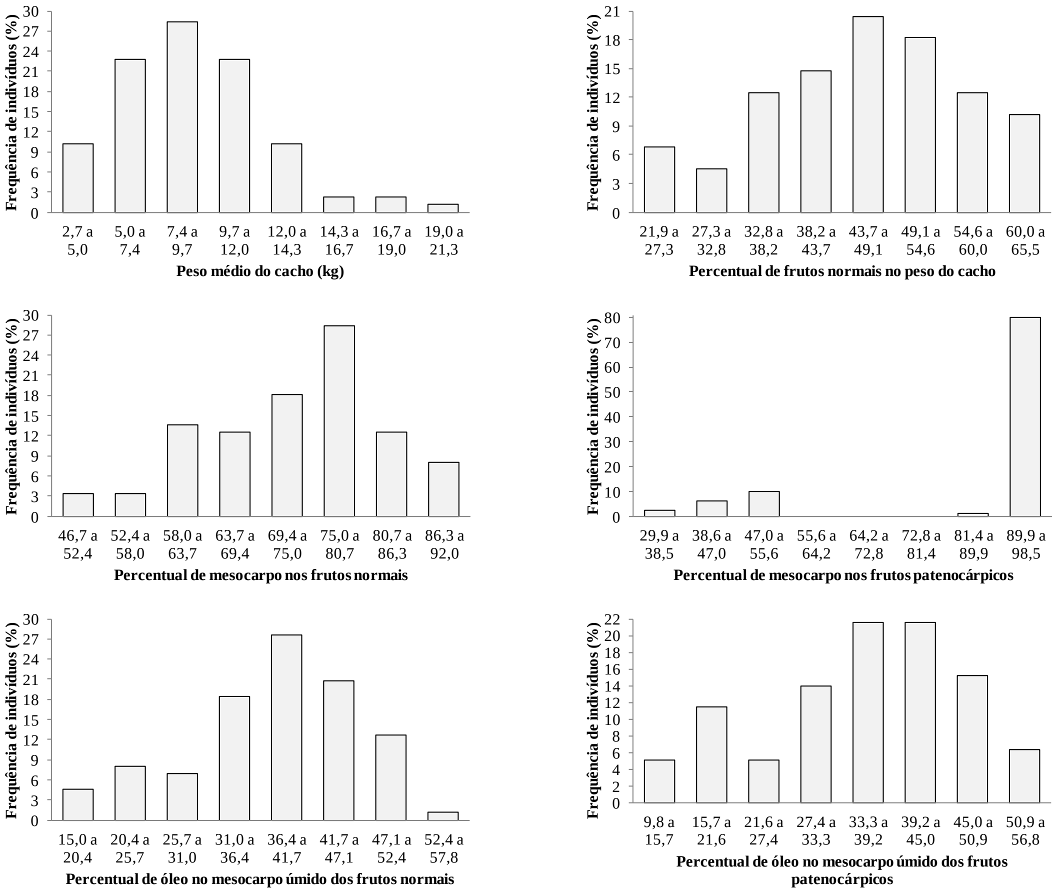
The mean value for FFB weight (BW) was 9.0 kg, with a variation from 2.7 kg to 21.3 kg. In the evaluation of five BC OGxG progenies, Bastidas *et al.* (2007) observed for BW a mean of 15.1 kg and a variation from 12.5 kg to 18.4 kg. In caiaué populations of Colombian origin, Rey *et al.* (2004) found BW between 5.0 kg and 11.0 kg. Rios *et al.* (2015) reports variation in BW (average of at least 30 bunches per plant) between 5.5 kg and 18.9 kg for caiaué plants of Brazilian origin Manicoré, with controlled pollination of inflorescences using oil palm pollen. For oil palm, mean values for BW between 10.2 kg and 19.1 kg are reported in Dura variety of Angolan origin (REY *et al.*, 2004), 10.0 kg to 24.0 kg in Dura variety and 10.0 kg to 13.5 kg in Tenera variety of Nigerian origin (OKWUAGWU *et al.*, 2011). According to reports in the literature, when compared to oil palm, caiaué generally presents a lower BW and, in BC OGxG progenies, it is expected that the BW is closer to the oil palm average, which is the recurrent parent of the backcross. In the evaluated BC OGxG progeny, some individuals with low BW were found, however, around 16% of the individuals had a BW greater than 12.0 kg, indicating that it is possible in the first generation of the backcross to select individuals with BW similar to that seen in the oil palm.

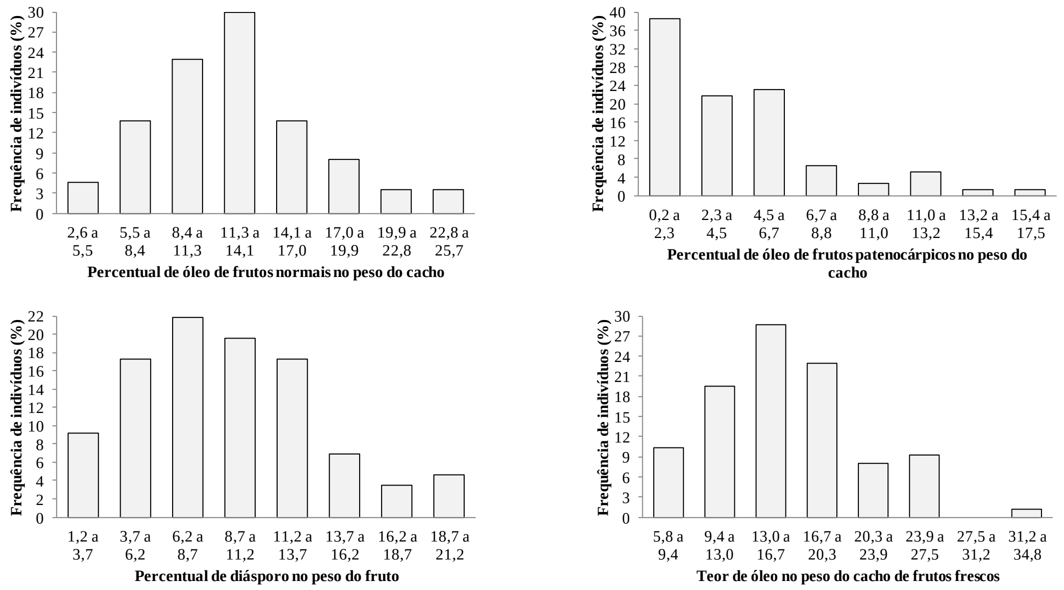
Table 1. Descriptive statistics of the bunches components of 90 plants from a backcross progeny (caiaué x oil palm) x oil palm.

Variable	Descriptive statistics				
	Mean	**Minimum**	**Maximum**	**DP**	**CV (%)**
BW	9.0	2.7	21.3	3.4	37.5
NFB	46.0	21.9	65.5	10.6	23.0
PFB	11.6	0.5	42.8	9.3	80.1
MNF	72.7	46.7	92.0	9.7	13.4
MPF	86.5	29.9	98.5	20.5	23.7
DIASP	9.4	1.2	21.2	4.5	48.2
OMNF	37.6	15.0	57.8	8.7	23.1
OMPF	35.9	9.8	56.8	11.1	30.9
OBNF	12.6	2.6	25.7	4.5	36.1
OBPF	4.2	0.17	17.5	3.6	85.3
POB	16.0	5.81	34.8	5.4	34.0
ODMNF	62.4	47.15	79.8	7.3	11.7

BW: fresh fruit bunches (FFB) weight in kilograms, NFB: percentage of normal fruits in FFB weight, PFB: percentage of parthenocarpic fruits in FFB weight, MNF: percentage of mesocarp in normal fruits, MPF: percentage of mesocarp in parthenocarpic fruits, DIASP: percentage of diaspore in fruit weight, OMNF: percentage of oil in humid mesocarp of normal fruits, OMPF: percentage of oil in humid mesocarp of parthenocarpic fruits, OBFN: percentage of oil from normal fruit in FFB weight, OBPF: percentage of oil from parthenocarpic fruit in FFB weight; POB: percentage of oil in FFB weight and ODMNF: percentage of oil in dry mesocarp of normal fruits.

Figure 2. Distribution of 90 individuals from an interspecific backcross progeny (caiaué x oil palm) x oil palm in percentage value classes for different components of the bunches.





An important difference between oil palm and caiaué is the percentage of parthenocarpic fruits in the FFB weight (PFB), which is higher in caiaué. In caiaué families of Colombian origins, Rey *et al.* (2004) reported 52.0% to 58.0% PFB, for Brazilian origins, information compiled by Rios *et al.* (2015) indicate a variation from 0.0% to 45.7%. For Tenera oil palm cultivars grown in the Brazilian Cerrado, the PFB ranged from 7.0% to 26.0% (TELES *et al.*, 2016). In the BC OGxG progeny, the PFB was 11.6% and varied from 0.5 to 42.8% (Table 1), with 74.0% of the individuals showing values below 16.0% and only 7.4% of the individuals presenting values greater than 20.0%, indicating that in the first generation of interspecific backcrossing it is possible to select individuals with a low percentage of parthenocarpic fruits in the bunch.

The mean for the percentage of mesocarp in normal fruits weight (MNF) was 72.7% (range from 46.7% to 92.0%), a lower value (test T, p> 0.05) than the percentage of mesocarp in parthenocarpic fruits weight (MPF) which was 86.5% (range from 29.9% to 98.5%). At the evaluation of BC OGxG progenies, Bastidas *et al.* (2007) found a mean value of 58.0% for MNF, with a variation from 53.0% to 63.8%. Because there is a great variability in the percentage of mesocarp in the fruit among the Caiaué populations (REY *et al.*, 2004; MURUGESAN; SHAREEF, 2014; RIOS *et al.*, 2015), it is expected to observe variations in the interspecific crossing progenies according to the origins of the parents used in it. Despite showing a higher percentage of mesocarp, parthenocarpic fruits are smaller and lighter than normal fruits when they do not abort before ripening, therefore, the least possible occurrence of this type of fruit in the bunch is desired. The average percentage of oil from normal fruits in FFB weight (OBNF) was 12.6% and in the parthenocarpic fruits (OBPF), it was only 4.2% (Table 1). The results show that when backcrossing is carried out using oil palm as a recurrent parent, the average percentage of parthenocarpic fruits is close to that seen in oil palm.

The diaspore of normal fruits is composed of the embryo, endocarp and endosperm, the latter used to extract palm kernel oil. The percentage of diaspore in fruit weight (DIASP) of the BC OGxG progeny was 9.4%, varying from 1.2% to 21.2%, and the variation coefficient was 48.2% (Table 1). The highest proportion of progeny individuals (75%) showed DIASP between 3.7% to 13.7%; however, 14.9% had values greater than 13.7% and 9.2% less than 3.7% (Figure 2). In the evaluation of BC OGxG progenies, Bastidas *et al.* (2007) observed a mean of 10.5% for DIASP, with a variation from 8.1% to 12.2% between progenies. DIASP presents a large variation both in caiaué and oil palm populations. In caiaué populations of Colombian origin, Rey *et al.* (2004) reported 48.0% to 69.0% for DIASP, while for Brazilian caiaué populations, Rios *et al.* (2015) found values from 7.0% to 23.5%. For oil palm, Okwuagwu *et al.* (2011) found a mean of 60.7% for DIASP in Dura variety genotypes and 36.0% in Tenera variety. For Tenera variety oil palm cultivars, Teles *et al.* (2016) observed palm oil content in the FFB ranging from 25.0% to

36.0% and palm kernel oil in the endosperm from 0.8% to 2.5%. As palm kernel oil is a secondary product in the palm oil production chain, since it represents only around 10.0% of the production of this oil, the breeding programs have not considered the production of this oil in the selection of genotypes.

For the percentage of palm oil in the humid mesocarp, no statistically significant difference was found in the progeny BC OGxG (T test, P <0.05) between the mean obtained for OMNF (37.6%) and OMPF (35.9 %). In a study carried out with caiaué plants from five different origins in the Brazilian Amazon, España *et al.* (2018) found a mean value of 28.6% for OMNF, with a variation from 19.8% to 33.6% between origins, values below the mean observed in the progeny BC OGxG. Despite their higher proportion of mesocarp in the fruit and a percentage of oil in the mesocarp similar to normal fruits, parthenocarpic fruits result in less oil production over the bunch weight. In addition to parthenocarpic fruits having a high percentage of abortion before maturation, they also have a problem in industrial processing. As parthenocarpic fruits do not have a diaspore as in normal fruits, the efficiency of industrial presses in oil extraction is lower, as this equipment are developed and adjusted to extract oil from the mesocarp of fruits with diaspores produced by normal fruits (FREITAS *et al.*, 2021). In the processing, after fruits being separated from bunches in the threshing machine, these are transfer to the digester, whereby through the action of the rotating beater arms the fruit is pounded and obtained the digested mash (oil, moisture, fiber and diaspore). When there is high quantity of parthenocarpy fruits the efficiency of the digester is reduced. After digest the nuts are separated from the mash and the palm oil is extracted from the fibers by mechanical pressure in a pressing machine. When analyzing the percentage of oil in the FFB, the average value of the oil from normal fruits (OBNF) was 12.6%, varying from 2.7% to 25.7%, and from parthenocarpic fruits (OBPF), the average was 4.2%, ranging from 0.2% to 17.5%. The percentage of oil in the dry mesocarp was evaluated only for the mesocarp of normal fruits (ODMNF) and varied from 47.2% to 79.8%, with a mean of 62.4%. In the final stages of oil palm fruit maturation oil accumulation in the mesocarp is accompanied by loss of water, but without increase in non-oily solids content (FREITAS *et al.*, 2021). The palm oil content in humid mesocarp of normal fruits was no statistically significant difference from the found in the paternocarpic fruits, therefore, the oil content in the dry mesocarp should also not be significantly different between these types of fruits.

A compilation of the literature reporting a variation in the percentage of palm oil in FFB (POB) from 18.3% to 25.5% in palm oil, 1.7% to 4.4% in caiaué and 3.8% to 17.0% in interspecific F1 hybrids (caiaué x oil palm) (RIOS *et al.*, 2015). POB is an important characteristic for the genetic improvement of oil palm, since palm oil is the product traded as commodity, although FFB production is the main component of palm oil productivity (OKWUAGWU *et al.*, 2008; OKOYE *et al.*, 2009). The POB found in the BC OGxG progeny was 16.0% with a range from 5.8% to 34.8% and CV of 34,0% (Table 1), with a higher proportion of progeny individuals in the range of 9.4 % to 20.3% (Figure 2), values that are similar to the range reported for ISH OxG by Rios *et al.* (2015). Approximately 10.0% of the progeny individuals showed values higher than those reported by Rios *et al.* (2015) for oil palm and all of them were higher than the values of caiaué, indicating that the genetic inheritance of oil palm predominated for this variable.

The correlations between the bunches components (Table 2) demonstrated that the percentage of palm oil in fruit mesocarp is the principal determinant of the percentage of oil in FFB weight (POB), with greater importance for OMNF and OBNF than for OMPF and OBFP, as indicated by the high and positive correlations between OMNF x POB (0.72), OMPF x POB (0.63), OBNF x POB (0.75) and OBPF x POB (0.56). Mean, positive and significant values were observed for the correlations between BW x POB (0.23), FNC x POB (0.27), PFB x POB (0.32) and MNF x POB (0.26). The frequencies of individuals in classes according to the mean for the bunch components (Figure 2), as well as the correlations observed between these components (Table 2), indicate that it is possible in BC OGxG progenies to select individuals with favorable physicochemical characteristics of the bunches for genetic improvement, with gains for POB.

Table 2. Correlations between bunches components of 90 plants from a backcross progeny (caiaué x oil palm) x oil palm.

Variable	NFB	PFB	MFN	MPF	DIASP	OMNF	OMPF	OBNF	OBPF	POB	ODMNF
BW	0.17	-0.07	0.05	-0.06	0.02	0.17	0.17	**0.28****	-0.05	**0.23***	-0.13
NFB		**-0.45****	**-0.25***	-0.21	**0.32****	0.10	0.08	**0.63****	**-0.36****	**0.27***	-0.02
PFB			0.14	**0.42****	**-0.27***	0.03	0.10	**-0.22***	**0.80****	**0.32****	-0.09
MNF				-0.03	**-0.61****	0.01	-0.15	**0.28****	0.02	**0.26***	-0.13
MPF					0.01	0.03	0.10	-0.13	**0.34****	0.15	0.00
DIASP						-0.07	0.09	-0.10	-0.16	-0.20	0.12
OMNF							**0.72****	**0.67****	**0.28***	**0.72****	**0.25***
OMPF								**0.42****	**0.49****	**0.63****	0.20
OBNF									-0.10	**0.75****	0.04
OBPF										**0.56****	0.02
POB											0.06

BW: fresh fruit bunches (FFB) weight in kilograms, NFB: percentage of normal fruits in FFB weight, PFB: percentage of parthenocarpic fruits in FFB weight, MNF: percentage of mesocarp in normal fruits, MPF: percentage of mesocarp in parthenocarpic fruits, DIASP: percentage of diaspore in fruit weight, OMNF: percentage of oil in humid mesocarp of normal fruits, OMPF: percentage of oil in humid mesocarp of parthenocarpic fruits, OBFN: percentage of oil from normal fruit in FFB weight, OBPF: percentage of oil from parthenocarpic fruit in FFB weight; POB: percentage of oil in FFB weight and ODMNF: percentage of oil in dry mesocarp of normal fruits. **and*: significant at 1 and 5% of probability of the t test.

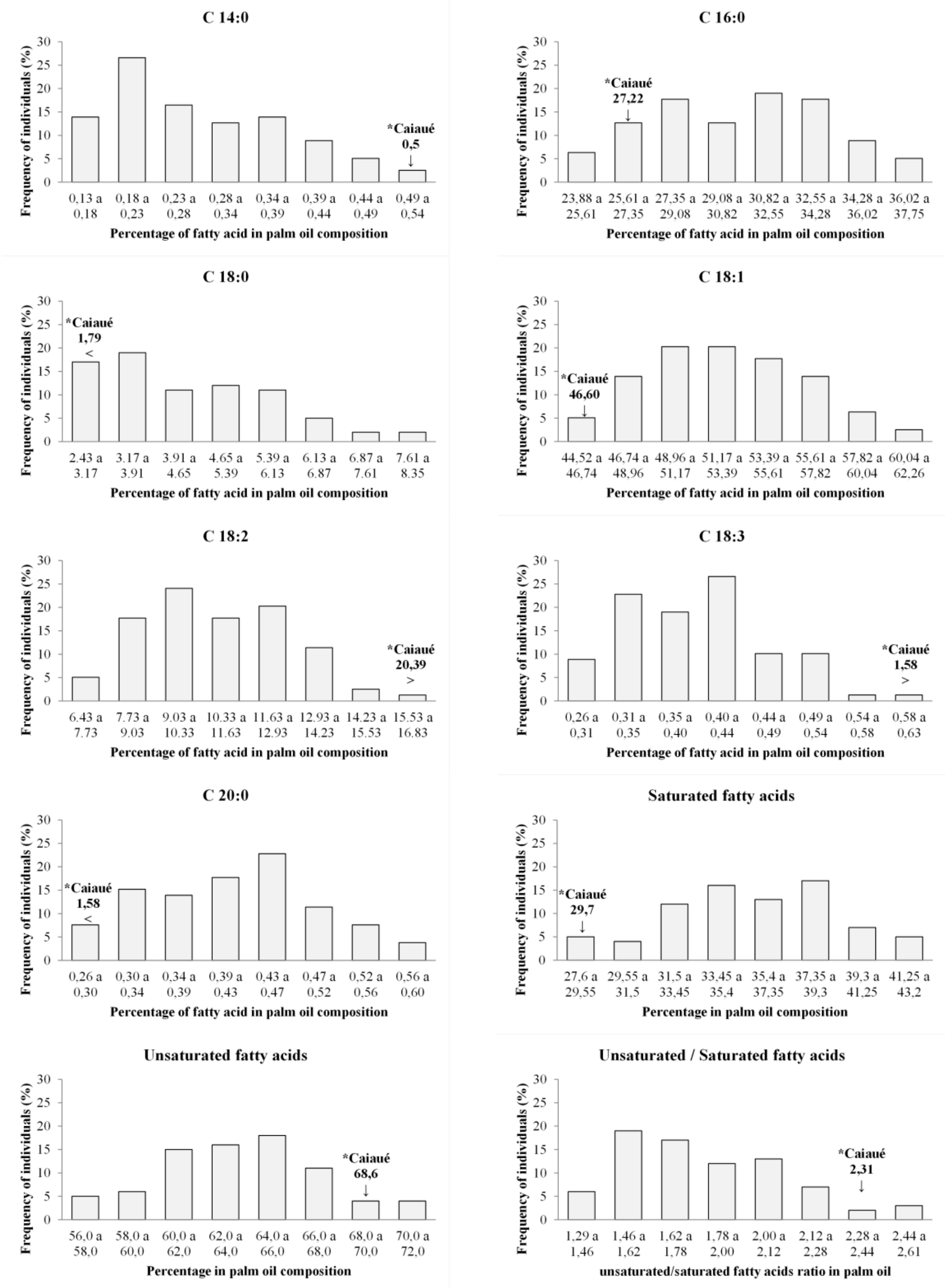
Descriptive statistics (Table 3) and the distribution of means (Figure 3) for the percentage composition of fatty acids in palm oil indicate wide variation in the BC OGxG progenies. The largest variation among fatty acids was found for C18:0, with an amplitude of 1.4% to 8.4% and CV of 32% and 100% of individuals with a value higher than that observed for the ancestral caiaué, which contributes, on average, with 25% of the genome in the BC OGxG progeny. It is observed that some individuals (~ 11%) of the progeny present values for C18:0 above 6.1% (Figure 3), therefore, above the range established by Codex Alimentarius (FAO, 2017) for palm oil, between 3.5% and 6.0%.

Table 3. Descriptive statistics of the percentage composition of fatty acids[1] in palm oil produced by 90 plants from a backcross progeny (caiaué x oil palm) x oil palm and oil in the dry mesocarp of normal fruits (ODMNF).

Fatty acid	Statistics observed in the BC OGxG progeny					*Caiaué
	Mean[2]	Standard deviation	Maximum value	Minimum value	CV (%)	
C14:0 – Myristic	0.28	0.09	0.54	0.13	33.66	0.50
C16:0 – Palmitic	30.67	3.32	37.75	23.88	10.83	27.22
C18:0 – Stearic	4.40	1.39	8.35	2.43	31.66	1.79
C18:1 – Oleic	52.45	3.85	62.26	44.52	7.35	46.60
C18:2 – Linoleic	10.75	2.02	16.83	6.43	18.76	20.39
C18:3 – Linolenic	0.40	0.07	0.63	0.26	18.38	1.58
C20:0 – Arachidic	0.42	0.08	0.60	0.26	19.42	0.18
SFA	35.77	3.66	43.20	27.60	10.00	29.69
UFA	63.60	3.60	72.00	55.9	5.70	68.57
USR	1.81	0.30	2.61	1.29	16.40	2.31
ODMNF	62.85	7.72	79.75	47.15	12.28	43.10

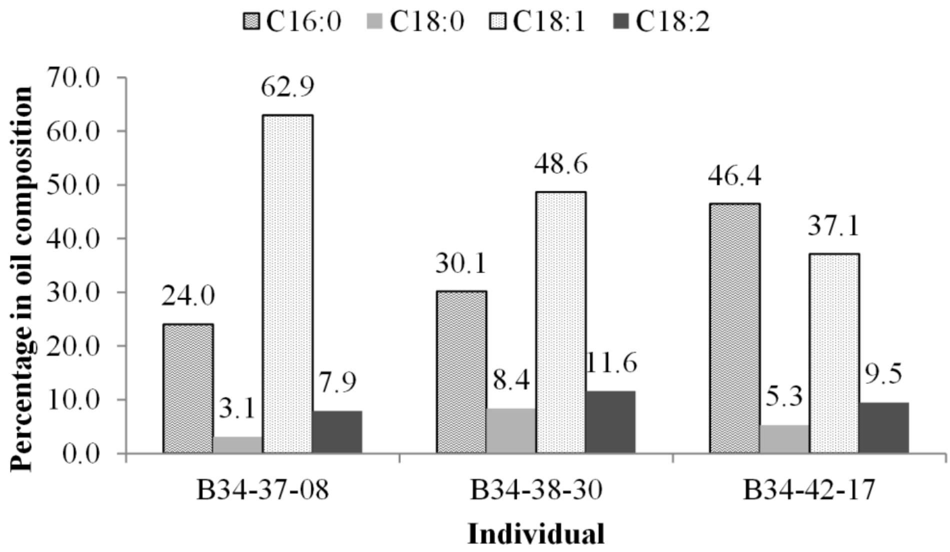
SFA: saturated fatty acids, UFA: unsaturated fatty acids and USR: unsaturated/saturated fatty acids ratio. * Female parent *Elaeis oleifera* (O) of the interspecific hybrid plant (ISH OxG) used to generate the backcross (BC OGxG) characterized for the composition of the bunches. [1] The identification of fatty acids was performed with the commercial fatty acid methyl esters (FAME) available which present all the fatty acids from the mesocarp oil. The retention times of C14:0, C16:0, C18:0, C18:1, C18:2, C18:3 and C20:0 was 3.84, 5.28, 7.32, 7.65, 8.23, 9.15, 10.09 minutes respectively.
[2] mean obtained from samples of two bunches with three replicates of each sample.

Figure 3. Distribution of 90 individuals from an interspecific backcross progeny (caiaué x oil palm) x oil palm in class of percentage values of fatty acids in the composition of palm oil. * Values regarding the female parent of the species caiaué (*E. oleifera*) used in the generation of the F1 hybrid.



To represent the magnitude of the differences within the BC OGxG progeny and the selection possibilities, one can compare, for example, three individuals considering the principal fatty acids in the composition of palm oil (Figure 4).

Figure 4. Fatty acid composition of palm oil from three individuals from a backcross progeny (caiaué x oil palm) x oil palm.



As shown by Sambanthamurthi *et al.* (2000), it is found in the typical composition of palm oil produced in Malaysia, the mean values of 43.5% (39.2% to 45.8%) of C16:0, 39.8% (37.4% to 44.1%) of C18:1; 10.2% (8.7% to 12.5%) of C18:2 and 4.3% (3.7% to 5.1%) of C18:0. These four fatty acids together represent on average, 97.8% of the total fatty acids in palm oil. When analyzing the composition of the palm oil produced by five different Brazilian caiaué origins, Espana *et al.* (2018) reports values between 25.7% to 29.3% for C16:0; 45.9% to 53.3% for C18:1; from 13.4% to 18.3% for C18:2 and from 1.4% to 3.6% for C18:0. In the BC OGxG progeny, the individual B34-42-17 presented 46.4% of C16: 0 and 5.3% of C18:0 in the oil composition, which are high values for palm oil, while the B34-38-30 presents 30% C16:0 and 8.5% C18:0, therefore, compositions where stearins would present very different melting behavior, attending to different applications of fats in the food industry. The individual B34-37-08 presented 62.9% of C18:1 in the composition of its oil, which is the highest value for this fatty acid among individuals of the progeny, and 8% of C18:2, where both unsaturated fatty acids represented 70.9% of the oil composition. On the other hand, it presented 24% of C16:0, a value much lower than that usually found in oil produced by oil palm (39.2% to 45.8%) and also when considering the values found in caiaué oil (25.7% to 29.3%). The high percentage of the principal unsaturated fatty acids (C18:1 and C18:2), associated with the low percentage of the main saturated fatty acid (C16:0), in the oil of individual B34-37-08 indicates that most of the oil can remain in the liquid form at room temperature, similar to what occurs with caiaué oil.

The following fatty acids stood out in the average of the BC OGxG progeny: the unsaturated C18:1 (52.5%) and C18:2 (10.8%) and the saturated C16:0 (30.7%) and C18:0 (4.4%) fatty acids. In total, these four fatty acids add up to 98.4% of the total fatty acids. In comparison with the ancestral caiaué, 94.9% of individuals from the BC OGxG progeny showed higher values for C18:1, 100% lower values for C18:2 and 81% higher values for C16:0. Montoya *et al.* (2013) characterized palm oil from individuals from a progeny BC OGxG and also found as the principal components the saturated fatty acid C18:1 (45.0%) and C18:2 (11.0%) together representing 56% of the fatty acids in the oil, followed by C16:0 (38.8%). In the characterization of ISH OxG palm oil samples produced by two companies in the State of Pará (Brazil), Antoniassi *et al.* (2018) found values of 52.7% to 56.9% and from 11.2% to 12.7% for the unsaturated fatty acids C18:1 and C18:2, respectively. The results are consistent with the types of the materials evaluated because using oil palm as a recurrent parent results in a reduction in the percentage of unsaturated fatty acids in the backcross mean, although, as it was found, individuals may present really differentiated oil compositions. However, the values observed for C16:0 (24.9% to 29.5%) in the ISH OxG palm oil by Antoniassi *et al.* (2018) were lower than those observed on average in the progenies of the BC OGxG evaluated by Montoya *et al.* (2013), 38.8%, and the value of 30.7% found in this study, therefore demonstrating that, on average, oil in the BC OGxG progenies have a higher proportion of saturated fatty acids than the oil produced by caiaué and also by the first generation of interspecific crossing (ISH OxG).

The percentage of saturated fatty acids (SFA) in the palm oil of the BC OGxG progeny (35.8%) was higher than that found in the ancestral caiaué (29.7%), whereas the percentage of unsaturated fatty acids (UFA) (63.6%) was lower (68.6%). As a result of these values, the UFA/SFA ratio (USR) in the palm oil of the BC OGxG progeny (1.81) was lower than that observed in the ancestral caiaué (2.31). In the BC OGxG progeny, on average, 25.0% of the caiaué genome is maintained, thus, the observed values tend to distance themselves from this parent and approach the recurrent parent, the oil palm. However, as there is a variation in the proportion of the caiaué genome in the backcross progeny, some individuals may be genetically closer to this species than the average progeny, which may explain, for example, individuals of the progeny (~ 6.0%) that presented a percentage of AGI similar to the value observed in caiaué.

The fatty acid C18:1 (oleic), the main fatty acid in the composition of BC OGxG palm oil, showed a negative and significant correlation (Table 4) with the SFA C14:0 (-0.45), C16:0 (-0.75), C18:0 (-0.39) and the UFA C18:2 (-0.39). Yet, with the FA C18:3 (-0.01) and C20:0 (-0.17) the correlation, although negative, was low and not significant. The negative correlation between FA C18:1 and C18:2 was also reported by Montoya *et al.* (2013), that explain this negative correlation due to the fact that FA C18:1 is a substrate for the production of C18:2, which occurs due to the action of the enzyme FAD2. High and positive correlations were identified between FA C14:0 and C16:0 (0.69), C18:2 and C18:3 (0.57) and C18:0 and C20:0 (0.72). The variation in the composition of the oil in fatty acids did not show a significant correlation with the percentage of oil in dry mesocarp (ODM), which indicates that the selection for a high percentage of ODM does not affect the composition of the oil and, on the other hand, the selection for gains in oil composition will not affect the gains for ODM.

Table 4. Correlations between the percentage of fatty acids in the palm oil of 90 plants from a backcross progeny (Caiaué x palm oil) x palm oil.

Fatty acid	C16:0	C18:0	C18:1	C18:2	C18:3	C20:0	ODM
C14:0	**0.69****	-0.21	**-0.45****	-0.11	**-0.25***	**-0.39****	0.00
C16:0		-0.01	**-0.75****	-0.19	**-0.28***	-0.18	-0.06
C18:0			**-0.39****	0.07	-0.19	**0.72****	-0.03
C18:1				**-0.39****	-0.01	-0.17	0.00
C18:2					**0.57****	0.10	0.09
C18:3						0.02	0.01
C20:0							-0.13

ODM: percentage of the oil in the dry mesocarp. ** and *: significant at 1 and 5% of probability by the t test.

The interspecific hybridization between caiaué and oil palm has as main objective the introduction of genetic resistance to Bud Rot desease in the oil palm, which has already been demonstrated in the F1 hybrids (GOMES JR *et al.*, 2019). The genetic control of resistance to BR is unknown and there is no information about segregation of this characteristic in backcross generations. However, the backcross of the interspecific F1 hybrid with the oil palm was recommended as a solution to the fertility problems verified in the interspecific F1 hybrids (BARBA, 2016). The results of this study indicate that the use of caiaué in the oil palm genetic improvement will allow also the development of cultivars with different oil compositions, with specific profiles to attend differents purpose of use. However, the commercial use of first-generation backcross genotypes will depend of cloning, since these cannot be reproduced by seeds due to segregation. Once cloned, genotypes can be evaluated for other characteristics, such as resistance to Bud Rot and bunches productivity.

4 Conclusions

The large phenotypic variation is observed in interspecific backcross (caiaué x oil palm) x oil palm, both for the physicochemical characterization of the bunches and in the composition of palm oil in fatty acids.

Unsaturated fatty acids predominate in composition of interspecific backcross (caiaué x oil palm) x oil palm, with predominance of oleic fatty acid.

The simultaneous selection of individuals from progenies of the BC OGxG is possible for high yield of palm oil in the fresh fruits bunch and increasing or reducing the percentage of saturated or unsaturated fatty acids in the oil composition.

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