BUNCH OIL AND FATTY ACID PROFILE IN *Elaeis oleifera* TAISHA-ECUADOR, *Elaeis guineensis* Jacq., INTERSPECIFIC HYBRIDS AND BACKCROSSES

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ABSTRACT

In this study, bunch oil content and fatty acid profile in the Elaeis oleifera *species from Taisha, Morona-Santiago, Ecuador, its interspecific hybrid descendants and backcrosses were determined in contrast to* Elaeis guineensis. *Results showed that* E. oleifera *from Taisha presented an average of 10.74% oil in bunch, being lower than those presented by hybrids of 25.80%, backcrosses of 25.98%, and* E. guineensis *of 29.49%. The most abundant fatty acids in the mesocarp corresponded to C16:0, C18:1n9, and C18:2n6, where* E. oleifera *from Taisha, although it had a lower content of palmitic acid (27.82%) compared to the rest of the genotypes. This did not present statistical differences for C18:1n9 because of the same behaviour as an* E. guineensis, *and therefore did not classify as a high oleic material. However, for C18:2n6, which is in the group of unsaturated fatty acids, it presented higher values than any of the other materials, indicating that its oil synthesis converts C18:1 to C18:2 more easily than other* E. oleifera *of different places in America. The average iodine value was 76.93%, compared to hybrids with 67.14%, backcrosses with 60.20%, and* E. guineensis *with 55.65%.*

INTRODUCTION

In 2020, 209.9 million tonnes of vegetable oil were produced, 31.4% of the production corresponded to crude palm oil (CPO) obtained from the mesocarp and palm kernel, which are the two types of oil produced from the oil palm fruit (Oil World, 2020). Approximately 70.0% of world palm oil production is used in the food industry (Lieb *et al.*, 2017). The fatty acid composition determines the nutritional suitability of palm oil (Sambanthamurthi *et al.*, 2000).

Palm oil is a lipid, composed of glycerol esters and long-chain fatty acids that are insoluble in water, but soluble in various organic solvents such as ether, chloroform, certain alcohols, and benzene (Corley and Tinker, 2009). Fatty acids can be saturated or unsaturated, depending on the number of double bonds in their chain; saturated does not have double bonds and unsaturated do. Its structure is designated by a symbol that indicates the length of the carbon chain and the number of double bonds. Thus, palmitic acid (C16:0) has 16 carbons with no double bonds and oleic acid (C18:1) has 18 carbons and one double bond (Sambanthamurthi *et al.*, 2000). The main fatty acids in palm oil are myristic (C14:0), palmitic (C16:0), stearic (C18:0), oleic (C18:1), and linoleic (C18:2). C16:0 is the main saturated fatty acid and is balanced by C18:1 monounsaturated and C18:2 polyunsaturated (Sambanthamurthi *et al.*, 2000).

The fatty acids composition of CPO is substantially different within the *Elaeis* genus,

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which comprises two species: *Elaeis guineensis* Jacq., originally from Africa, planted commercially worldwide, and *Elaeis oleifera* HBK Cortés from America, which represents an important genetic source in the generation of interspecific hybrids with *E. guineensis*. African palm contains approximately 50% saturated fatty acids, with 44% C16:0, 5% C18:0, and trace amounts of C14:0; unsaturated fatty acids represent approximately 40% of C18:1 and 10% of C18:2 and α-linolenic acid (C18:3) (Montoya *et al.*, 2014). Generally, the unsaturated fatty acids content of the American palm varies from 47.0% to 69.0% for C18:1, 2.0% to 19.0% for C18:2, and 0.1% to 1.2% for C18:3 (Montoya *et al.*, 2014). *Elaeis oleifera* oil contains more unsaturated fatty acids (C18:1 and C18:2) and a higher iodine value than *Elaeis guineensis*, being quite similar to olive oil in its composition (Corley and Tinker, 2009). Consequently, the iodine value, which is a multiparameter measure of the global degree of unsaturation of fatty acids in vegetable oil, presents values between 70.0% and 87.0% for *E. oleifera*, while the value for *E. guineensis* is between 53.0% and 60.0% (Montoya *et al.*, 2014).

The interspecific hybrid resulting from the cross between *E. oleifera* and *E. guineensis* presents an intermediate oil composition between the parents, indicating additive inheritance (Hardon, 1969; Meunier and Boutin, 1975; Sambanthamurthi *et al.*, 2000). This oil is called high oleic oil, which comprise 33% saturated fatty acids with around 28% being C16:0, and 66% unsaturated fatty acids with around 54% of C18:1 (Mozzon *et al.*, 2013). Backcrosses between hybrids and either parent exhibit intermediate oil between the hybrid and the recurrent parent (Corley and Tinker, 2009; Sambanthamurthi *et al.*, 2000), again suggesting additive inheritance.

This study would provide an insight into the variability of oil content and quality within the genus *Elaeis*. The objective was to determine the amount of oil in the bunch and the composition of fatty acids in *E. oleifera* from Taisha, Morona Santiago, Ecuador, its interspecific hybrids and backcrosses, in comparison with *E. guineensis*. This is a new work where the fatty acid profile of *E. oleifera* from the locality of Taisha, Morona Santiago, Ecuador and its hybrids and backcrosses with different *E. guineensis* parents will be shown.

MATERIALS AND METHODS

Study Site

The study was carried out at the Palmar del Río company located in San José de Guayusa, province of Francisco de Orellana, Amazon region of Ecuador. The geographic coordinates of the locations were 0º 19' S and 77º 06' W, at an altitude of 280 m above sea level. The average rainfall was 266 mL/month, solar radiation of 4148 watts/month, minimum temperature of 18.6°C and a maximum of 32.8°C, relative humidity of 78.13% and Inceptisol soils with relatively flat topography (Barba, 2016).

Vegetal Material

The study was focused on *E. oleifera* palms from the town of Taisha, Morona Santiago, Ecuador; interspecific hybrids derived from *E. oleifera* Taisha crossed with *pisifera guineensis* of Yangambi, La Mé, and AVROS origins; backcross from interspecific hybrids of Taisha x AVROS origin crossed with *E. guineensis* AVROS, and *tenera guineensis* palms of AVROS origin. The genotypes and their names are described in *Table 1*.

Oil Content

A bunch of fresh fruit at the point of physiological maturity was harvested from each palm, based on more than five naturally detached fruits, taking into consideration that *E. oleifera* from Taisha do not have loose fruits, unlike some other *oleifera* and

TABLE 1. DESCRIPTION OF THE GENOTYPES OF *Elaeis oleifera* TAISHA, *Elaeis guineensis*, OXG HYBRIDS AND BACKCROSSES PALMS

Genotypes	Treatments	Abbreviation	Age (yr)
E. oleifera Taisha x *E. guineensis* Yangambi	Taisha x Yangambi	H1	13
E. oleifera Taisha x *E. guineensis* La Mé	Taisha x La Mé	H2	13
E. oleifera Taisha x *E. guineensis* AVROS	Taisha x AVROS	H3	14
Backcross: (*E. oleifera* - Taisha x *E. guineensis* - AVROS) x *E. guineensis* AVROS	Backcross	BC	8
E. oleifera - Taisha	Taisha	Taisha	21
E. guineensis AVROS	AVROS	AVROS	9

interspecific hybrids. The harvested bunch was placed in a bag and labelled with each genotype. The bags of fruit bunch were taken to the laboratory for bunch analysis, where the weight of the bunch was recorded and subsequently chopped into peduncle, spikelets, and fruits. The fruits were then separated into fertile, parthenocarpic and abortive fruits, counted and weighed, using the method described by Prada and Romero (2012).

The oil potential in bunch (OB) was estimated using three variables: Fruit in the bunch (FB), mesocarp in fruit (MF), and oil in fresh mesocarp (OFM). In consideration that *oleifera* and hybrids contain two types of oil, the fertile fruits contains the kernels but there are no kernel in the parthenocarpic fruits. A sample of 300 g of each fertile and parthenocarpic fruits were taken from each bunch, manually pulped with pruning shears, separating the mesocarp and kernel from the fertile ones, while the parthenocarpic ones were cut into small pieces. The mesocarp was weighed and dried in an oven at 105°C for 24 hr, then crushed in a blender and dried again in the oven for 12 hr at 60°C. A 5 g sample taken from the crushed mesocarp was put in a thimble, then placed in a soxhlet system with chloroform (98.2% $CHCl_3$) as the oil extraction solvent for approximately 24 hr. Once the oil was extracted, the thimble was dried in the oven at 105°C for 12 hr, then it was weighed and the oil content in wet mesocarp was calculated, according to Equation (1). In bunch analysis, besides measuring the oil content, it also can determine other parameters such as predicting the behavior of other agronomic factors that can be useful in the field and genetic improvement programmes.

$$OB (\%) = FB*MF*OFM \qquad (1)$$

Determination of the Fatty Acid Profile

A sample of crude oil from the mesocarp was taken from each palm for analysis. The repeatability of measurements for fatty acid composition is high, hence a single measurement is sufficient to describe the fatty acid content of a group (Rajanaidu *et al.*, 1983). Three 240 g oil samples were taken from each genotype or treatment, making a total of 18 samples. The chemical analysis of fatty acids content was carried out in the laboratory of the Colombian Oil Palm Research Center, Palmar de la Vizcaina Experimental Field, Barrancabermeja, Colombia. Fatty acid profiles were determined according to the American Oil Chemist's Society method (AOCS, 1994). The fatty acid methyl esters were determined using gas chromatography with flame ionisation detector. Oil samples were saponified with KOH/MeOH. The fatty acids were derivatised to esters using a solution of BF3 in methanol. The esters were extracted and 1 μL was injected into the

chromatographic system. The equipment used was a 7890 A gas chromatograph (Agilent Technologies, Wilmington, USA). The column used in the analysis was a DB-23 (J&W Scientific, Cat. 1222362) of 60 m x 0.25 mm I.D. x 0.25 μm f.e., and the injection was performed in split mode (50:1). Hydrogen was used as carrier gas at a constant flow rate of 33 cm/s. The reference standard used to determine the retention time was FAME blend of Supelco™ 37 components (Supelco, Bellefonte, PA, Cat No 47885U). The fatty acid methyl esters were identified by comparison with the retention times of the standard mixture, analysed under the same chromatographic conditions. The quantification was performed using area normalisation method. Results were expressed as mass to mass percentage (m/m) according to the official method AOCS Ce 1-62 (AOCS, 1997).

The fatty acids used for analysis in this study were myristic acid (C14:0), palmitic acid (C16:0), stearic acid (C18:0), palmitoleic acid (C16:1), oleic acid (C18:1n9c), vaccenic acid (C18:1n7c), linoleic acid (C18:2n6c) and α-linolenic acid (C18:3n3), which are the most representative in crude palm oil.

Determination of the Iodine Value

The method used as described in the AOCS manual, method Cd 1b-87 (AOCS, 1994). This method is used by the laboratory of the Colombian Oil Palm Research Center where the analyses were carried out. The iodine value is defined as the g of iodine that react with 100 g of fat or oil (12 g/100 g oil). This determination is related to the content of unsaturated fat (mono and polyunsaturated fatty acids). In the case of crude palm oil, high iodine values imply higher olein yields during fractionation. This determination can also be used as a criterion for the identity and purity of the product.

Statistical Analysis

A completely randomised design was used with six treatments made up of three experimental units as indicated in *Table 1*. The fatty acid profile and iodine value data were processed through an analysis of variance, after ShapiroWilk checked the normality of the variances and Levene's test for homoscedasticity. To evaluate the interspecific variation between the species, the genetic distance was calculated with the Euclidean distance. The comparison of means was carried out with orthogonal contrast analysis between the groups of *E. oleifera*, OxG hybrids, backcrosses, and *E. guineensis*. To determine the assignment of positive or negative coefficients to each group, the percentage of *E. guineensis* in each palm was considered as a reference, positively favoring the highest percentage of *E. guineensis* in all contrasts, corresponding to each group: *E. oleifera* from Taisha with 0%, OxG hybrids with

50%, backcross with 75% and *E. guineensis* AVROS with 100%. Additionally, a multivariate principal components analysis was performed to select discriminant variables. For the selection of significant eigenvalues or eigenvalues, the Kaiser criterion was used, which consists of selecting the components whose eigenvalue is > = 1 and a Pearson correlation was performed on the selected variables. Data were processed with Statistical Analysis Systems software (SAS® 9.2).

RESULTS AND DISCUSSION

Bunch Oil Content

The bunch oil content obtained in the laboratory (*Table 2*), statistically shows highly significant differences in the analysis of variance between treatments (*Table 3*). The differences were corroborated with orthogonal contrasts in *Figure 1*. *Elaeis oleifera* from Taisha had an average of 10.74%, the lowest compared to hybrids, backcrosses, and *E. guineensis* AVROS, which together presented 26.58%. Likewise, there was significant differences between hybrids and backcrosses against *E. guineensis* AVROS, and between hybrids and backcrosses; however,

there were no significant differences between hybrids. Regarding the low oil content of the Taisha *oleifera*, it was reported that the general yield of *E. oleifera* from different places in Latin America is much lower, with a 5.0% bunch oil ratio, compared to *E. guineensis* type *tenera* with an amount of 25.0% bunch oil (Rajanaidu *et al.*, 2000). However, Rey *et al.* (2014), in their study of *oleifera* from the Amazon trapezium reported a range between 4.4% to 13.0% of bunch oil values which are nearer to those found in *E. oleifera* from Taisha. The bunch oil content of OxG hybrids was 18.0% (Ochoa *et al.*, 2013), very similar to the results of Preciado *et al.* (2011) and the hybrids derived from *oleiferas* of Cerete-Colombia was 19.3%. Nevertheless, Torres *et al.* (2014), found variations between 18.0% and 29.0% of oil in the bunch in different progenies of OxG hybrids, while Castro and Amézquita (2007) reported variations from 5.0% up to 25.0%.

In their study of OxG hybrids descending from *E. oleiferas* from Taisha, Barba and Baquero (2013) reported that there are OxG PDR-Taisha hybrids that achieved an average value of 23.39% oil in the bunches with the lowest value at 18.01%, and the average obtained from all the evaluated progenies was 20.89% of oil in bunches. The results of different bunch oil content studies validate

### TABLE 2. RESULTS BY GENOTYPE OF BUNCH OIL CONTENT AND FATTY ACID PROFILE

Fatty acid composition	*Elaeis oleifera* Taisha		Hybrids						Backcross		*Elaeis guineensis* AVROS	
			Taisha x La Mé		Taisha x Yangambi		Taisha x AVROS					
C14:0	0.24	±0.1	0.20	±0.1	0.31	±0.1	0.50	±0.2	0.64	±0.2	0.78	±0.3
C16:0	27.82	±3.2	29.59	±1.3	33.60	±6.0	37.41	±2.4	39.2	±0.4	41.25	±1.9
C16:1	3.54	±1.2	0.40	±0.2	0.34	±0.1	0.63	±0.1	0.40	±0.1	0.13	±0.0
C18:0	1.42	±0.1	3.06	±1.0	3.05	±0.0	2.49	±0.3	3.27	±0.1	5.07	±0.3
C18:1n9c	39.37	±5.6	51.64	±2.0	47.95	±5.8	40.63	±4.8	41.7	±0.7	40.41	±0.1
C18:1n7c	4.16	±0.4	1.28	±0.5	1.16	±0.1	1.53	±0.1	1.15	±0.0	0.65	±0.0
C18:2n6c	21.53	±1.4	12.91	±0.9	12.76	±0.3	15.99	±2.4	12.6	±1.3	10.69	±1.9
C18:3n3	1.26	±0.3	0.43	±0.1	0.37	±0.0	0.51	±0.1	0.42	±0.0	0.23	±0.0
Others	0.60	±0.6	0.33	±0.3	0.46	±0.9	0.31	±0.1	0.60	±0.0	0.68	±0.0
SFA	30.15	±3.4	33.27	±1.6	37.34	±6.1	40.71	±2.2	43.65	±0.8	47.75	±2.0
MUFA	47.07	±4.5	53.32	±2.3	49.45	±5.8	42.79	±4.7	43.24	±0.6	41.20	±0.0
PUFA	22.78	±1.7	13.33	±0.9	13.12	±0.3	16.50	±2.5	12.99	±1.3	10.91	±2.0
IV	76.93	±2.7	69.77	±1.0	66.20	±5.6	65.47	±0.3	60.20	±1.8	55.65	±3.7
OB	10.74	±2.7	26.13	±1.6	24.89	±1.1	26.40	±3.0	25.98	±0.7	29.49	±2.2

Note: Others - Including the minor fatty acids 12:0, 15:0, 17:0, 20:0, 20:1n9; SFA - Saturated fatty acids; MUFA - Monounsaturated fatty acids; PUFA - Polyunsaturated fatty acids; IV - Iodine value; OB - Bunch oil.

TABLE 3. ANALYSIS OF VARIANCE FOR BUNCH OIL CONTENT, FATTY ACID PROFILE AND IODINE VALUE

| Variable | Oil bunch | Fatty acids | | | | | | | | Iodine value |
		C14:0	C16:0	C16:1	C18:0	C18:1n9c	C18:1n7c	C18:2n6c	C18:3n3	
Mean squares	132.48	0.17	101.50	5.09	4.35	62.62	4.57	41.40	0.32	164.57
Significance	**	*	*	**	**	*	**	**	*	**
Coefficient of variation (%)	8.57	39.19	8.28	52.94	14.25	8.88	15.04	10.89	32.34	4.66
Mean	23.94	0.44	34.55	0.91	3.05	44.22	1.64	14.33	0.52	65.70

Note: C14:0 - myristic acid; C16:0 - palmitic acid; C16:1 - palmitoleic acid; C18:0 - stearic acid; C18:1n9 - oleic acid; C18:1n7c - vaccenic acid; C18:2n6c - linoleic acid; C18:3n3 - α-linolenic acid; *Significant F-Test ($p<0.05$); ** Highly significant F-Test ($p<0.01$).
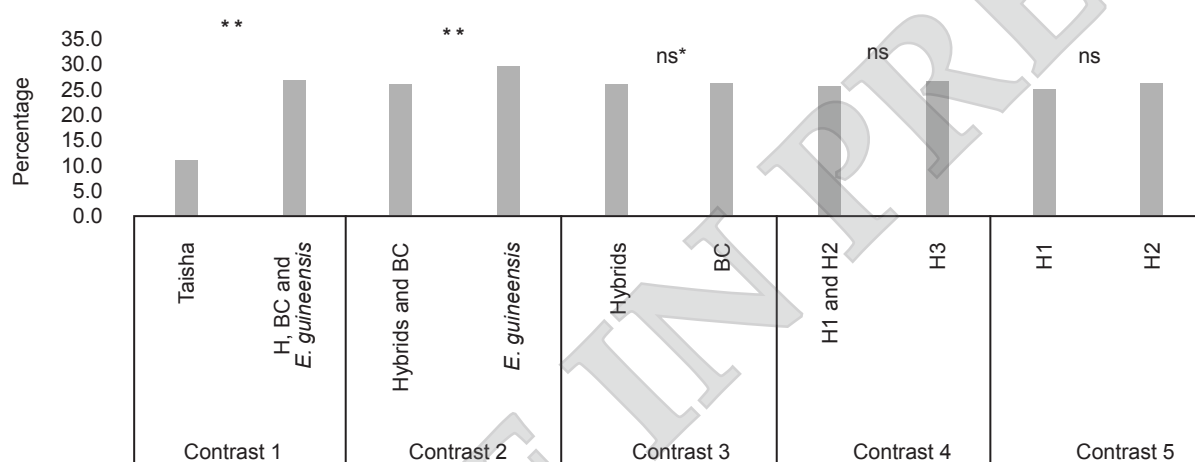
Note: ns - Non-significant F-test; ** - Significant F-Test ($p<0.01$).

Figure 1. Orthogonal contrasts between treatments of Elaeis oleifera *Taisha, interspecific hybrids (H), backcrosses (BC) and* Elaeis guineensis *Avros for the potential bunch oil variable.*

the results obtained in the analysed OxG hybrids, which did not present significant differences between them. However, it is worth mentioning that the oil content is influenced by the quality in the formation and composition of the bunch, fruits produced in conjunction with pollination. Meanwhile, for backcrosses Bastidas *et al.* (2007), reported 19.60% oil extraction potential in the bunch. When comparing the *E. oleifera* with hybrids, backcrosses, and *E. guineensis*, it can be seen that it has lower amount of oil extracted from the bunch, which is the reason for the difference from the other genotypes.

Fatty Acid Profile and Iodine Value

The profile of fatty acids in the mesocarp of *E. oleifera* palms from Taisha, its hybrids, backcrosses, and *E. guineensis*, made it possible to determine that the main fatty acids found were C14:0, C16:0, C16:1n7, C18:0, C18:1n9, C18:1n7,

C18:2n6 and C18:3n3 (*Table 2*). Additionally, trace amount of other minor fatty acids does not exceed 0.60% and these fatty acids are C12:0, C15:0, C17:0, C20:0, and C20:1n9, which were not considered in this study. It should be noted that these fatty acids are part of the normal constitution of crude palm oil, which are predominantly even, while the odd chain saturated fatty acids pentadecanoic (C15:0) and heptadecanoic (C17:0) represent a small part of the total plasma concentration of fatty acids, especially in milk fat, meat, fish and some algae, and can occur endogenously in humans (Jenkins *et al.*, 2015). These long, odd-chain fatty acids are oxidised via the same route as the even-numbered fatty acids, by beta-oxidation, starting at the carboxyl end of the chain. However, its penultimate metabolite is an acyl-CoA in which the fatty acid has five carbon atoms. When it undergoes oxidation and breakdown, the products are acetyl-CoA and propionyl CoA. Acetyl-CoA can be oxidised by entering the Krebs cycle, but

propionyl-CoA enters the Krebs cycle as succinyl-CoA for transformation to succinyl-CoA; propionyl-CoA undergoes three enzymatic processes (Nelson and Cox, 2006). For human health, C15:0 and C17:0 acids have been linked to a lower risk of type 2 diabetes and cardiovascular disease (Jenkins *et al.*, 2015).

Statistical differences were found between treatments in all the variables as indicated in *Table 3* of the analysis of variance, and the orthogonal contrasts between treatments allowed us to appreciate differences between the means of the different palm genotypes according to the number of fatty acids.

The saturated fatty acids from different palms shows that in the *E. oleifera* of Taisha palmitic acid of 27.82% was different from the group of hybrids with 33.53%, backcrosses with 39.22% and *E. guineensis* with 41.21% (*Figure 2*). This observation shows a differential proportion between materials as reported by Guerin *et al.* (2016), who stated that the level of palmitic acid (16:0) in *E. oleifera* is approximately two times lower than in *E. guineensis*, which is around 25 and 45%, respectively.

For *E. oleifera* from Taisha, 28.2% palmitic acid has been reported (Lieb *et al.*, 2017), while for other *E. oleifera* from Brazil, Peru, and Colombia the values were 27.5%, 37.5% and 19.4% respectively (Chaves *et al.*, 2018). This indicates that there is a variation of palmitic acid content among *E. oleifera* from different localities. Likewise, palmitic acid content has been reported for OxG hybrids from *E. oleifera* from Taisha, where it was highlighted that the higher or lower palmitic acid content depends on the male

parent used. The authors also reported that the hybrids from *E. guineensis* AVROS had an amount of 36.11% while those of La Mé 29.69% (Barba and Baquero, 2013). These results are similar to those obtained in this study for the Taisha x AVROS and Taisha x La Mé hybrids. Likewise, for the backcross, the percentage of C16:0 reported was intermediate with an amount between *E. oleifera* and *E. guineensis*, corroborating results from Guerin *et al.* (2016), who confirmed that for the backcrosses the amount of C16:0 was between 32% to 47%.

These differences between palm materials occur because palmitic acid represents 44.0% of the total fatty acid composition of *E. guineensis* palm oil (Sambanthamurthi *et al.*, 2000), while *E. oleifera* ranges from 20.0% to 29.0% (Meunier and Boutin, 1975), with interspecific hybrids and backcrosses recorded intermediate range of their parents (Sambanthamurthi *et al.*, 2000). Saturated oils such as palm oil have many advantages for the food industry due to the high oxidative stability and high melting point, which makes them a good alternative to trans fats (hydrogenated oils) (Guerin *et al.*, 2016).

Elaeis oleifera from Taisha in comparison to the group of hybrids, backcrosses and *E. guineensis*, did not show statistical differences for the oleic acid, likewise, with regards to hybrids and backcrosses against *E. guineensis* and hybrids against backcrosses, did not differ in the percentage of oleic acid. However, the Taisha x AVROS hybrid with 40.63% oleic acid was statistically different from Taisha x Yangambi and Taisha x La Mé with 49.80%, while there were no significant differences between Taisha x Yangambi and Taisha x La Mé (*Figure 3*).
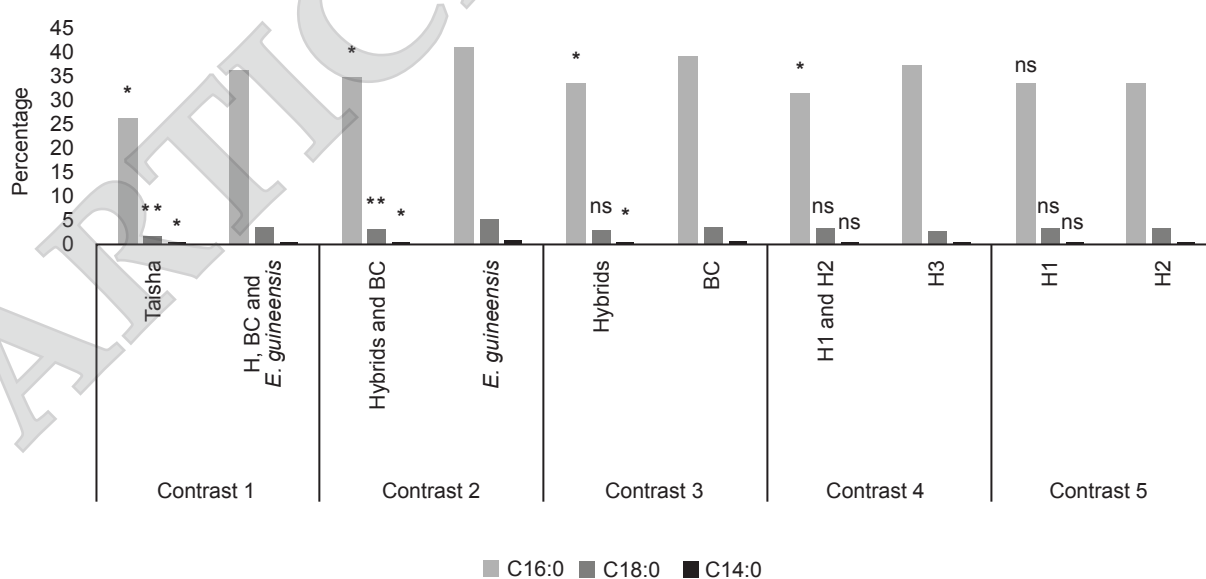
Note: ns - Non-significant F-test; * - Significant F-test (*p*<0.05); ** - Significant F-Test (*p*<0.01).

Figure 2. Orthogonal contrasts between groups of Elaeis oleifera *Taisha, hybrids (H), backcrosses (BC) and* Elaeis guineensis *for saturated fatty acids.*
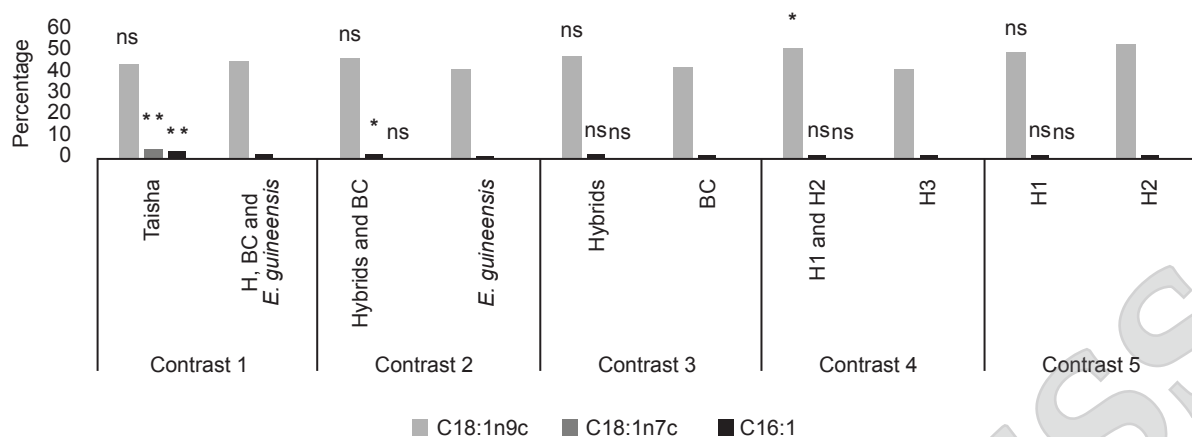
Note: ns - Non-significant F-test; * - Significant F-test ($p<0.05$); ** - Significant F-Test ($p<0.01$).

Figure 3. Orthogonal contrasts between groups of Elaeis oleifera *Taisha, hybrids (H), backcrosses (BC) and* Elaeis guineensis *for monounsaturated fatty acids.*

Other studies indicated that *E. oleifera* had oleic acid contents that varied from 47.0% to 69.0% (Montoya *et al.*, 2014). Lieb *et al.* (2017), reported oleic acid contents of 36.4%, 61.7% and 46.3%, respectively, for *E. oleifera* from Taisha, Surinam, and Manaus. Zapata-Munevar (2010) used the term "high oleic" referring to the high concentration of oleic acid present in the oil of interspecific hybrids OxG-cultivar Coari x La Mé (54.0% to 57.0%, by weight) and this is because of the increase in oleic acid in *oleifera* and their hybrids when compared with the *guineensis*. The oleic acid content is a character transmitted by the *oleifera*, compared to the conventional palm oil *Tenera* DxP (*E. guineensis* x *E. guineensis*), which has a concentration of this fatty acid between 36.0% and 44.0% by weight (Rincón and Martínez, 2009). Since *E. oleifera* from Taisha does not show significant differences from *E. guineensis* in the C18:1 content, hence the oil cannot be categorised as high oleic oil which is an important characteristic of interspecific hybrids.

The additive inheritance of the genes that make up the fatty acids plays an important role in the amount of C18:1 that an OxG interspecific hybrid can inherit, given that the composition of fatty acids is intermediate between the parents, attributing to co-dominant and additive inheritance (Sambanthamurthi *et al.*, 2000). In the case of the Taisha x La Mé hybrid, it was the one with the highest C18:1 content compared to AVROS and Yangambi. This was probably due to the La Mé parent and this is supported by Monde *et al.* (2009) who stated that the La Mé origin has a high proportion of C18:1.

Elaeis oleifera from Taisha had the highest values of 3.55% palmitoleic and 4.09% vaccenic acids, in contrast to 0.38% and 1.15% for the group of hybrids, backcrosses, and *E. guineensis* (*Figure 3*). Ngando and Koh (1988) were the first to identify vaccenic acid in

palm mesocarp and identified that in *E. oleifera* the proportion reached up to 5.00%, a value that is higher than that found in *E. oleifera* from Taisha, while for hybrids, backcrosses and *E. guineensis* the amount was even lower. *Cis*-vaccenic acid is formed by the elongation of palmitoleic acid, therefore, for these monounsaturated fatty acids such as palmitoleic there is a pharmaceutical demand because of the antithrombotic properties, while for *cis*-vaccenic acid there are industrial applications, hence it may be useful to produce these fatty acids on a large scale in the oil palm industry (Sambanthamurthi *et al.*, 2000).

Regarding polyunsaturated fatty acids, the linoleic acid content of *E. oleifera* from Taisha at 21.07% was higher compared to the hybrids, backcrosses, and *E. guineensis* AVROS; although, Taisha x AVROS had a higher content compared to the other hybrids (*Figure 4*). It was reported that the percentage of linoleic acid in *E. guineensis* is 10% (Sambanthamurthi *et al.*, 2000), while that of *E. oleifera* varied from 2% to 19%. This amount of linoleic acid is higher than that of *E. oleifera* from Taisha, hence this observation explained the lower amount of oleic acid in comparison with other *E. oleifera* from America. Guerin *et al.* (2016), found that the FAP1 and ACBP6 genes encode the enzyme that converts C18:1 to C18:2, adding as active variables, KASII being the only gene that opposes C16:0, and ACBP6 opposes C18:0, suggesting that cytosolic ACBP converts unsaturated fatty acids into C18:0 fatty acids during rearrangement of triacylglycerol (TAG). However, for hybrids and backcrosses, the values obtained do not differ from those of *E. guineensis*, because linoleic acid has non-additive genetic determinism in the inter and intraspecific genetic material, with *E. guineensis* being predominant over *E. oleifera* (Montoya *et al.*, 2014).
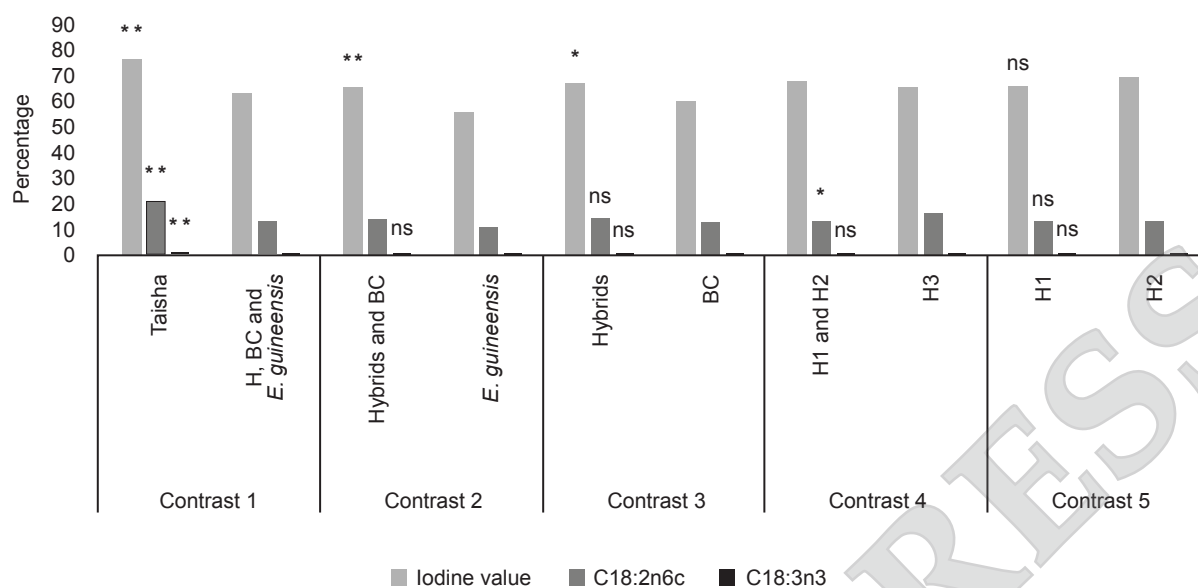
Note: ns - Non-significant F-test; * - Significant F-test ($p<0.05$); ** - Significant F-Test ($p<0.01$).

Figure 4. Orthogonal contrasts between groups of Elaeis oleiferas *Taisha, hybrids (H), backcrosses (BC) and* Elaeis guineensis *for polyunsaturated fatty acids and iodine value.*

In the same way as linoleic acid, *E. oleifera* from Taisha had the highest mean value of 1.16% of α-linolenic acid, in contrast to 0.39% for the group of hybrids, backcrosses and *E. guineensis*, and these values are within the range from 0.10% to 1.20% for α-linolenic acid (Montoya *et al.*, 2014). In the treatments of *E. oleifera* from Taisha and its OxG hybrids, high proportions of linoleic acid known as omega 6 and traces of α-linolenic acid known as omega 3 were found. Fatty acids such as omega-6 and omega-3 are considered essential fatty acids since they cannot be synthesised by the human body, therefore they must be provided by the diet in an adequate proportion (Turner *et al.*, 2011). They fulfill functions within the organism, such as being metabolic regulators in the cardiovascular, pulmonary, immune, secretory and reproductive systems, preserving the functionality of cell membranes and participating in genetic transcription processes (Carrillo *et al.*, 2011). Meanwhile, the oleic fatty acid known as omega-9 can be formed in a small proportion by the human body, so it is considered non-essential (León et al., 2004). However, the α-linolenic acid found in traces in palm oil differs from a marine oil, which is characterised by its high content of omega-3 polyunsaturated fatty acids, of which the most important are eicosapentaenoic acid (C20:5) and docosahexaenoic acid (C22:6), which are easily ingested by the human body, producing beneficial effects on health and nutrition (Coultate, 2007).

The α-linolenic fatty acid of plant origin, due to its shorter carbon chain length, cannot be directly assimilated by the human body, however, once the body has them, they must act as precursors for the synthesis of C20:5 and C22:6, through a series of elongation and desaturation reactions, so that in this way it produces health benefits (León *et al.*, 2004).

With regards to the iodine value, it is higher in *E. oleifera* than in *E. guineensis* because as suggested by Shah and Cha (2000) that there is a unique sesquiterpene synthase gene in the mesocarp of *E. oleifera* during 12 to 20 weeks of age, but absent in *E. guineensis* and in other tissues of both species, hence this requires additional analysis to establish the relationship with quality of American palm oil. Likewise, it has been stated that the differences in the composition of fatty acids must be related to the expression of genes encoding the enzyme KAS II and stearoyl/palmitoyl-ACP D9-desaturase (Mozzon *et al.*, 2013). The pathway for fatty acid biosynthesis in which C16:0 is elongated to C18:0 by the enzyme β-ketoacyl-ACP synthase II (KASII), and C18:0 will subsequently be desaturated by atur9-stearoyl-ACP desaturase to form C18:1 (Singh *et al.*, 2009). Therefore, in this study, the results reflect an increase in unsaturated fatty acids at the expense of saturated fatty acids.

According to Arias *et al*. (2015), *E. oleifera* from different locations in America, present a specific genetic structure and phenotypic variability with

different characteristics between origins, and the harvest from each country of origin contributed to the increase in total genetic diversity, where the analysis of simple sequence repeat (SSR) markers revealed a high genetic diversity (HT=0.797) and the presence of specific alleles for each country of origin of *E. oleifera*. Additionally, in the same study Arias *et al.* (2015) found that the Taisha *oleifera* are highly monomorphic, presenting a genetic similarity of 92%, compared to the rest of *E. oleifera* that presented 80%, phenotypically the families of *E. oleifera* from Taisha-Ecuador have unique qualitative traits, such as the absence of peduncular bracts, cone-shaped bunches, green immature fruits, and long stems. For this study, a dendrogram was drawn up by calculating the genetic distances between *E. oleifera* from Taisha, its descendants, and *E. guineensis* AVROS (*Figure 5*), considering that *E. oleifera* from Taisha differs from the rest of *E. oleifera* in America, either by its morphoagronomic characteristics or fatty acid profile. It is noted that *E. oleifera* from Taisha distances itself in most of the backcrosses and *E. guineensis*, being the hybrids Taisha x La Mé and Taisha x Yangambi the closest, while the hybrid Taisha x AVROS remains intermediate between *E. oleifera* from Taisha and the *E. guineensis*.

Selection and Association of Variables for Oil Content, Fatty Acid Profile and Iodine Value

In the analysis of principal components (APC) for the selection of the significant eigenvalues, the Kaiser criterion was used, indicating that the first four components are the most important because they present an eigenvalue greater than 1 and, in turn, accumulate 99.67% of the variance total, in their order the first two components accumulate 96.67% of the variance (*Table 4*). Regarding the discrimination of the variables by importance in PC1 with 72.55% of the total variance explained, the iodine value was the variable that contributed most positively to the component, followed by linoleic acid; whereas, bunch oil and palmitic acid were the two variables that contributed most negatively. The iodine value is the measure that determines the number of unsaturations that the triglycerides of the oil have, related to the content of mono and polyunsaturated fatty acids such as linoleic acid (Rincón and Martínez, 2009), which is why the iodine value and linoleic acid are related. In the case of crude palm oil, high iodine value values imply higher olein yields during fractionation. Consequently, the iodine number value will be higher due to the presence of the main oleic acid and linoleic acid.
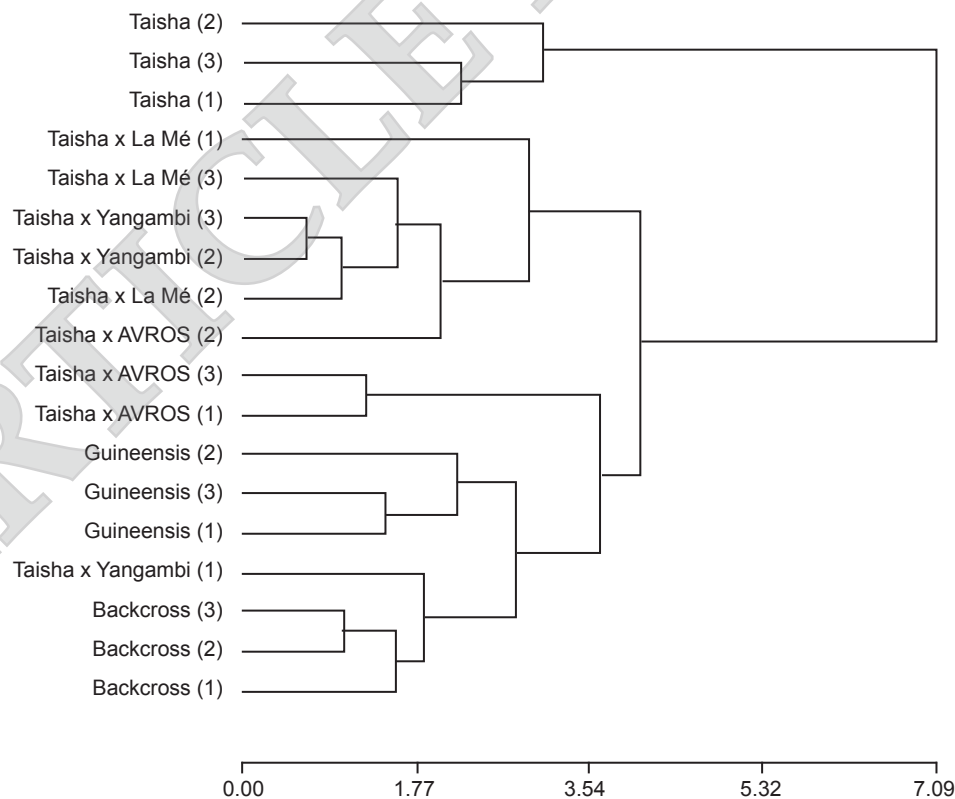

Figure 5. Interspecific variation between genotypes, shown with genetic distances.

TABLE 4. ASSOCIATION BETWEEN BUNCH OIL VARIABLES, FATTY ACID PROFILE AND IODINE VALUE

	Pearson correlation coefficients			
Variable	C18:1n9c	C18:2n6c	Iodine value	Bunch oil
C16:0	-0.5604 *	-0.4886 *	-0.9316 **	0.5899 *
C18:1n9c	1.0000	-0.4051 ns	0.3656 ns	0.2740 ns
C18:2n6c		1.0000	0.7028 *	-0.9078 **
Iodine value			1.0000	-0.7103 *

Note: Number of observations = 22; ns - Non-significant F-test; * - Significant F-Test ($p<0.05$); ** - Significant F-Test ($p<0.01$).

In addition, the first component allows us to interpret that at a higher iodine value and linoleic acid, the genotypes register low bunch oil and palmitic acid values, however, this correlation is likely related to the differences between *E. guineensis* and *E. oleifera*, and the differences in oil in a bunch between materials may be linked to factors unrelated to the characteristics of the oil, such as the percentages of mesocarp, fruit in the bunch, among others. In a different study involving 1182 *E. guineensis* palms from 16 different sibling families, the iodine value was positively correlated ($p<0.01$) with the percentage of oil in the mesocarp (Billotte *et al*., 2010). In this study a factor to be considered were palms of different origins such as *E. oleifera* from Taisha, its OxG hybrids, backcrosses, and *E. guineensis*, which showed different behaviours in the content of fatty acids, iodine value, and oil content. However, in the olive tree (*Olea europaea* L.), the correlations between the characteristics of the fruit, the components of the oil yield, and the composition of the fatty acids in the progenies of different crosses showed significant positive relationships between the oil content and percentage of oleic acid, which are negatively correlated with palmitic, palmitoleic, and linoleic acid contents (León *et al*., 2004).

For CP2 with 24.12%, the oleic acid variable was the one that contributed positively and importantly to the component to discriminate the genotypes. Oleic acid being the main unsaturated fatty acid for *E. oleifera* from Taisha, hence the mesocarp oil contains higher oleic and linoleic acid, and lower content of palmitic acid and other unsaturated acids. According to Sambanthamurrhi *et al*. (2000), oleic acid is formed by the aerobic desaturation of stearic acid by the action of the enzyme Δ9 stearoyl ACP desaturase. The oleate desaturase is active in the conversion of oleic acid into linoleic acid, which is the reason for the main components to indicate that when a higher percentage of oleic acid was present, linoleic acid was low, but the association was not significant.

It has been reported that β-ketoacyl ACP synthase II (KAS II) is a condensing enzyme exclusively responsible for the conversion of palmitic acid to stearic acid, therefore, there is considerable interest in this enzyme regarding its role in determining the ratio of C16 to C18 fatty acids (Sambanthamurthi *et al*., 2000). In this study, palmitic acid presented a significant negative correlation with oleic and linoleic acids, as argued by Singh *et al*. (2009), and this is due to the enzyme stearoyl ACP desaturase which even though is very specific for the conversion of C18:0 to C18:1, it is also known to sometimes act on C16:0 as a poor substrate for the conversion to C16:1; hence explained the strong negative correlation (r=-0.734) between C18:0 and C16:1.

The variables discriminated in the first two main components were correlated, indicating that palmitic acid presents a significant negative correlation with oleic acid, linoleic acid, and iodine value, while with bunch oil the correlation is positive. Inversely, while bunch oil was positively correlated with palmitic acid, its correlation is negative with oleic and linoleic fatty acids.

The oleic and palmitic fatty acids, which are the most important in the mesocarp oil of the oil palm fruit, presented a significant negative correlation, however, it has been shown that the activities of palmitoyl ACP thioesterase and oleoyl ACP thioesterase are two separate proteins, and therefore, they could be independently susceptible to genetic manipulation (Sambanthamurthi *et al*., 2000). However, Salas and Ohlrogge (2002), report that acyl-ACP thioesterases are divided into two classes, called FATA and FATB, where FATA enzymes preferentially hydrolyze 18:1-ACP while 16:0-ACP is the preferential substrate of the FATB enzymes. Additionally, Guerin *et al*. (2016) state that in plants, KASII is responsible for the elongation of 16:0ACP to 18:0-ACP. Thus, there is competition for the 16:0 substrate between acyl-ACP thioesterases that are capable of hydrolysing 16:0-ACP and KASII. This fact suggested that low transcription of KASII is the main contributing factor in the accumulation of C16:0.

The positive correlation between iodine value and linoleic acid of 0.700, as well as the negative correlation between iodine value and palmitic acid of -0.930 reported in this study, was similar to those reported by Singh *et al*. (2009), where the iodine value showed a correlation of 0.733 and 0.517 for oleic and linoleic acids, respectively, whereas the palmitic acid showed a correlation of -0.879. Moreover, the extracted bunch oil content in terms of percentages showed a positive correlation with palmitic acid and a negative correlation with linoleic acid and iodine value, indicating that a better quality of the oil is linked to the proportion of unsaturated fatty acids, and that it opposes the higher content of oil that is correlated with saturated fatty acids.

CONCLUSION

Improving the quality of palm oil with a higher concentration of oleic acid is not feasible using only *E. oleifera* from Taisha, hence it is necessary to obtain OxG interspecific hybrids, careful selection of the male parent *E. guineensis*, preferably with an outstanding amount of oleic acid such as the material of La Mé origin. Likewise, for the improvement of *E. oleifera* from Taisha, it can be crossed with *E. oleifera* from other American origins that have a high concentration of oleic acid, to preserve the good agronomic characteristics of Taisha such as long peduncle, flower free of spathes, and a high number of fertile fruits in the bunch.

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