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Genetic variability for bunches and oil production in American oil palm progenies from the Brazilian Amazon

Variabilidade genética para produção de cacho e óleo em progênies de caiaué da Amazônia Brasileira

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Abstract:
American oil palm is an important source of genetic variability for the improvement of oil palm, the species responsible for most of the vegetable oil produced in the world. The main product of oil palm oil is the palm oil, extracted from the mesocarp of the fruit, so it is important to evaluate the variability for components associated with the bunch and oil production in the American oil palm germplasm from the Brazilian Amazon, which is still poorly characterized and evaluated. The objective of this study was to evaluate the genetic variability for components of bunch and oil production in 30 American oil palm progenies from different regions of the Brazilian Amazon. The experiment was carried out in a randomized block design with four replications and nine plants per plot. The evaluations of the production and the components of bunches were carried out from the 12th to the 14th year after planting, in total, 16 variables were evaluated. The variables were submitted to analysis of variance, the test of means, and analysis of correlations. Multivariate methods were used to estimate genetic similarity and progeny clustering. The traits with the greatest contribution to genetic divergence among the progenies were average bunch weight (24.8%), number of bunches (8.6%), total bunch weight (8.5%), and oil production per plant (6.6%). The genetic variability observed in the American oil palm progenies from the Brazilian Amazon indicates that it is possible to diversify the genetic basis used in the improvement and contribute to the development of new cultivars of interspecific hybrids with oil palm.

Keywords: *elaeis oleifera*, characterization, evaluation, germplasm

Resumo:
O caiaué é importante fonte de variabilidade genética para o melhoramento da palma de óleo, espécie responsável pela maior parte do óleo vegetal produzido no mundo. O principal produto da palma de óleo é o óleo de palma, extraído do mesocarpo do fruto, por isso, é importante avaliar a variabilidade para componentes associados à produção de cachos e do óleo no germoplasma de caiaué da Amazônia brasileira, ainda pouco caracterizado e avaliado. O objetivo desse estudo foi avaliar a variabilidade genética para componentes de produção de cachos e óleo em 30 progênies de caiaué de diferentes regiões da Amazônia Brasileira. O experimento foi conduzido no delineamento blocos ao acaso com quatro repetições e nove plantas por parcela. As avaliações da produção e dos componentes de cachos foram realizadas do 12º ao 14º ano após o plantio, no total, 16 características foram avaliadas. As

características foram submetidas à análise de variância, teste de médias e análise de correlações. Métodos multivariados foram utilizados para estimar a similaridade genética e agrupar as progênies. As características com maior contribuição para divergência genética entre as progênies foram peso médio de cacho (24,8%), número de cachos (8,6%), peso total de cachos (8,5%) e produção de óleo por planta (6,6%). A variabilidade genética verificada nas progênies de caiaué da Amazônia brasileira indica que é possível diversificar a base genética utilizada no melhoramento e contribuir para o desenvolvimento de novas cultivares de híbridos interespecíficos com a palma de óleo.

Palavras-chave: *elaeis oleifera*, avaliação, caracterização, germoplasma

1. Introduction

The American oil palm (*Elaeis oleifera* (HBK) Cortes) is an oil palm native to Central and South America that belongs to the same genus as the African oil palm (*Elaeis guineensis* Jacq.), the crop responsible for most of the vegetable oil produced in the world (USDA, 2021). Both species produce two types of oil: palm oil, extracted from the mesocarp, and palm kernel oil, extracted from the endosperm. Howover, the oil extracted from the mesocarp of the American oil palm fruit has better qualities than the oil produced by oil palm, as lower acidity, a higher content of carotenoids, tocopherols and tocotrienols, and a higher proportion of unsaturated fatty acids (Cadena *et al.*, 2012; Lopes *et al.*, 2021).

Despite its qualities, the oil extracted from the American oil palm fruit has little commercial and industrial importance in comparison to that of palm oil, although it is commonly used by indigenous peoples and traditional populations for food, medicinal and cosmetic purposes (Mohd Din *et al.*, 2000; Udeh & Obibuzor, 2017). The lack of interest in the commercial cultivation of American oil palm is mainly because of its low productivity in oil when compared to that of oil palm.

In addition to the better quality oil, American oil palm has other characteristics of high interest for the genetic improvement of oil palm, such as a reduced rate of vertical growth of the trunk, which provides lower harvesting costs and prolongs the period of commercial exploitation of the plantations, and resistance to pests and diseases, such as bud rot, red ring, and defoliating caterpillars (Barcelos *et al.*, 2015; Oteyami *et al.*, 2019; Pinto *et al.*, 2019; Gomes Jr *et al.*, 2019). Because of the characteristics of agronomic and industrial interest displayed by the American oil palm, the species is considered a primary source of genetic variability and used in the leading oil palm genetic improvement programs conducted in Latin America, Africa, and Asia (Barcelos *et al.*, 2015).

Populations of American oil palm from the Brazilian Amazon show wide genetic variability, as demonstrated in characterization studies using molecular markers (Barcelos *et al.*, 2002; Moretzsohn *et al.*, 2002; Pereira *et al.*, 2020) and oil composition (España *et al.*, 2018). However, there is little information associated with the production of bunches and oil from these populations under experimental conditions, which is essential to promote the use of available germplasm in genetic improvement. The exploration of the potential of Brazilian American oil palm germplasm depends on the characterization and evaluation for characteristics of interest, particularly the production potential of palm oil, a product of greater economic importance in the commercial planting of oil palm and, therefore, the most important characteristic for genetic improvement. As observed with the use of molecular markers, morphological characteristics, and oil composition, it is expected to find genetic variability for the production of bunches and oil in the American oil palm germplasm existing in the Brazilian Amazon.

The objective of this work was to evaluate the genetic variability for the components of bunches and oil production in progenies of American oil palm from the Brazilian Amazon.

2. Material and Methods

The experiment was carried out in the Campo Experimental do Rio Urubu, Eastern Amazon Embrapa, located 140 km from Manaus, in the municipality of Rio Preto da Eva, Amazonas, Brazil, latitude 2º 26’36” S and longitude 59º34’11” W, and altitude of 200 m above sea level. According to the Köppen-Geiger classification (https://en.climate-data.org/), the climate is Af-type, hot, and humid, with a constant high temperature with mean values of 31.2 ºC and 23.5 ºC for maximum and minimum, respectively, and a very high rainfall rate, around 2,200 mm/year. The relative humidity of the air varies around 85%, with an average annual total insolation of 1,940 hours. The soil in the experimental area is of the Yellow Latosol type with a very clayey texture (Santos *et al.*, 2018).

In this experiment 30 American oil palm half-sib progenies were evaluated (Table 1) in a randomized block design with four replications and nine plants per plot. The planting was carried out at a spacing of 9 m x 9 m in an equilateral triangle. In the management of the experimental area, mechanized mowing was carried out between the rows and manual or chemical mowing in the crown of the plants, whenever necessary. Pruning was performed once a year, mainly to remove dry leaves. Fertilizer was applied following soil and leaf tissue analysis and the fertilization recommendation for oil palm (Rodrigues, 2002), as there are no specific recommendations for American oil palm. Doses were adjusted based on field observations, such as the occurrence of boron deficiency.

Table 1. Identification of 30 caiaué progenies evaluated in the experiment.

Tabela 1. Identificação das 30 progênies de caiaué avaliadas no experimento.

Identification code	Municipality (Localy)/State	Region
RUC163	Caracaraí / RR	BR 174 – Km 157
RUC175	Caracaraí / RR	BR 174 – Km 490
RUC051	Careiro / AM	BR 319
RUC056	Careiro / AM	BR 319
RUC139	Itacoatiara (Amatari) / AM	Rio Amazonas
RUC225	Itacoatiara (Amatari) / AM	Rio Amazonas
RUC143	Autazes / AM	Rio Amazonas
RUC144	Autazes / AM	Rio Amazonas
RUC148	Autazes / AM	Rio Amazonas
RUC160	Maués / AM	Rio Amazonas
RUC162	Maués / AM	Rio Amazonas
RUC076	Manicoré / AM	Rio Madeira
RUC078	Manicoré / AM	Rio Madeira
RUC095	Manicoré / AM	Rio Madeira
RUC096	Manicoré / AM	Rio Madeira
RUC104	Manicoré / AM	Rio Madeira
RUC105	Manicoré / AM	Rio Madeira
RUC109	Manicoré / AM	Rio Madeira
RUC089	Manicoré (Rio Mad Sup) / AM	Rio Madeira
RUC113	Nova Aripuanã / AM	Rio Madeira
RUC116	Nova Aripuanã / AM	Rio Madeira
RUC185	Barcelos (Moura) / AM	Rio Negro
RUC188	Barcelos (Moura) / AM	Rio Negro
RUC194	Novo Airão / AM	Rio Negro
RUC198	Novo Airão / AM	Rio Negro
RUC064	Iranduba (Caldeirão) / AM	Rio Solimões
RUC216	Anori / AM	Rio Solimões
RUC206	Tefé / AM	Rio Solimões
RUC211	Tefé / AM	Rio Solimões
RUC230	Tonantins / AM	Rio Solimões

Bunch production was evaluated from the 12th to the 14th year after planting in the field, with biweekly harvests, for 36 consecutive months. In the evaluation of bunch production, the following were recorded: bunch number (BN), in bunches plant year^{-1}; fresh fruit bunch production (FFB), in kilograms plant year^{-1}; average bunch weight (ABW), in kilograms. Regarding the analysis of the composition of bunches, five bunches were sampled per experimental plot, randomly collected between the 13th and 14th year after planting in the field. The bunch analysis methodology was adapted from the Nigerian Institute for Oil Palm Research, as presented by Lopes *et al*. (2021). In bunches weighing less than 14 kg, all spikelet of the bunch were sampled, and from those with higher weight, 50% of spikelet were sampled, and from these samples, the following variables (%) were obtained: rachis weight on bunch weight (RWB); spikelet weight on bunch weight (SWB); fruit weight on bunch weight (FWB). Out of the total number of fruits produced by the bunch, two random samples of 30 normal fruits were taken and the following variables were obtained: fruit weight (FW), in grams; mesocarp weight over fruit weight (MWF), in percentage; diaspore weight (DWF), in grams; diaspore weight over fruit weight (DWF), in percentage; almond weight (AW), in grams; endocarp weight over fruit weight (EWF), in percentage. From the mesocarp extracted from one of the samples of 30 fruits, a sample of 60 g of wet mesocarp was taken to determine the moisture of the mesocarp. From the dry mesocarp sample, two 10 g samples were taken for oil extraction and the following variables were obtained: oil in the dry mesocarp (ODM), in percentage; oil in the wet mesocarp (OWM), in percentage. The percentage of oil in the bunch (OB) was obtained from the variables OWM, MWF, and FWB and the oil production per plant (OPP), in kilograms plant year^{-1}, obtained by the product of FFB and OB.

The data were submitted to analysis of variance and when there was a significant effect of genotypes, the means were grouped using the Scott and Knott test (5% probability of error). Data fit the normal distribution was verified by the Lilliefors test (5% probability of error), not requiring data transformation for analysis of variance. Genotypic correlations between the evaluated traits were obtained and their significance was verified by the t-Test (5% probability of error).

Using the means and matrices of variance and covariance of the variables analyzed, the generalized Mahalanobis distance between the progenies was calculated, using standardized data. The relative contribution of the traits to the dissimilarity of the progenies was obtained using the Singh criterion. Based on the dissimilarity matrix, the progenies were clustered using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method. The Mojena criterion, mean + 1.2 standard deviation, was used as a cut-off point for group definition. The consistency of the clustering pattern was verified using the cophenetic correlation, obtained between the original distances and those expressed by the dendrogram, as well as by the values of distortion and stress.

Statistical and multivariate analyses were performed using the GENES Software: Computer Application in Statistics Applied to Genetics (Cruz, 2016).

3. Results and Discussion

The analysis of variance (Table 2) revealed genetic variability for 14 of the 16 evaluated variables. Only FWB and OB showed no significant effect of the progenies. For most variables, the coefficient of variation values was low (CV ≤ 10%: FWB, FW, MWF, DWF, EWF and ODM) or intermediate (10% < CV ≤ 20: AWB, RWB, DW, AW, OWM, and OB), only for the BN, FFB and OPP variables were high (20% ≤ CV ≤ 30%). Although classified as high, the CV values for TWB (24.0%) and BN (22.8%) observed in the evaluation of American oil palm progenies were similar or lower than those reported in experiments with oil palm by Swaray et al. (2021), 23.2% for FFB and 27.2% for BN, and by Myint *et al*. (2019), 33.4% for FFB and 25.0% for BN. Therefore, the observed CV values indicated good accuracy of the performed evaluations.

Table 2. Summary of analysis of variance for components of bunch and oil production evaluated in 30 half-sib progenies of caiaué.

Tabela 2. Resumo da análise de variância de componentes da produção de cacho e óleo avaliados em 30 progênies de meio irmãos de caiaué.

Variable	Mean Square (Degrees of freedom)			Mean	CV (%)
	Block (3)	Progenies (29)	Residual (87)		
BN	11.6	7.3 **	1.6	5.5	22.8
FFB	1411.4	543.04 **	119.4	45.5	24.0
AWB	3.2	11.8 **	0.9	8.4	11.2
OPP	10.8	3.3 **	0.9	3.2	30.6
RWB	3.0	17.8 **	7.3	13.2	20.5
SWB	23.2	49.9 *	27.2	24.6	21.2
FWB	10.6	60.8 ns	38.9	60.2	10.4
FW	2.1	2.5 **	0.9	8.8	10.8
MWF	40.5	53.7 **	17.9	47.0	9.0
DW	1.14	1.30 **	0.44	4.7	14.2
DWF	40.5	53.7 **	17.9	53.0	8.0
AW	72.7	101.7 **	44.6	33.4	20.1
EWF	12.3	44.6 **	14.7	40.3	9.5
OWM	14.9	16.6*	9.2	24.61	12.36
ODM	29.6	31.6*	16.5	38.6	10.6
OB	3.2	1.8 ns	1.6	6.9	18.5

BN – bunch number; FFB – Fresh Fruit Bunches Production (kg); ABW - average bunch weight (kg); OPP - oil production per plant (kg); RWB - rachis weight on bunch weight (%); SWB - spikelet weight on bunch weight (%), FWB - fruit weight on bunch weight (%); FW - normal fruit weight (g); MWF - mesocarp weight over fruit weight (%); DW - normal fruit diaspore weight (g); DWF - diaspore weight over fruit weight (%); AW - almond weight (g); EWF – endocarp weight over fruit weight (%); OWM – oil in the wet mesocarp (%); ODM - oil in the dry mesocarp (%) and OB - oil in the bunch (%).
* and **, respectively, significant by the F Test at 5% and 1% probability of error.
BN – número de cachos; FFB – produção de cachos de frutos frescos (kg); ABW – peso médio do cacho (kg); OPP – produção de óleo por planta (kg); RWB – peso da ráquis sobre o peso do cacho (%); SWB – peso das espiguetas sobre o peso do cacho (%), FWB – peso de frutos sobre peso do cacho (%); FW – peso do fruto normal (g); MWF – peso do mesocarpo sobre o peso do fruto (%); DW – peso do diásporo (g); DWF – peso do diásporo sobre o peso do fruto (%); AW – peso da amêndoa (g); EWF – peso do endocarpo sobre o peso do fruto (%); OWM – óleo no mesocarpo úmido (%); ODM – óleo no mesocarpo seco (%) e OB – óleo no cacho (%).
* e **, respectivamente, significativo pelo teste F a 5% e 1% de probabilidade de erro.

In the test of means (Tables 3 and 4), the variables that showed greater discrimination of the progenies were those associated with the components of the annual production of bunches (BN, FFB, and ABW) and oil (OPP), while for the other variables, bunch components, when significant, the means were divided into only two groups. Palm oil is the main commercial product of oil palm cultivation; thus, oil productivity is the most important variable, which is obtained by the product of the total weight of fresh fruits bunches produced and the percentage of palm oil in the weight of the bunches, therefore, the results indicate important variability to be explored in the genetic improvement.

Table 3. Means for bunch and oil production of 30 half-sib progenies of caiaué.

Tabela 3. Médias da produção de cacho e óleo de 30 progênies de meio irmãos de caiaué.

Progenie	BN		FFB		AWB		OPP		ODM		OWM		OB	
RUC051	5.1	b	42.6	b	8.3	c	3.3	a	42.1	a	27.5	a	7.7	a
RUC056	6.1	a	50.6	a	8.3	c	3.8	a	41.8	a	25.3	a	7.2	a
RUC064	2.6	c	30.6	b	11.9	a	2.2	b	41.5	a	26.0	a	7.2	a
RUC076	7.4	a	58.4	a	7.8	d	3.8	a	38.5	b	24.8	b	6.4	a
RUC078	5.0	b	42.5	b	8.7	c	3.5	a	40.5	a	26.7	a	8.0	a
RUC089	4.8	b	40.5	b	8.4	c	2.8	b	37.7	b	23.9	b	7.0	a
RUC095	6.7	a	50.6	a	7.5	d	3.9	a	39.2	a	24.7	b	7.7	a
RUC096	8.6	a	62.5	a	7.3	d	4.8	a	39.3	a	24.4	b	7.4	a
RUC104	7.8	a	56.2	a	7.2	d	3.5	a	35.6	b	22.6	b	6.2	a
RUC105	4.9	b	39.7	b	8.2	c	2.9	b	38.1	b	24.6	b	7.2	a
RUC109	5.3	b	45.1	b	8.7	c	3.2	a	36.7	b	23.3	b	7.0	a
RUC113	6.0	a	42.4	b	7.0	d	2.7	b	36.5	b	23.1	b	6.4	a
RUC116	5.2	b	41.3	b	7.6	d	2.9	b	36.9	b	23.4	b	7.0	a
RUC139	7.0	a	47.5	a	6.7	d	2.9	b	41.1	a	26.2	a	6.4	a
RUC143	6.3	a	56.5	a	8.7	c	5.0	a	43.5	a	27.2	a	8.7	a
RUC144	6.3	a	58.3	a	9.2	c	3.4	a	38.7	b	23.6	b	5.8	a
RUC148	6.9	a	64.4	a	9.3	c	4.7	a	38.2	b	24.8	b	7.2	a
RUC160	5.6	b	38.0	b	6.8	d	2.7	b	41.2	a	25.7	a	7.0	a
RUC162	3.9	c	36.1	b	9.2	c	2.4	b	35.4	b	21.9	b	6.8	a
RUC163	5.4	b	32.7	b	6.1	d	1.9	c	36.1	b	23.4	b	5.7	a
RUC175	2.8	c	9.6	c	3.5	e	0.7	c	34.3	b	22.6	b	7.2	a
RUC185	4.5	b	38.4	b	8.6	c	2.9	b	38.6	b	24.8	b	7.6	a
RUC188	5.3	b	50.3	a	9.6	c	3.4	a	42.2	a	29.0	a	6.7	a
RUC194	5.7	b	51.4	a	9.1	c	3.3	a	36.1	b	23.3	b	6.6	a
RUC198	5.3	b	51.4	a	9.8	c	3.5	a	39.2	a	26.2	a	6.9	a
RUC206	3.4	c	35.5	b	10.5	b	2.4	b	33.6	b	20.5	b	6.6	a
RUC211	5.0	b	29.1	b	5.8	d	1.6	c	42.1	a	26.9	a	5.7	a
RUC216	4.6	b	54.5	a	11.8	a	3.4	a	33.4	b	21.1	b	6.3	a
RUC225	5.4	b	54.1	a	10.1	b	4.0	a	42.1	a	27.8	a	7.4	a
RUC230	6.0	a	54.4	a	9.0	c	3.6	a	36.4	b	23.2	b	6.7	a
Mean	5.5		45.5		8.4		3.2		38.6		24.6		6.9	
Highest	8.6		64.4		11.9		5.0		43.5		29.0		8.7	
Lower	2.6		9.6		3.5		0.7		33.4		20.5		5.7	

BN – bunch number; FFB – Fresh Fruit Bunches Production (kg); ABW - average bunch weight (kg); OPP - oil production per plant (kg); ODM - oil in the dry mesocarp (%); OWM – oil in the wet mesocarp (%) and OB - oil in the bunch (%). Means followed by distinct letters in the column differ each other by Scott-Knott test. *significant at 5% probalility of error. Source: Own authorship.

BN – número de cachos; FFB – produção de cachos de frutos frescos (kg); ABW – peso médio do cacho (kg); OPP – produção de óleo por planta (kg); ODM – óleo no mesocarpo seco (%); OWM – óleo no mesocarpo úmido (%) e OB – óleo no cacho (%).

Médias seguidas por letras distintas na coluna diferem uma das outras pelo teste de Scott-Knott.

* significativo a 5% de probabilidade. Fonte: Autoria própria.

Table 4. Means for bunches components evaluated in 30 half-sib progenies of caiaué.

Tabela 4. Médias de componentes de cacho avaliados em 30 progênies de meio irmãos de caiaué

Progenie	RWB	SWB	FWB	FW	MWF	DW	DWF	AW	EWF
RUC051	13.3 b	22.6 a	62.8 a	7.1 b	43.7 b	4.0 b	56.3 a	29.4 b	40.2 b
RUC056	14.3 a	18.4 a	65.3 a	7.8 b	43.5 b	4.4 b	56.5 a	37.7 a	40.2 b
RUC064	13.4 b	27.3 a	56.7 a	7.9 b	49.6 a	4.0 b	50.4 b	31.9 b	37.3 b
RUC076	16.0 a	28.1 a	55.3 a	8.8 b	48.2 a	4.5 b	51.8 b	32.2 b	41.0 b
RUC078	13.3 b	25.5 a	58.7 a	8.6 b	51.8 a	4.1 b	48.2 b	32.1 b	35.8 b
RUC089	13.8 b	22.6 a	60.4 a	8.3 b	48.4 a	4.3 b	51.6 b	29.8 b	38.3 b
RUC095	14.5 a	24.9 a	58.7 a	8.5 b	52.1 a	4.2 b	47.9 b	28.5 b	37.5 b
RUC096	16.1 a	25.2 a	58.4 a	8.0 b	50.2 a	4.0 b	49.8 b	25.6 b	36.2 b
RUC104	16.6 a	24.3 a	58.2 a	8.7 b	47.1 a	4.5 b	52.9 b	33.3 b	39.0 b
RUC105	13.6 b	26.4 a	59.0 a	8,5 b	49.9 a	4.3 b	50.1 b	27.1 b	37.8 b
RUC109	13.1 b	24.7 a	61.0 a	8.8 b	50.1 a	4.4 b	49.9 b	30.5 b	40.8 b
RUC113	11.7 b	30.5 a	55.7 a	9.0 b	50.0 a	4.4 b	50.0 b	30.0 b	37.1 b
RUC116	12.9 b	22.9 a	63.4 a	9.3 a	47.9 a	4.9 a	52.1 b	31.9 b	39.4 b
RUC139	12.5 b	23.6 a	61.4 a	9.8 a	39.0 b	6.0 a	61.0 a	36.8 a	49.7 a
RUC143	12.5 b	20.5 a	66.0 a	9.3 a	48.2 a	4.8 a	51.8 b	38.1 a	37.7 b
RUC144	11.2 b	26.6 a	60.1 a	10.3 a	42.2 b	6.0 a	57.8 a	48.9 a	43.5 a
RUC148	9.9 b	31.6 a	56.7 a	9.5 a	51.8 a	4.5 b	48.2 b	38.0 a	38.5 b
RUC160	11.4 b	24.9 a	62.7 a	9.6 a	43.3 b	5.4 a	56.7 a	37.8 a	43.7 a
RUC162	9.7 b	22.9 a	64.3 a	9.8 a	48.2 a	5.1 a	51.8 b	36.1 a	39.0 b
RUC163	15.6 a	21.2 a	60.9 a	7.3 b	41.0 b	4.4 b	59.0 a	30.4 b	45.2 a
RUC175	17.9 a	21.0 a	60.0 a	7.8 b	51.6 a	3.9 b	48.4 b	21.9 b	34.1 b
RUC185	11.6 b	22.8 a	64.8 a	8.7 b	47.4 a	4.6 b	52.6 b	35.5 a	43.0 a
RUC188	11.6 b	32.2 a	49.4 a	9.2 a	46.2 a	5.0 a	53.8 b	35.9 a	40.7 b
RUC194	12.0 b	26.7 a	58.9 a	8.0 b	47.7 a	4.2 b	52.3 b	31.0 b	39.7 b
RUC198	9.8 b	24.1 a	63.2 a	8.8 b	42.0 b	5.1 b	58.2 a	35.1 a	43.7 a
RUC206	12.4 b	16.2 a	67.2 a	9.9 a	47.1 a	5.3 a	52.9 b	32.3 b	42.6 a
RUC211	16.5 a	28.1 a	53.0 a	8.7 b	40.9 b	5.2 a	59.2 a	35.7 a	44.0 a
RUC216	13.5 b	21.7 a	61.9 a	9.8 a	47.5 a	5.2 a	52.5 b	35.0 a	40.1 b
RUC225	10.5 b	24.3 a	61.6 a	9.5 a	43.0 b	5.4 a	57.0 a	40.3 a	44.4 a
RUC230	14.0 a	25.6 a	59.4 a	8.8 b	49.1 a	4.5 b	50.9 b	33.8 a	37.8 b
Mean	13.2	24.6	60.2	8.8	47.0	4.7	53.1	33.4	40.3
Highest	17.9	32.2	67.2	10.3	52.1	6.0	61.0	48.9	49.7
Lower	9.7	16.2	49.4	7.1	39.0	3.9	47.9	21.9	34.1

RWB - rachis weight on bunch weight (%); SWB - spikelet weight on bunch weight (%), FWB - fruit weight on bunch weight (%); FW - normal fruit weight (g); MWF - mesocarp weight over fruit weight (%); DW - normal fruit diaspore weight (g); DWF - diaspore weight over fruit weight (%); AW - almond weight (g) e EWF – endocarp weight over fruit weight (%).
Means followed by distinct letters in the column differ each other by Scott-Knott test. *significant at 5% probalility of error. Source: Own authorship.
RWB - peso da ráquis sobre peso do cacho (%); SWB - peso das espiguetas sobre peso do cacho (%), FWB - peso de frutos sobre o peso do cacho (%); FW - peso do fruto normal (g); MWF - peso do mesocarpo sobre o peso do fruto (%); DW - peso do diásporo do fruto normal (g); DWF - peso do diásporo sobre peso do fruto (%); AW - peso da amêndoa (g) e EWF – peso do endocarpo sobre peso do fruto (%).
Médias seguidas por letras distintas na coluna diferem uma das outras pelo teste de Scott-Knott. * significativo a 5% de probabilidade. Fonte: Autoria própria.

The mean of the progenies for the number of bunches (BN) was 5.5 bunches plant^{-1} year^{-1} (2.6 and 8.6 for minimum and maximum, respectively), for a total weight of bunches (FFB) of 45 kg plant year^{-1} (minimum of 9.6 and maximum of 64.4) and an average bunch weight (ABW) of 8.4 kg (minimum of 3.5 and maximum of 11.9). The observed values were lower than those reported by Mohd Din *et al*. (2000) in Malaysia for American oil palm progenies introduced from Colombia, Panama, Costa Rica, and Honduras, evaluated from the 8th to the 10th year after planting, with a general average for BN of 7.5 plant year^{-1}, FFB of 76.5 kg plant^{-1} year^{-1} and 10.1 kg for ABW, with no statistical difference among the means of progenies from different origins. Due to the pedoclimatic differences in the places where the progenies were evaluated, particularly soil fertility, which was more favorable for oil palm in the locality where the experiment was carried out in Malaysia than in Brazil, it is not possible to quantify the variations in the performance of the progenies that can be attributed to the effect of genotypes.

As for the composition of the bunches, the average percentage of fruits in the weight of the bunch (FWB) was 60.2% (49.4 and 60.2 for minimum and maximum, respectively), a variation similar to that observed by Rey *et al*. (2004) in 16 American oil palm half-sib progenies collected in the Amazon trapeze along the Amazon River basin in Colombia, which ranged from 54% to 69%, and higher than that observed by Romero *et al.* (2013) for ten American oil palm progenies, which ranged from 30.1% (origin Manaus, Brazil) to 56.7% (origin Cuchillo, Perú). The average weight of the normal fruit (FW) was 8.8 g (7.1 and 10.3 for minimum and maximum, respectively) and the percentage of mesocarp in the fruit (MWF) was 47% (39.0 and 52.1 for minimum and maximum, respectively), values also similar to those reported by Rey *et al*. (2004), with a variation from 5.3 g to 14.4 g for FW and from 30% to 55% for MWF. For the percentage of oil in the wet mesocarp (OWM), it was found a mean of 24.6%, with a minimum value of 20.5% and a maximum of 29.0%, a variation smaller than that reported by Rey *et al.* (2004), from 26% to 43%, and by Romero *et al*. (2013), who reported a mean of 42.7%. For the percentage of oil in the bunch (OB) the analyses did not indicate a statistically significant difference between the progenies and the overall mean was 6.9% (5.7% and 8.7% for minimum and maximum, respectively), a value within the range reported for the trait in the progenies evaluated by Rey *et al*. (2004), from 4.4% to 13%, but higher than the variation observed by Romero *et al*. (2013), from 3.0% for Coari origin (Brazil) to 4.8% for Taisha origin (Ecuador). The OB is the most important variable in the composition of the bunch, as it defines the oil production obtained from the total weight of bunches of fresh fruits produced. Although there was no statistically significant difference between the progenies, the values observed are similar or higher than those reported by other authors, demonstrating good bunch quality in populations of Brazilian origin.

The oil production per plant (OPP), the main variable for the selection of parents, showed strong and positive genetic correlations with the components of bunch production, pointing out a very strong and positive correlation (0.98) with the total weight of the bunch (FFB) and strong and positive correlation (0.73) with the number of bunches (BN) (Table 5). OPP also showed a moderate and positive correlation (0.52) with the percentage of oil in the bunch (OB). Because of its practicality and requiring less evaluation time, a variable generally used in the evaluation and preliminary selection of oil palm germplasm is the proportion of mesocarp in the fruit, represented by the variable weight of the mesocarp over the fruit weight (MWF), which showed a strong and positive correlation (0.84) with OB and a very strong and negative correlation (-0.97) with endocarp weight over fruit weight (EWF). The highlighted correlations indicated that in the selection of parents of American oil palm for greater oil productivity should focus on progenies with greater production in weight of fresh fruit bunches and with a greater proportion of mesocarp in the fruit.

Table 5. Genotypic correlation between bunches and oil production components evaluated in 30 half-sib progenies of caiaué.

Tabela 5. Correlação genotípica entre componentes de produção de cachos e de óleo avaliados em 30 progênies de meio irmãos de caiaué.

Variable	FFB	AWB	OPP	RWB	SWB	FWB	FW
BN	0.76**	-0,22	0,73**	0,21	0,42*	0,31	0,13
FFB		0,44*	0,98**	-0,38*	0,38*	0,05	0,43*
AWB			0,43*	-0,80**	0,02	0,29	0,40*
OPP				-0,36*	0,44*	-0,09	0,27
RWB					-0,56**	0,07	-1,00
SWB						-0,84**	-0,02
FWB							0,60**

Variable	MWF	DW	DWF	AW	EWF	ODM	OB
BN	-0,07	0,10	0,07	0,19	0,05	0,27	-0,14
FFB	0,03	0,27	-0,03	0,57**	0,02	0,22	0,29
AWB	0,06	0,25	-0,06	0,54**	0,06	0,02	0,36*
OPP	0,11	0,09	-0,11	0,46*	-0,13	0,26	0.52**
RWB	0,19	-0,86**	-0,19	-1,06	-0,44*	-0,50**	-0,27
SWB	0,39*	-0,27	-0,39*	0,16	-0,34	0,49**	1,08
FWB	-0,39*	0,66**	0,39*	0,46**	0,51**	-0,20	-0,56**
FW	-0,16	0,82**	0,16	0,71**	0,50**	-0,45*	-0,77**
MWF		-0,68**	-1,00	-0,65**	-0,97**	-0,62**	0,84**
DW			0,68	**0,85**	0,91**	-0,01	-1,00
DWF				0,65**	0,97**	0,62**	-0,84**
AW					0,73**	0,48**	-0,64**
EWF						0,32	-1,00
ODM							0,02

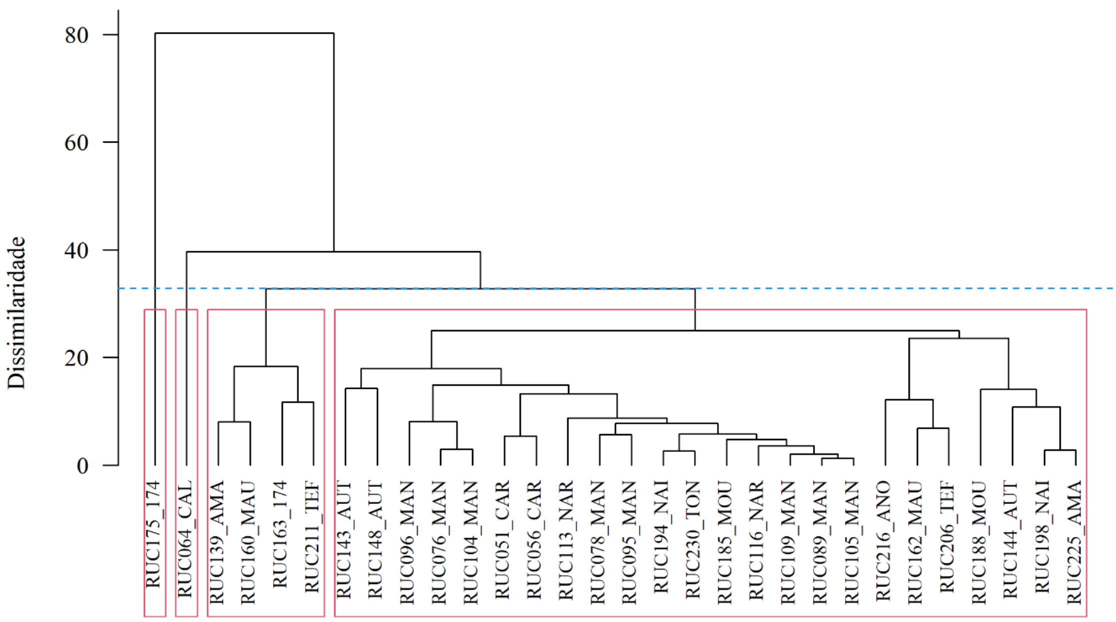
BN – bunch number; FFB – Fresh Fruit Bunches Production (kg); ABW - average bunch weight (kg); OPP - oil production per plant (kg); RWB - rachis weight on bunch weight (%); SWB - spikelet weight on bunch weight (%), FWB - fruit weight on bunch weight (%); FW - normal fruit weight (g); MWF - mesocarp weight over fruit weight (%); DW - normal fruit diaspore weight (g); DWF - diaspore weight over fruit weight (%); AW - almond weight (g); EWF – endocarp weight over fruit weight (%); ODM - oil in the dry mesocarp (%) and OB - oil in the bunch (%).
* and **, respectively, significant by the t Test (DF) at 5% and 1% probability of error.
BN – número de cachos; FFB – produção de cachos de frutos frescos (kg); ABW – peso médio do cacho (kg); OPP – produção de óleo por planta (kg); RWB – peso da ráquis sobre o peso do cacho (%); SWB – peso das espiguetas sobre o peso do cacho (%), FWB – peso de frutos sobre peso do cacho (%); FW – peso do fruto normal (g); MWF – peso do mesocarpo sobre o peso do fruto (%); DW – peso do diásporo (g); DWF – peso do diásporo sobre o peso do fruto (%); AW – peso da amêndoa (g); EWF – peso do endocarpo sobre o peso do fruto (%); ODM – óleo no mesocarpo seco (%) e OB – óleo no cacho (%).
* e **, respectivamente, significativo pelo teste t (GL = 28) a 5% e 1% de probabilidade de erro.

Based on the values of Mahalanobis distance (matrix not shown) among the progenies, calculated from the 16 variables evaluated, the most distant progenies were RUC-144, from Autazes, Amazonas, and RUC-175, from Caracaraí, Roraima, and the most similar were RUC-089 and RUC-105, both from Manicoré, Amazonas. The clustering of the progenies using the UPGMA method (Figure 1) showed consistency to the original genetic distances, the cophenetic correlation between the distances was high (82.7%), whereas the values of distortion (11.7%) and stress (34, 2%) were low, values that indicated that the dendrogram represented adequately the genetic distance between the progenies. Four groups were formed (Figure 1), the largest, with 24 progenies (80%), including all origins from the municipalities of the Madeira (Manicoré and Novo Aripuanã) and Negro

(Barcelos and Novo Airão) channel rivers, five of the seven progenies from the Amazon river channel (Autazes, Maués, and Itacoatiara) and three out of the five from the Solimões river channel (Anori, Tefé, and Tocantins), in addition to the two progenies from Careiro, located on BR319. The second largest group included four progenies, two originated from the Amazon River channel (Itacoatiara and Maués), one from the Solimões River (Tefé) and one from Caracaraí (BR 174 highway), state of Roraima. The progenies RUC-175, from Caracaraí, Roraima, and RUC-064, from Iranduba, Amazonas, were not clustered with the other progenies.

Figure 1. Dendrogram obtained by Unweighted Pair-Group Method with Arithmetic Mean (UPGMA) from the generalized Mahalanobis distance between 30 half-sib progenies of caiaué evaluated for 16 components of bunches and oil production. A dissimilarity value of 33% (dashed blue line) was defined as a cutoff point for group formation (encased in red) using the mean + 1.2SD (Mojena's criterion). Cophenetic correlation coefficient = 82.7%, distortion = 11.7% and stress = 34.2%.

Figura 1. Dendrograma obtido pelo método Ligação Média Entre Grupo (UPGMA) a partir da distância generalizada de Mahalanobis entre 30 progênies de meios-irmãos de caiaué avaliados para 15 componentes de produção de cachos e óleo. O valor de dissimilaridade de 33% (linha tracejada azul) foi definido como ponte de corte para formação dos grupos (envoltos em vermelho) usando como critério média + 1,2DP (Mojena, 1977). Coeficiente de correlação cofenética = 82,7%, distorção = 11,7% e estresse = 34,2%.



The clustering pattern observed with the genetic distances calculated from the components of bunch and oil production, different from the analysis of variability organization based on molecular markers (Barcelos *et al*., 1999; Morerzohn *et al*., 2002; Pereira *et al*., 2020) did not show a strong relationship with the local hydrographic network. However, the results corroborate those obtained with molecular ones for some populations that were more genetically distinct from the others, such as those originated from Caracaraí (BR174), with one progeny that did not cluster with the others and one clustered with two progenies from Amazonas river and one from Solimões river, and also the progeny RUC064, from the municipality of Iranduba, which also did not cluster with the others. The genetic variability observed between the progenies can be considered moderate, as observed in studies with molecular markers (Morerzohn *et al*., 2002; Pereira *et al*., 2020). It is noteworthy that the samples used in studies carried out with molecular markers differ from this one, which is restricted to 30 progenies with variable representation among their regions of origin, which, in part, may explain the differences in clustering patterns. As observed for populations of other palm species important to indigenous peoples and traditional populations in the Brazilian Amazon, such as açai-do-Amazonas (Ramos *et al*., 2021), tucumã-do-Amazonas (Corrêa *et al*., 2020), and peach palm (Santos *et al*., 2017), although moderate, there is also important genetic variability in American oil palm populations, which demonstrates the potential of this group of plants for genetic improvement and the development of sustainable production chains in the region.

The components of bunch production were the traits that contributed the most to the genetic divergence between the American oil palm progenies (Table 6), with emphasis on the contribution of average bunch weight (24.8%), followed by bunch number (8.6%) and fresh fruit bunches production (8.5%), which, together with oil production per plant (6.6%), accounted for 48.5% of the total variation obtained with the 16 variables. The variable with the highest contribution to genetic divergence are the same ones that showed greater discrimination of the progenies in the test of the means as well as those with the lowest relative contribution to genetic divergence were those that did not reveal the statistical difference between the progenies: oil in the bunch (2.0%), fruit weight on bunch weight (2.9%), spikelet weight on bunch weight (3.4%), along with oil in the wet mesocarp (3.3%) and oil in the dry mesocarp (3.6%).

Table 6. Estimate of the relative contribution of 16 variables to genetic divergence between 30 half-siblings progenies of caiaué.

Tabela 6. Estimativa da contribuição relativa de 16 variáveis para a divergência genética de 30 progênies de meio-irmãos de caiaué.

Variable	S.j[1]	Value (%)
Average bunch weight (kg)	2901,38	24,8
Bunch number	1008,22	8,6
Fresh fruit bunches production (kg)	989,62	8,5
Oil production per plant (kg)	774,97	6,6
Endocarp weight over fruit weight (%)	662,40	5,7
Mesocarp weight over fruit weight (%)	652,49	5,6
Diaspore weight over fruit weight (%)	652,49	5,6
Diaspore weight (g)	646,42	5,5
Normal fruit weight (g)	607,47	5,2
Rachis weight on bunch weight (%)	530,78	4,5
Almond weight (g)	492,44	4,2
Oil in the dry mesocarp (%)	415,83	3,6
Spikelet weight on bunch weight (%)	399,10	3,4
Oil in the wet mesocarp (%)	389,40	3,3
Fruit weight on bunch weight (%)	339,54	2,9
Oil in the bunch (%)	237,10	2,0

[1] S.j value obtained by the Singh criterion. Calculation realized with non-standard means.
[1] Valor S.j obtido pelo critério de Singh. Cálculo feito com médias não padronizadas.

In the interspecific genetic improvement experiments conducted in Brazil, the American oil palm of Manicoré origin was predominantly exploited (Pinto *et al*., 2019; Gomes Jr. *et al.*, 2019; Gomes et al., 2021) and the only hybrid cultivar developed in the country was obtained from parents of this origin (Cunha & Lopes, 2010). It is also noteworthy that the main interspecific hybrid cultivars developed by other countries were obtained from the germplasm of the collection in the Brazilian Amazon, as in Colombia using American oil palm collected in Coari and Manicoré, Amazonas (Palmelite, 2021), and in Costa Rica, using American oil palm collected in Manaus, Amazonas (ASD Semillas, 2021), indicating the high potential of the populations found in the region. Nevertheless, studies on the ability of combination between Brazilian Amazon American oil palm populations and oil palm populations are still needed to define strategies that maximize selection gains in interspecific breeding.

The results obtained in the present study indicated that the American oil palm progenies from the Brazilian Amazon show genetic variability for the components of production and composition of the bunch and for oil production, the product of the total weight of fresh fruit bunches produced and the percentage of oil in the bunch, main variable for which genetic gains are sought in oil palm improvement. So far, the main interest in American oil palm is not its improvement *per se*, but as a gene donor for the improvement of oil palm, with emphasis on resistance to bud rot. Simultaneously, other important variables are also transferred, such as resistance to pests (defoliating caterpillars) and diseases (red ring), lower vertical growth of the stem, and better composition of the oil (more unsaturated and with higher concentrations of bioactive compounds). The results showed that with the genetic variability present in the populations of the Brazilian Amazon it is possible to diversify the origins of American oil palm used in the interspecific improvement with oil palm and to expand the genetic base of the planting material.

4. Conclusion

The American oil palm progenies from the Brazilian Amazon show genetic variability for components of bunch and palm oil production and may contribute to diversifying the narrow genetic base of the species used in interspecific improvement with oil palm.

Variables associated with bunch production have a greater contribution to genetic divergence among progenies than those associated with buch composition.

The evaluation of the American oil palm progenies showed that as a selection criterion, the variables total weight of bunches and proportion of mesocarp in the fruit should be prioritized.

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