

Selection gains for the palm oil production from progenies of American oil palm with oil palm







Abstract – The objective of this work was to estimate the genetic parameters, correlations, and selection gains for the oil production of interspecific hybrids progenies between American oil palm, of 'Manicoré' origin, and oil palm, of 'La Mé' origin. Thirty-nine progenies were evaluated from the sixth to the ninth year after planting, for the productivity of fresh fruit bunches (PROD_FFB), oil content in the bunch (OCB), and palm oil productivity (PROD_OP). The genetic parameters and gains from direct (GDS) and indirect (GIS) selection were estimated for PROD_OP. High values of heritability for the CVg/CVe ratio indicated favorable conditions for the selection. With the selection of 20% of the progenies (selection in both sexes), the following estimates were obtained: 11.15% GDS for PROD_OP, 9.1% GIS for OCB, and 8.1% GIS for PROD_FFB. The PROD_OP of the progenies was of 6,175, 6,057, and 5,995 kg ha⁻¹ per year with GDS and GIS for OCB and PROD_FFB, respectively. The restricted selection of the LM2T male genitor offspring resulted in 5.1% estimated GSD and in a mean of 5,800 kg ha⁻¹ per year for PROD_OP. Selection gains for PROD_OP can be achieved immediately through the selection restricted to oil palm male genitors, and, in the medium and long term, through the interspecific reciprocal recurrent selection between American oil palm and oil palm populations.

Index terms: *Elaeis guineensis*, *Elaeis oleifera*, genetic breeding, interspecific hybridization, selection strategies.

Ganhos de seleção para a produção de óleo de palma em progênies de caiaué com dendê

Resumo – O objetivo deste trabalho foi estimar os parâmetros genéticos, as correlações e os ganhos de seleção para a produção de óleo de progenies de híbridos interespecíficos entre caiaué, da origem 'Manicoré', e dendê da origem 'La Mé'. Trinta e nove progênies foram avaliadas, do sexto ao nono ano pós-plantio, quanto a produtividade de cachos de frutos frescos (PROD_FFB), teor de óleo no cacho (OCB) e produtividade de óleo de palma (PROD_OP). Foram estimados os parâmetros genéticos e os ganhos de seleção direta (GDS) e indireta (GIS) para PROD_OP. Altos valores de herdabilidade para a razão CVg/CVe indicaram condições favoráveis para a seleção. Com a seleção de 20% das progênies (seleção em ambos os sexos), as seguintes estimativas foram obtidas: 11,15% de GDS para PROD_OP, 9,1% GIS para OCB e 8,1% GIS para PROD_FFB, respectivamente. A PROD_OP das progênies foi de 6.175, 6.057 e 5.995 kg ha⁻¹ por ano, com GSD e GSI em OCB e PROD_CFF, respectivamente. A seleção restrita a genitores masculinos de dendê LM2T resultou em 5,1% de GSD e na média de 5.800 kg ha⁻¹ por ano para PROD_OP. Ganhos de seleção para PROD_OP podem ser obtidos imediatamente pela seleção restrita de genitores masculinos de dendê e, em médio e longo prazo, pela seleção recorrente recíproca interespecífica entre as populações de caiaué e dendê.


Termos para indexação: *Elaeis guineensis*, *Elaeis oleifera*, melhoramento genético, hibridação interespecífica, estratégias de seleção.

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Introduction

Palm oil extracted from the mesocarp (pulp) of the oil palm fruit (*Elaeis guineensis* Jacq.) is the most produced and commercialized vegetable oil in the world (USDA, 2021). This rank is the result of the high productivity of the crop that is the highest among oilseeds, and the low cost of oil production (OECD-FAO..., 2019). Because of these advantages, palm oil is expected to supply most of the growing international demand for vegetable oil (Alain, 2020).

The sustainable expansion of palm oil in the country requires the development of cultivars adapted to local conditions and that are mainly of high productivity and resistance to pests and diseases (Cunha et al., 2012). In the 1980s, Embrapa started the interspecific genetic improvement of oil palm (*E. guineensis*) with American oil palm (*Elaeis oleifera* (HBK) Cortés), a species native to Central and South America (Cunha et al., 2012). The interspecific hybridization between American oil palm and oil palm (ISH OxG) has been exploited mainly for the resistance of the American species and F1 hybrids to bud rot, a disorder of undefined etiology that has extinguished thousands of hectares of oil palm plantations in Latin America, including Brazil. The HIE OxG hybrid also shows less vertical growth of the stem (Gomes Junior et al., 2015), besides resistance to other pests and diseases, and a more unsaturated oil than the palm oil (Cunha et al., 2012). In South America, Brazil and Colombia conduct the principal genetic improvement programs using the interspecific hybridization between American oil palm and oil palm (Rey B. et al., 2004; Bastidas et al., 2007; Cunha et al., 2012).

In 2010, Embrapa launched the first ISH OxG cultivar developed in Brazil, denominated 'BRS Manicoré', which shows bunch and oil productivity similar to that of the tenera-type oil palm cultivars, which already have at least five decades of genetic improvement (Cunha & Lopes, 2010). 'BRS Manicoré' was obtained by combining the populations of 'Manicoré'-originated American oil palm and 'La Mé'-originated oil palms, in which there is still a high genetic variability to be explored. This fact allows of the prediction of high genetic gains with the continuity of interspecific improvement between these populations, including the obtention of more productive interspecific cultivars than the teneras of African oil palms (Lopes et al., 2012; Gomes Jr et al., 2014; Gomes Junior et al., 2015,

2016, 2019). The selection provided gains from distinct oil palm populations (Bakoumé & Louise, 2007; Bakoumé et al., 2010; Noh et al., 2012) and should also be effective for breeding of HIE OxG hybrids.

The parameters of genetic variance and genetic gains for bunch production, vegetative characters and components of bunch have already been estimated from interspecific progenies obtained from populations between 'Manicoré'-originated American oil palm and 'La Mé'-originated oil palm (Gomes Jr. et al., 2014; Gomes Junior et al., 2015, 2016, 2019; Freitas et al., 2021). However, the principal economic product of oil palm plantation is the palm oil, so estimates of genetic gain for oil productivity are important for the continuity of interspecific genetic improvement using these populations.

The objective of this work was to estimate the genetic parameters, correlations, and selection gains for the oil production of interspecific hybrids progenies between American oil palm, of 'Manicoré' origin, and oil palm, of 'La Mé' origin.

Materials and Methods

Three experiments were set up in February 2007, in a continuous area of 17.6 ha, at the company Marborges Agroindustry S.A., in the municipality of Mojú (1°58'42"S, 48°36'50"W), in the state of Pará, Brazil. The soil type in the experimental area is a Latossolo Amarelo distrófico, according to the Brazilian system of soil classification (Santos et al., 2018), i.e., a Dystric Xanthic Ferralsol (IUSS Working Group WRB, 2015). According to the Köppen-Geiger's classification, the local climate is the Af type (Alvares et al., 2013), with 2,786 mm annual mean precipitation (2007 to 2016), with a greater concentration of rainfall in the first semester of the year. The region is classified as preferred for the cultivation of oil palm, according to the Agroecological Zoning for the Oil Palm Crop in the Deforested Areas of the Legal Amazon – ZAE-Dendê (Ramalho Filho et al., 2010).

The experiments consisted of 39 progenies of full siblings obtained from controlled crosses involving 32 'Manicoré'-originated American oil palm female genitors, from 18 different families, and 13 'La Mé'-originated pisifera-type oil palm male genitors, seven of which were from three different families of LM10T progenies, and six were from four different families of

LM2T progenies (Table 1). Two experiments included 14 progenies, and one involved 15 progenies, with two progenies common to the three experiments (RUB 1195 and RUB 1213). The populations of the American oil palm and oil palm genitors are maintained in the Rio Urubu Experimental Field (CERU), Rio Preto da

Eva, state of Amazonas, Brazil, and they are used in the production of commercial seed of the 'BRS Manicoré' cultivar (RNC 26031).

The three experiments were established in a randomized complete block design, with four replicates, and 12 plants per plot (four lines of three

Table 1. Genealogy of 39 F1 progenies from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms.

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

plants). As a border, a line was used at each side of the experimental area, with a plant at each end of the lines of the experiment. The planting was performed at 143 plants ha⁻¹ and conducted according to the management practices adapted by the company Marborges S.A. (Pina, 2010). The assisted pollination practice is the main differential in relation to the production system of the oil palm cropping.

Bunch production was evaluated in the adult phase of the plants, at intervals between 15 and 20 days, for four consecutive years, from January 2013 (sixth year after planting) to December 2016 (ninth year after planting). The values of the fresh fruit bunch production (FFB) from plots were transformed into productivity, considering the planting density adopted in the experiment, and they were expressed in productivity (Mg ha⁻¹ per year) of fresh fruit bunch (PROD_FFB). The oil content in the bunch (OCB) was obtained by means of physical analysis of the bunches and chemical extraction (Soxhlet) of palm oil from the mesocarp, following the methodology adapted from the proposal of the Nigerian Institute for Palm Oil Research (Black et al., 1963; Rao et al., 1983). The average of 55 bunches per progeny harvested in 2015, 2016, and 2017 were analyzed. In the physical analysis of the bunches, the spikelets with fruit and rachis of the bunches were first separated and weighed. To determine the proportion of fruit on the bunch weight and the oil content, bunches weighing less than 14 kg were used with all spikelets, whereas in the cases with bunch weight greater than this value, half of the spikelets was used. Fruit were manually removed from the spikelets, classified as normal and parthenocarpic and, then, they were weighed. A sample with 30 normal fruit and 30 parthenocarpic fruit was randomly selected from each bunch and used to calculate the proportion of mesocarp in the weight of the fruit. The mesocarp was manually extracted from the fruit with the aid of a stainless-steel knife, then the weight of the mesocarp and the weight of the kernel almonds in the sample were obtained. Fresh mesocarps were dried at 105°C for 24 hours, in an oven with air circulation and renewal (model TE-394, Tecnal, SP, Brazil). After the drying time, the mesocarps were cooled in a desiccator, at room temperature, and then weighed and crushed in a domestic processor (model LN 73, Arno, SP, Brazil), until a particle size of approximately 2.0 mm was obtained. The extraction of lipids from the mesocarps was performed in a 5 g sample of dry mesocarp, in a

Soxhlet system, using petroleum ether as solvent. The analyses were carried out at the laboratory of Embrapa Amazônia Oriental Agroindústria.

The oil content in the bunch (OCB) (Equation 1), expressed as a percentage of the weight of fresh fruit bunches (FFB), was determined by the sum between the percentage of lipids over the FFB weight of normal fruit (NF) and parthenocarpic fruit (PF) (Equation 2).

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

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

in which: NF or PF/FFB (%) is the percentage of NF or PF in FFB (equation 3); M/NF or PF (%) is the mesocarp (M) percentage in NF or PF (equation 4); O/M NF or PF (%) is the oil percentage in the NF or PF mesocarp (equation 5).

$$\frac{NF \text{ or } PF}{FFB} (\%) = 100 \left[\left(\frac{NF \text{ or } PF}{SWF} \right) \left(\frac{FFB-R}{FFB} \right) \right] \quad (3)$$

in which: SWF represents spikelets with fruit, and R represents the rachis.

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

$$\frac{O}{M_{NF \text{ or } PF}} (\%) = \frac{1}{100} \left[(100 - MM_{NF \text{ or } PF} (\%)) \left(\frac{O}{M_{NF \text{ or } PF} (\text{dry})} (\%) \right) \right] \quad (5)$$

in which: MM is the mesocarp moisture.

From the direct product of PROD_FFB and OCB, the palm oil productivity (PROD_OP) (kg of palm oil ha⁻¹ per year) was calculated. The gains in palm oil productivity, estimated with the extraction rate obtained in the laboratory, were also expressed in expected values at the level of industrial extraction, using the mean value for industrial efficiency of 93.1% as a reference, that is the mean value reported for industries used as benchmarking (optimal processing parameters) in a study developed with the Malaysian Palm Oil Board (Menon, 2012).

The results of the three experiments were subjected to the analysis of grouped variance, with the adjustment of the mean of the progenies. Genetic parameters, genetic correlations, and direct and indirect selection gains were estimated in an aleatory model (Cruz, 2006a), using the Genes software (Cruz, 2006b),

for the characteristics PROD_FFB, PROD_OP, and OCB. In the analysis of grouped variance of the three experiments, the values Z and Y were used to refer to the same variable, and to represent the values of common and regular progenies, respectively, as follows:

$$Z_{ijk} = \mu + Tc_i + B_{j(k)} + E_k + TcE_{ik} + \varepsilon_{ijk} \quad (6)$$

in which: Z_{ijk} is the observation under the i^{th} common progeny, in the j^{th} block, in the k^{th} experiment; μ is the experimental average; Tc_i is the i^{th} common progeny effect; $B_{j(k)}$ is the effect of j^{th} block, within k^{th} experiment; E_k is the k^{th} experiment effect; TcE_{ik} is the interaction effect of i^{th} common progeny x, in the k^{th} experiment; ε_{ijk} is the aleatory error.

$$Y_{ijk} = \mu + Tr_i + B_j + \varepsilon_{ijk(k)} \quad (7)$$

in which: Y_{ijk} is the observation under the i^{th} regular progeny, in the j^{th} block, in the k^{th} experiment; μ is the experimental average; Tr_i is the i^{th} regular progeny effect; B_j is the effect of the j^{th} block, at the k^{th} experiment; ε_{ijk} is the aleatory error.

The genetic selection gain was estimated considering the selection of the best 20% classified progenies (eight progenies) for selection in both parent populations, female genitors of 'Manicoré'-originated American oil palm, and male genitors of 'La Mé'-originated oil palm. In the case of selection restricted to male population, the select genetic gain was estimated considering the higher progenies mean among LM2T and LM10T genitors. The genetic gain from direct selection (GDS) was estimated by $GDS = h_m^2 \times SD$ and $GDS (\%) = 100 \times GDS / \bar{X}_o$, in which: h_m^2 is the heritability at progeny mean level, estimated from the matrices of genotypic and phenotypic variances and covariances among progeny means; $SD = \bar{X}_s - \bar{X}_o$ is the selection differential, where \bar{X}_o is the overall adjusted mean; and \bar{X}_s is the adjusted mean of the selected progenies. Estimates for indirect genetic gain (GIS) was calculated by $GIS_{j(i)} = h_{m(j)}^2 \times SD_{j(i)}$, in which $GIS_{j(i)}$ is the indirect gain selection on characteristics j, by selection on characteristics i; $SD_{j(i)} = \bar{X}_{sj} - \bar{X}_{oj}$ is the indirect selection differential, where \bar{X}_{oj} is the overall adjusted mean of characteristics j; and \bar{X}_{sj} is the adjusted mean of characteristics j of the selected

progenies on characteristics i. The indirect selection efficiency was calculated by $ISE = GIS_{j(i)} / GDS_j$.

The genetic correlations (r_g) between characteristics x and y were estimated by $r_g = COVg(xy) / \sqrt{Vg(x) \times Vg(y)}$, in which: $COVg(xy)$ is the covariance of the genotypic characteristics x and characteristics y; $Vg(x)$ and $Vg(y)$ are the variances of the genotypic characteristics x and characteristics y, respectively.

Results and discussion

The coefficients of experimental variation (CV%) for all traits were low, following the classification by Pimentel-Gomes (2009), which indicates the high precision of the experiment (Table 2). Out of the 2,030 useful plants of the experiments, only 34 (1.68% lost data) were excluded from the analysis, due to dead, or abnormal development, that is a low percentage of lost data for a 9-year experiment. The results can be attributed to the good crop management adopted during the research and the environmental favorable conditions for oil palm cultivation. The percentage of dead plants was lower than that observed in hybrids of the same origin cultivated in the municipality of Una, in the state of Bahia, Brazil, where eight years after planting there were 4% loss of plants due to death, mainly due to red ring disease (Pinto et al., 2019). The grouped variance analysis indicated a significant effect with high F values of the adjusted mean of the progenies for palm oil productivity (PROD_OP), fresh fruit bunch productivity (PROD_FFB), and palm oil content in the fresh fruit bunch (OCB).

The estimates of the genetic parameters indicated favorable conditions for selection with the possibility of genetic gain for PROD_OP and for the other evaluated characteristics (Table 2). The estimated heritability at the level of mean of progenies was high, which reflects the predominance of the variance of genetic origin over the environmental variance. In the same sense, the CVg/CVe relation also indicated that the genetic variance exceeded the environmental one. Similar results for HIE OxG evaluated for PROD_FFB were observed (Lopes et al., 2012; Gomes Jr et al., 2014; Gomes Junior et al., 2015, 2016), and for OCB by Freitas et al. (2021).

The means of the progenies for PROD_FFB (Table 3) were great than the means values observed for FFB_PROD by Amiruddin et al. (2015) in ISH

OxG progenies evaluated in four different locations in Malaysia, which were from 12.7 to 28.9 Mg ha⁻¹ per year (estimated values from PROD_FFB kg plant⁻¹ per year presented by the authors, considering the planting density of 143 plants ha⁻¹). When considering the industrial extraction efficiency (IEE) of 93.1%, the mean of progenies for PROD_OP varied from 3,987 to 6,580 kg ha⁻¹ per year, and for OCB, from 18.4 to 23.3%. Lower mean values for OCB in ISH OxG than those registered in the present work were observed by Mandal et al. (2009) and Amiruddin et al. (2015). According to Woittiez et al. (2017), the average productivity of palm oil at the international level, in the 2013 harvest, was from 3.0 to 3.2 Mg ha⁻¹ per year, and the productivity in Indonesia, the world's largest producer, was estimated as 3.8 Mg ha⁻¹ per year. In Malaysia, the second largest world's producer and technological reference, it was between 4.2 to 4.5 Mg ha⁻¹ per year, and in Brazil, between 2.8 to 3.1 Mg ha⁻¹ per year. The observed values for PROD_OP are high and indicate a great potential for interspecific hybrids improvement between the female genitors 'Manicoré'-originated American oil palm and the male genitors 'La Mé'-originated of oil palm.

High values of genetic correlation were found between PROD_OP and PROD_FFB and between PROD_OP and OCB, which indicates that the increases

of PROD_FFB and OCB will result in greater PROD_OP (Table 4). In addition, the low correlation between PROD_FFB and OCB indicates a nonsignificant impact of selecting one characteristic on the variation of the other. Kruallee et al. (2013) identified in *dura* x *pisifera* oil palm progenies positive genotypic and phenotypic correlation coefficient values between PROD_FFB and PROD_OP, while Rios et al. (2018) verified a high and positive phenotypic correlation between FFB_PROD and PRO_PO in half sibs of *dura*-type oil palm progenies.

The direct genetic selection (GDS) in PROD_OP was high, with the selection of 20% of the progenies with the best performance, which represents 11.2% over the mean of the original population (Table 5). When considering the demand for 11 years of experimentation, from the crossing to the conclusion of the progeny evaluation, GDS was estimated at approximately 1% per year for PROD_OP. The genetic improvement of oil palm yield started in the 1920s through the mass selection, and the genetic progress of PROD_OP for the best breeding programs around the world is about 1 to 1.5% per year (Nyouma et al., 2019).

The GIS in PROD_OP indicated a greater efficiency of indirect selection for OCB (81.1% of GSD) than for PROD_FFB (72.7% GSD). The genetic progress in PROD_OP via indirect selection in OCB and PROD_

Table 2. Analysis of grouped variance and estimates of genetic parameters for the variables palm oil productivity (PROD_OP), productivity of fresh fruit bunch (PROD_FFB), and content of palm oil in the fresh fruit bunch (OCB), evaluated from the 6th to the 9th years after planting, in 39 F1 progenies from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms.

Source of variation	DF	Mean Square					
		PROD_OP (kg ha ⁻¹ per year)		PROD_FFB (Mg ha ⁻¹ per year)		OCB (%)	
		QM	F	QM	F	QM	F
Replicates	9	139,174		3.66		0.74	
Trials	2	7,908,881	48.0**	92.3	30.9**	11.9	11.9**
Common trat. x Trials	2	249,321	1.5 ^{ns}	3.69	1.2 ^{ns}	0.49	0.5 ^{ns}
Adjusted treatments	38	1,235,461	7.5**	15.5	5.2**	7.03	7.0**
Residual	120	164,622		2.99		1.00	
Means ⁽¹⁾		5,429	(4,615)	25.2	(23.5)	21.5	(18.3)
CV (%)		7.47		5.62		4.65	
Genotypic variance (mean)		267,709		3.38		1.51	
Heritability (%)		86.7		87.1		85.7	
Intraclass correlation (%)		61.9		62.9		60.0	
CVg (%)		9.43		7.23		5.70	
CVg/Cve		1.26		1.29		1.23	

⁽¹⁾The estimates of population mean of PROD_OP and OCB are shown in the absolute scale and in values with 93.1% adjustment (in parentheses), referring to the benchmarking for the industrial efficiency of palm oil extraction (Menon, 2012). **Significant at 1% probability by the F test.

Tabela 3. Palm oil productivity (PROD_OP), productivity of fresh fruit bunch (PROD_FFB), and palm oil content in the fresh fruit bunch (OCB), evaluated from the 6th to the 9th year after planting, in 39 F1progenies from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms.

Progeny	Male origin	PROD_OP		PROD_FFB		OCB	
		(kg ha ⁻¹ per year)	Rank	(Mg ha ⁻¹ per year)	Rank	(%)	Rank
RUB 1199	LM 2T	7,068 (6,580)	1	29.4	1	23.8 (22.16)	3
RUB 1218	LM 2T	6,293 (5,858)	2	27.9	4	22.5 (20.9)	7
RUB 1211	LM 2T	6,263 (5,830)	3	25.0	26	25.0 (23.3)	1
RUB 1250	LM 10T	6,120 (5,697)	4	26.0	15	23.7 (22.1)	4
RUB 1198	LM 2T	5,997 (5,583)	5	28.2	2	21.2 (19.7)	23
RUB 1196	LM 2T	5,970 (5,558)	6	26.5	9	22.4 (20.9)	8
RUB 1227	LM 2T	5,962 (5,550)	7	26.4	10	22.7 (21.1)	6
RUB 1215	LM 10T	5,889 (5,482)	8	27.7	5	21.2 (19.7)	22
RUB 1210	LM 2T	5,883 (5,477)	9	26.6	8	22.0 (20.5)	13
RUB 1209	LM 10T	5,698 (5,304)	10	28.1	3	20.2 (18.8)	33
RUB 1274	LM 2T	5,676 (5,284)	11	25.6	21	22.2 (20.7)	11
RUB 1212	LM 10T	5,648 (5,258)	12	27.0	7	20.9 (19.5)	27
RUB 1217	LM 10T	5,645 (5,255)	13	25.8	17	21.8 (20.3)	16
RUB 1208	LM 2T	5,625 (5,236)	14	23.1	35	24.2 (22.5)	2
RUB 1283	LM 2T	5,610 (5,222)	15	26.0	16	21.7 (20.2)	18
RUB 1226	LM 2T	5,559 (5,175)	16	26.4	11	21.1 (19.6)	25
RUB 1220	LM 10T	5,545 (5,162)	17	25.0	25	22.2 (20.7)	12
RUB 1200	LM 10T	5,495 (5,115)	18	26.1	14	21.0 (19.6)	26
RUB 1271	LM 2T	5,493 (5,113)	19	25.8	19	21.4 (19.9)	21
RUB 1205	LM 10T	5,483 (5,104)	20	27.6	6	19.9 (18.5)	37
RUB 1231	LM 10T	5,456 (5,079)	21	26.3	12	20.8 (19.5)	28
RUB 1195	LM 10T	5,439 (5,063)	22	24.9	27	21.9 (20.4)	14
RUB 1225	LM 10T	5,409 (5,035)	23	25.2	24	21.5 (20.0)	19
RUB 1219	LM 2T	5,352 (4,982)	24	25.3	22	21.2 (19.7)	24
RUB 1206	LM 10T	5,297 (4,931)	25	26.1	13	20.2 (18.8)	32
RUB 1197	LM 10T	5,292 (4,926)	26	25.7	20	20.6 (19.2)	31
RUB 1232	LM 2T	5,200 (4,841)	27	23.9	29	21.8 (20.3)	17
RUB 1277	LM 10T	5,158 (4,802)	28	23.2	33	22.3 (20.8)	10
RUB 1204	LM 10T	5,154 (4,798)	29	22.4	36	23.0 (21.4)	5
RUB 1233	LM 10T	5,129 (4,775)	30	23.5	32	21.9 (20.4)	15
RUB 1224	LM 10T	5,094 (4,742)	31	25.2	23	20.1 (18.7)	34
RUB 1202	LM 2T	5,052 (4,703)	32	24.4	28	20.7 (19.3)	30
RUB 1214	LM 10T	5,046 (4,697)	33	25.8	18	19.5 (18.2)	38
RUB 1203	LM 10T	5,022 (4,675)	34	22.3	37	22.4 (20.9)	9
RUB 1221	LM 10T	4,931 (4,590)	35	23.7	31	20.8 (19.4)	29
RUB 1213	LM 10T	4,758 (4,429)	36	22.2	38	21.4 (19.9)	20
RUB 1223	LM 10T	4,639 (4,318)	37	23.2	34	20.1 (18.7)	36
RUB 1201	LM 10T	4,378 (4,075)	38	23.8	30	18.4 (17.1)	39
RUB 1234	LM 10T	4,283 (3,987)	39	21.2	39	20.1 (18.7)	35
Minimum		4,283 (3,987)		21.2		18.4 (17.1)	
Maximum		7,068 (6,580)		29.4		25.0 (23.3)	
Mean		5,462 (5,085)		25.3		21.5 (20.0)	

The phenotypic values of the PROD PO and OCB are shown in the absolute scale and in values with 93.1% adjustment (in parentheses), referring to the benchmarking for the industrial efficiency of palm oil extraction (Menon, 2012).

FFB was approximately 0.7 and 0.8% per year. Despite generating significant gains, up to 494 kg ha⁻¹ per year in PROD_OP, the indirect selection is not capable of obtaining gains compatible with the most successful oil

palm genetic improvement programs in the world. The estimates of improved population were 5,767, 5,639, and 5,581 kg ha⁻¹ per year, considering direct selection and indirect selection via OCB and via PROD_FFB, respectively.

Table 4. Genotypic (top of the table) and phenotypic (bottom of the table) correlations between the variables palm oil productivity (PROD_OP), productivity of fresh fruit bunch (PROD_FFB) and oil content in the bunch (OCB), evaluated from the 6th to the 9th year after planting, in 39 F1 progenies, from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms.

Variable	PROD_OP	PROD_FFB	OCB
PROD_OP	-	0.761	0.683
PROD_FFB	0.764	-	0.050
OCB	0.680	0.051	-

Genetic gain estimates with the restrict selection of male genitors indicated the possibility of immediate gains for PROD_OP (Table 6). The restricted selection of male genitors LM 2T progeny resulted in the estimated genetic gains for PROD_OP of 5,1% of immediate gain over the mean of the original population. In the PROD_FFB evaluation, Gomes Junior et al. (2019) and Pinto et al. (2019) also observed the superiority of 'Manicoré' x LM2T progenies, in comparison with 'Manicoré' x LM10T progenies. From the results attained by the authors, it can be concluded that, on average, the capacity of combining LM2T oil

Table 5. Direct (GDS) and indirect (GIS) genetic selection gain estimates for palm oil productivity (PROD_OP), evaluated from the 6th to the 9th year after planting, in 39 F1 progenies, from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms, with indirect selection based on the productivity of fresh fruit bunch (PROD_FFB), oil content in the fresh fruit bunch (OCB), and selection of 20% of the progenies.

Selected variable	Selected progenies	Response on PROD_OP				
		\bar{X}_s	SD	SD	GS	ISE
		------(kg ha ⁻¹ per year) ⁽¹⁾ -----			------(%)-----	
PROD_OP	RUB 1199 (LM 2T), RUB 1218 (LM 2T), RUB 1211 (LM 2T), RUB 1250 (LM 10 T), RUB 1198 (LM 2T), RUB 1196 (LM 2T), RUB 1227 (LM 2T) e RUB 1215 (LM 10T)	6,195 (5,767)	733 (682)	609 (566)	11.2	-
PROD_FFB	RUB 1999 (LM 2T), RUB 1198 (LM 2T), RUB 1209 (LM 10T), RUB 1218 (LM 2T), RUB 1215 (LM 10T), RUB 1205 (LM 10 T), RUB 1212 (LM 10 T) e RUB 1210 (LM 2T)	5,995 (5,581)	533 (496)	442 (411)	8.10	72.7
OCB	RUB 1211 (LM 2T), RUB 1208 (LM 2T), RUB 1199 (LM 2T), RUB 1250 (LM 10 T), RUB 1204 (LM 10 T), RUB 1227 (LM 2T), RUB 1218 (LM 2T) e RUB 1196 (LM 2T)	6,057 (5,639)	595 (553)	494 (456)	9.10	81.1

\bar{X}_s estimates of mean of the selected progenies; SD, selection differential; and ISE, indirect selection efficiency. The genetic parameters \bar{X}_s , SD, and SG (kg ha⁻¹ per year) are shown in the absolute scale and in values with 93.1% adjustment (in parentheses), referring to the benchmarking for the industrial efficiency of palm oil extraction (Menon, 2012).

Tabela 6. Selection of genetic gains estimates (SG) for palm oil productivity (PROD_OP), evaluated from the 6th to the 9th year after planting, in 39 F1 progenies, from crosses between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated oil palms, based on the restricted selection of oil palm male genitors of LM2T e LM10T progenies.

Origin	Number of progenies	\bar{X}_s	SD	SG	SG (%)
LM2T	15	5,800 (5,399)	338 (314)	281 (262)	5.1
LM10T	24	5,250 (4,887)			

\bar{X}_s , estimates of the mean of the selected progenies; SD, selection differential. The genetic parameters \bar{X}_s , SD, and SG (kg ha⁻¹ per year) are shown in the absolute scale and in values with 93.1% adjustment (in parentheses), referring to the benchmarking for the industrial efficiency of palm oil extraction (Menon, 2012).

palm with 'Manicoré'-originated American oil palm is greater than that of LM10T. These results confirm the possibility of immediate genetic gains in PROD_OP with the selection only for males, enabling the immediate availability of this material to producers, until the period when the new multiplied parents reach the commercial seed production capacity.

Although the restrict selection for male genitors provide smaller genetic gain than the selection for both genitor sexes, this strategy do not require genotype multiplication to start the seed production of the improved hybrids. However, female genitors need to be multiplied to produce seed in a commercial scale, which requires approximately eight years (Gomes Junior et al., 2019). The selection of male parents (pisifera-type palm oil) is justified by the potential to produce a large number of seed from a single plant, since the production of pollen is high, in comparison with the potential of seed production from female genitor. In Papua New Guinea, using only five pisifera-type oil palm parents, more than 12 million tenera-type seed were produced per year (Corley & Tinker, 2016). As a result, gains are obtained in two stages, in the short term, with the selection restricted to male oil palm parents and in the medium (up to eight years) and long term (above eight years), with the selection practiced in the both genitor sexes.

According to Rethinam & Murugesan (2018), American oil palm is a promising source of genetic resources, with desirable characteristics related to tolerance to biotic and abiotic stresses. Despite this fact, the cultivation of pure American oil palm is not economically viable due to its low productivity of mesocarp oil (<1 Mg ha⁻¹ per year) in comparison to that of the oil palm (4 to 5 Mg ha⁻¹ per year) (Cunha et al., 2012). These authors report that interspecific hybrids may reach about 90% of palm oil productivity. The current study showed that improved oil palm hybrids with oil productivity greater than 5 Mg ha⁻¹ per year can be obtained by different selection strategies. This indicates their high performance and the possibility of launching a new cultivar in the short term (up to one year), with the restricted selection of LM 2T male parents, and cultivars with higher productivity in the medium (up to eight years) and long term (more than eight years), exploring interspecific reciprocal recurrent selection between 'Manicoré'-originated

American oil palm population (female genitors) and 'La Mé'-originated oil palm population (male genitors).

Conclusions

1. The high values obtained for F estimates, heritabilities and Cvg / Cve ratios indicate favorable conditions for the palm oil production improvement in F1 interspecific hybrid progenies between female genitors of 'Manicoré'-originated American oil palm and male genitors of 'La Mé'-originated pisifera-type oil palms.

2. The genetic gains of palm oil production in interspecific hybrids can be obtained immediately with the restricted selection of the male genitors LM2T of 'La Mé'-originated pisifera-type oil palm and, in the medium and long terms, greater genetic gains can be obtained with the interspecific reciprocal recurrent selection between parent populations of 'Manicoré'-originated American oil palm and 'La Mé'-originated oil palms.

3. The genetic correlations between the palm oil productivity with production of fresh fruit bunch and the palm oil content in fresh fruit bunch are high and positive; the indirect selection provides significant gains for the palm oil productivity, however, these gains are lower than those by direct selection.

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