PAB
Pesquisa Agropecuária Brasileira

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Genetics/ Original Article

Selection gains for bunch production in interspecific hybrids between "caiaué" and oil palm

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Received
May 29, 2018

Accepted
September 18, 2019

How to cite
GOMES JUNIOR, R.A.; LOPES, R.; CUNHA, R.N.V. da; PINA, A.J. de A.; QUARESMA, C.E.; CAMPELO, R.D.; RESENDE, M.D.V. de. Selection gains for bunch production in interspecific hybrids between "caiaué" and oil palm. **Pesquisa Agropecuária Brasileira**, v.54, e00819, 2019. DOI: https://doi.org/10.1590/S1678-3921.pab2019.v54.00819.

Abstract – The objective of this work was to estimate selection gains for bunch production in hybrids obtained from "caiaué" (*Elaeis oleifera*) parents from the Manicoré population and oil palm (*Elaeis guineensis*) parents from the La Mé population, from the third to the eighth year after planting. Thirty-nine full-sibling progenies were evaluated in experiments conducted in a randomized complete block design, with four replicates and 12 plants per plot. The genetic gain estimates were 27.6% for the ten best selected F1 individuals, 13.7% for the four best selected progenies from parents of both sexes, 6.4% for the selected progenies of the five best male parents, 6.0% for the selected progenies of the two best families from male parents, and 4.0% for the selected progenies of the best descendants from male parents. Genetic gains for bunch production can be achieved, in the short term, through selection restricted to male parents, and, in the medium term, through selection of both male and female parents and cloning of F1 individuals.

Index terms: *Elaeis guineensis*, *Elaeis oleifera*, bunch production, plant breeding, REML/BLUP.

Ganhos de seleção para produção de cachos em híbridos interespecíficos entre caiaué e dendê

Resumo – O objetivo deste trabalho foi estimar ganhos de seleção para produção de cachos em híbridos obtidos de genitores caiaué (*Elaeis oleifera*) da população Manicoré e dendê (*Elaeis guineensis*) da população La Mé, do terceiro ao oitavo ano após o plantio. Avaliaram-se 39 progênies de irmãos completos em experimentos conduzidos em delineamento de blocos ao acaso, com quatro repetições e 12 plantas por parcela. As estimativas de ganho genético foram de 27,6% para a seleção dos dez melhores indivíduos F1, 13,7% para a seleção das quatro melhores progênies de genitores de ambos os sexos, 6,4% para a seleção das progênies dos cinco melhores genitores masculinos, 6,0% para a seleção das progênies das duas melhores famílias de genitores masculinos e 4,0% para a seleção das progênies da melhor descendência de genitores masculinos. É possível obter ganhos genéticos para produção de cachos, em curto prazo, com a seleção restrita a genitores masculinos, e, em médio prazo, com a seleção de genitores masculinos e femininos e com a clonagem de indivíduos F1.

Termos para indexação: *Elaeis guineensis*, *Elaeis oleifera*, produção de cachos, melhoramento genético de plantas, REML/BLUP.

Introduction

Palm oil is extracted from the mesocarp of the fruit of oil palm (*Elaeis guineensis* Jacq.), a palm tree of African origin. It is the most produced and commercialized vegetable oil worldwide (FAO, 2017), mainly due to the species highest oil productivity among the grown oilseeds, its low production costs, and its multiple uses in the chemical, cosmetic, and food industries (Zimmer, 2009).

Native to the American continent, the "caiau*é*" [*Elaeis oleifera* (Kunth) Cortés] palm belongs to the same genus as *E. guineensis* and produces a similar oil, but with several other favorable characteristics, such as higher antioxidant concentrations, lower lipase enzyme activity, and higher unsaturated fatty acid content (Cadena et al., 2013; Lieb et al., 2017). However, the mesocarp of caiaué fruits is smaller and has a lower oil content than that of the African species (Lieb et al., 2017), which partly explains its lower potential for oil production despite the better quality of the oil produced from it.

The interspecific hybridization between caiaué and oil palm has been explored for genetic improvement, mainly to introduce caiaué-associated resistance to lethal yellowing into oil palm (Lopes et al., 2012). Lethal yellowing is a disorder of undefined etiology that has already decimated thousands of hectares of oil palm plantations in the Americas, including in Brazil (De Franqueville, 2003). Therefore, due to its inherited resistance to lethal yellowing, the interspecific hybrid between caiaué and oil palm (IEH O×G) is currently the only option for oil palm cultivation in areas where the disease occurs (Cunha & Lopes, 2010). Because the total weight of the bunches produced by oil palm cultivars is the main determinant of oil yield (Okwuagwu et al., 2008; Okoye et al., 2009), gains in bunch production are important for both the intra- and interspecific improvement of oil palm.

IEH O×G progenies, from female caiaué and male oil palm plants of the Manicoré and La Mé populations, respectively, have shown a high potential for bunch production, with a high genetic variability for this characteristic, from the third to the sixth year after planting (Gomes Junior et al., 2016). Those progenies were derived from the same caiaué and oil palm populations used to develop the BRS Manicoré cultivar (Cunha & Lopes, 2010), which is the only IEH O×G grown in Brazil to date. This is an indicative that selection gains for bunch production can be obtained using caiaué and oil palm parents from the Manicoré and La Mé populations, respectively, possibly exceeding the productivity of the BRS Manicoré cultivar. Genetic gains with selection can be assessed based on bunch production in the first years of crop production, whereas production potential and selection gains for the adult stage of the crop can be estimated up to the eighth year after planting, when the production peak is reached (Chia et al., 2009).

The objective of this work was to estimate selection gains for bunch production in hybrids obtained from caiaué parents from the Manicoré population and oil palm parents from the La Mé population, from the third to the eighth year after planting.

Materials and Methods

The experiments were set up at Marborges Agroindústria S.A., in the municipality of Moju, in the state of Pará, Brazil (1°58'42"S, 48°36'50"W), in February 2007. The soil of the site is a Latossolo Amarelo distrófico franco-arenoso (Santos et al., 2013), i.e., a dystrophic sandy loam Oxisol. The climate is Af according to Köppen's classification (Alvares et al., 2013), with an average rainfall of 2,850 mm from 1994 to 2015 and a rainy season that occurs in the first half of the year.

A total of 39 F1 full-sibling progenies were obtained from crosses between 32 caiaué females, all from 18 different families of the Manicoré population, and 13 oil palm males, 7 from three different LM 10T families and 6 from four different LM 2T families of the La Mé population (Table 1). These caiaué and oil palm populations were maintained at the Rio Urubu experimental field, located in the municipality of Rio Preto da Eva, in the state of Amazonas, and were used to produce commercial seeds of 'BRS Manicoré', an interspecific F1 hybrid launched by Embrapa in 2010 (Cunha & Lopes, 2010) and registered at Registro Nacional de Cultivares (RNC) (Brasil, 2019) under number 26031.

The progenies were divided into three experimental groups, two with 14 and one with 15 progenies; 2 progenies (RUB 1195 and RUB 1213) were common to the three experiments. The experimental design was a randomized complete block, with four replicates and 12 plants per plot (four rows of three plants each). As a

Table 1. Genealogy of the 39 assessed progenies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids.

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

DOI: 10.1590/S1678-3921.pab2019.v54.00819

border, a line – with one plant at each end – was used at each end of the experimental plots. Planting was done at a density of 143 plants per hectare in a contiguous area of 17.6 ha. It should be noted that no research-based production system has yet been established for IEH O×G cultivation, although there are some technical recommendations for seedling formation, for example (Gomes Junior et al., 2017). Therefore, producers have adapted the recommendations for oil palm cultivars obtained from empirical experiments in the cultivated areas (Menezes et al., 2017). In the present study, the management practices used were those adapted by Marborges Agroindústria S.A. to manage their cultivated areas, as described in Pina (2010).

Mature bunches were harvested at 15- to 20-day intervals from July 2010 (third year after planting) to December 2015 (eighth year after planting), with a total of 111 harvests in the 5.5 experimental years. The number and weight of the bunches produced per plant in each harvest were recorded, and weighing was performed in the field using a dynamometer. During the assessment, 56 plants (2.4% of the total) were excluded due to mortality, abnormal vegetative development, nutritional deficiency, or severe disease incidence. Bunch production per plant ($PROD_{ind}$), expressed in kilogram of fresh fruit bunches (FFB) per plant per year, was converted to production by area and expressed in Mg FFB per hectare per year, based on a planting density of 143 plants per hectare.

The genetic parameters were estimated by the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) mixed-effect model, using the Selegen-REML/BLUP software (Resende, 2002), through the following statistical model: y = Xr + Zg + Wp + Tb + e, where y represents the data; r are the fixed population effects added to the overall mean, including the population and common control means; g are the random genetic effects; p are the random plot effects; b are the random block effects; e are the random errors or residues; and X, Z, W, and T represent the incidence matrices for the r, g, p, and b effects, respectively.

The genotypic values for male parents (GV_p), as well as for their families and progenies, were estimated according to the equations:

$$h^2 = (N_p \times (PA_m)^2) / (1 + ((N_p - 1) \times (PA_m)^2))$$

$$\text{and } GV_p = (GV_m \times h^2{}_m / (PA_m)^2 \times (GV_{pm} / GV_{mm}),$$

where N_p is the number of progenies represented by the parent, PA_m is the mean progeny accuracy represented by the parent, GV_m is the mean genotypic value for the progenies represented by the parent, $h^2{}_m$ is the mean heritability of the progenies represented by the parent, GV_{pm} is the overall mean of the GV_p of all the parents of the experiment, and GV_{mm} is the overall mean of the GV_m of all the progenies of the experiment.Selection gains for bunch production were estimated for progenies from: female caiaué and male oil palm parents from the Manicoré and La Mé populations, respectively; only male parents, considering the selection of parent, family, and progeny; and F1 individuals for vegetative propagation. Assessing selection gain for male parents is interesting because this strategy allows bringing a new cultivar to the market faster, despite the lower genetic gain, compared with selection for both males and females, due to the great pollen production capacity of the oil palm plants used as male parents in hybridization. According to the statistics obtained at the seed production area at the Rio Urubu experimental field, a single parent can produce up to 50 g pollen per year, which is enough to pollinate 800 female caiaué inflorescences. Considering that each caiaué inflorescence produces a bunch with an average of 500 seeds, the pollen of a single male parent can produce approximately 400,000 seeds per year. Moreover, a caiaué plant used as a female parent in interspecific hybridization produces between five and ten bunches per year, with an average of 500 seeds each, resulting in 2,500 to 5,000 seeds per year. However, it should be pointed out that, to commercially reproduce superior progenies, the parents must be propagated, especially the females, which delays cultivar release but allows a greater genetic gain.

Results and Discussion

The low values observed for the coefficients related to the plot effects (c^2_{parc} = 2.9%) and to the genotype × environment interaction (c^2_{int} = 0.1%) indicate a good experimental accuracy (Table 2) based on the classification of Resende (2007).

The overall mean of the genotypic values (μGV) for $PROD_{ind}$ for all individual plants in the experiment was 157.1 kg FFB per plant per year, which corresponds to 22.5 Mg FFB per hectare per year (Table 2), indicating the high production potential of the progenies. It should be highlighted that these values were obtained based on bunch production from the third to the eighth year after planting, including the juvenile period from the third to the fifth year, when plant production is still below the potential of the adult stage. This explains why the values in the present study were higher than the overall mean of 20.6 Mg FFB per hectare per year found by Gomes Junior et al. (2016) when assessing the same progenies but only from the third to the sixth year of cultivation. Also in the municipality of Rio Preto da Eva, Lopes et al. (2012) assessed 59 IEH O×G adult-stage progenies from the seventh to the thirteenth year after planting and obtained genotypic values of 127.8, 128.9, 141.3, 144.6, and 150.4 kg FFB per plant per year for the five best progenies derived from different caiaué (Manicoré, Caimbé-Tefé, UEPAE-Manaus, and BR 174) and oil palm (Deli, La Mé, and Nigéria) populations. According to these authors, bunch production in Manicoré × LM 2T plants was particularly relevant, as four of the five most productive progenies were derived from this combination. However, the reported values were below the means for the progenies assessed in the present study, which may be explained by the fact that by Lopes et al. (2012) used different populations and combinations of caiaué and oil palm, whereas here only Manicoré × La Mé combinations were evaluated. The lower yields found by the authors may also be partly due to the assisted pollination performed in the present study during the entire assessment of bunch production, as well as to the genetically distinct progenies used and to the soil and climate differences between the experimental sites.

Table 2. Estimates of the genetic parameters for bunch production (kg per plant per year) from the third to the eighth year after planting in the field of 39 progenies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids.

Genetic parameter[(1)]	Estimate
V_g	166.3
V_{parc}	20.8
V_{int}	0.53
V_{within}	574.9
V_{phe}	762.6
h^2_a	0.44±0.06
h^2_{mc}	0.89
h^2_{ad}	0.29
c^2_{parc}	0.029
c^2_{int}	0.001
μGV	157.1
μPV	163.8

[(1)]V_g, genotypic variance between full-sibling progenies, equivalent to 1/2 of the additive genetic variance plus 1/4 of the dominance genetic variance, ignoring epistasis; V_{parc}, environmental variance between plots; V_{int}, genotype variance × environment interaction; V_{within}, residual variance within the plot; V_{phe}, individual phenotypic variance; h^2_a, individual narrow-sense heritability, obtained by ignoring the dominance genetic variance fraction (1/4); h^2_{mc}, adjusted heritability of the mean genotype, assuming complete survival; h^2_{ad}, additive heritability within a plot, obtained by ignoring the dominance genetic variance fraction (1/4); c^2_{parc}, coefficient to determine plot effects; c^2_{int}, coefficient to determine genotype × environment interaction effects; μGV, overall mean of genotypic values; and μPV, overall mean of phenotypic values.

The estimates of genetic variability and heritability for $PROD_{ind}$ were high, and the adjusted heritability of the genotypic mean (h^2_{mc} = 0.89) was higher than both the individual narrow-sense heritability (h^2_a = 0.44±0.06) and the additive heritability within a plot (h^2_{ad} = 0.29) (Table 2). These parameters indicate that there were favorable conditions for gains with the selection of both progenies and individuals. High estimates for bunch production heritability in IEH O×G were also observed in previous studies (Lopes et al., 2012; Gomes Jr. et al., 2014; Gomes Junior et al., 2016), including one on an oil palm population with a wide genetic variability (Okwuagwu et al., 2008). However, a low heritability for bunch production in oil palm populations with a narrow genetic base has also been reported (Soh et al., 2003; Noh et al., 2010; Marhalil et al., 2013), showing the importance of hereditary factors for the genetic improvement of a crop.

The phenotypic values for the $PROD_{ind}$ of the 39 progenies between the third and eighth year after planting ranged from 137.5 to 199.1 kg FFB per plant per year, while the genotypic values ranged from 132.0 to 187.7 kg FFB per plant per year. Progenies RUB 1199, RUB 1218, RUB 1205, and RUB 1209 stood out, showing genotypic values of 187.7, 176.3, 175.3, and 174.8 kg FFB per plant per year, respectively, which are equivalent to 26.8, 25.2, 25.1, and 25.0 Mg FFB per hectare per year (Table 3). Gomes Jr. et al. (2014) assessed the first two years of bunch production of the same progenies as those used in the present study and found that the most productive were RUB 1210, RUB 1274, RUB 1199, and RUB 1232. In a later study, considering the first four years of production, Gomes Junior et al. (2016) verified that RUB 1199, RUB 1209,

Table 3. Phenotypic values (PV), genotypic values (GV), and selection gains (SG) for bunch production from the third to the eighth year after planting of 39 progenies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids.

Order	Progeny	PV	GV	SG	New mean	SG (%)
		(kg per plant per year)				
1	RUB 1199	199.1	187.7	30.7	187.7	19.5
2	RUB 1218	186.3	176.3	24.9	182.0	15.9
3	RUB 1205	185.4	175.3	22.7	179.8	14.5
4	RUB 1209	184.8	174.8	21.5	178.5	13.7
5	RUB 1196	177.8	168.4	19.5	176.5	12.4
6	RUB 1195	167.6	167.8	18.0	175.1	11.5
7	RUB 1210	177.0	167.8	17.0	174.0	10.8
8	RUB 1200	177.2	167.7	16.2	173.2	10.3
9	RUB 1198	176.7	167.4	15.5	172.6	9.9
10	RUB 1283	175.2	166.2	14.9	171.9	9.5
11	RUB 1274	173.0	164.2	14.2	171.2	9.0
12	RUB 1232	172.3	163.5	13.6	170.6	8.6
13	RUB 1226	172.1	163.3	13.0	170.0	8.3
14	RUB 1215	171.8	163.1	12.5	169.5	8.0
15	RUB 1227	171.3	162.5	12.0	169.1	7.7
16	RUB 1271	170.6	162.0	11.6	168.6	7.4
17	RUB 1250	170.1	161.5	11.2	168.2	7.1
18	RUB 1231	167.8	159.4	10.7	167.7	6.8
19	RUB 1225	166.7	158.5	10.2	167.2	6.5
20	RUB 1206	166.3	158.0	9.7	166.8	6.2
21	RUB 1219	165.2	157.0	9.3	166.3	5.9
22	RUB 1197	164.7	156.5	8.8	165.9	5.6
23	RUB 1202	163.8	155.9	8.4	165.4	5.3
24	RUB 1208	162.6	154.6	7.9	165.0	5.0
25	RUB 1212	161.1	153.3	7.5	164.5	4.8
26	RUB 1214	159.6	152.0	7.0	164.0	4.4
27	RUB 1217	158.8	151.3	6.5	163.6	4.1
28	RUB 1201	158.7	151.0	6.1	163.1	3.9
29	RUB 1224	158.1	150.6	5.6	162.7	3.6
30	RUB 1233	155.9	148.6	5.2	162.2	3.3
31	RUB 1211	153.8	146.7	4.7	161.7	3.0
32	RUB 1204	149.6	142.9	4.1	161.1	2.6
33	RUB 1220	148.5	142.1	3.5	160.5	2.2
34	RUB 1203	146.9	140.4	2.9	160.0	1.9
35	RUB 1223	145.7	139.4	2.3	159.4	1.5
36	RUB 1277	144.7	138.5	1.7	158.8	1.1
37	RUB 1221	144.5	138.3	1.2	158.2	0.8
38	RUB 1213	138.2	138.3	0.7	157.7	0.4
39	RUB 1234	137.5	132.0	0.0	157.1	0.0

RUB 1218, and RUB 1232 were the most productive. However, only RUB 1199 remained among the four most productive progenies in three consecutive evaluations of brunch production at 1.5, 3.5, and 5.5 years, respectively, indicating the need for longer evaluation periods to obtain greater selection accuracy, as was also concluded by Lopes et al. (2012).

With the selection of the best classified progenies, the selection gain for $PROD_{ind}$ was 30.7 kg per plant per year (19.7% μGV) and the expected mean after selection was 187.7 kg per plant per year, equivalent to 26.8 Mg FFB per hectare per year. The selection gain with the four best progenies, using a selection pressure of 10.3%, was 21.5 kg per plant per year, i.e., 13.7% of the overall mean, and the expected mean after selection was 178.5 kg per plant per year, which is equivalent to 25.5 Mg FFB per hectare per year. The selection gains for the assessed progenies are comparable to those obtained in other international oil palm breeding programs (Gascon et al., 1988; Bakoumé & Louise, 2007; Bakoumé et al., 2010; Noh et al., 2012).

To avoid the narrowing of the caiaué genetic basis, as occurred with the Deli, La Mé, Yagambi, and Avros oil palm populations (Soh et al., 2003; Noh et al., 2010; Marhalil et al., 2013), and to maintain the possibility of long-term continuous gains, a lower pressure should be applied in the breeding population to maintain a greater genetic variability. However, to select progenies that will be propagated and made available to producers as new cultivars, the selection pressure should be more intense to guarantee a greater genetic gain than that of current cultivars, leading to greater short-term productivity gains.

For vegetative propagation potential, the mean phenotypic value of the 15 best individuals for $PROD_{ind}$, using a selection pressure of 0.75%, was 224.8 kg FFB per plant per year (32.1 Mg FFB per hectare per year), ranging from 210.2 to 256.6 kg FFB per plant per year (30.0 and 36.7 Mg FFB per hectare per year); in addition, the mean genotypic value was 198.3 kg FFB per plant per year (28.4 Mg FFB per hectare per year), ranging from 193.4 to 204.2 kg FFB per plant per year (27.7 to 29.2 Mg FFB per hectare per year) (Table 4). In these individuals, selection gains ranged from 41.2 (26.3%) to 47.2 (30.0%) kg FFB per plant per year, i.e., 5.9 to 6.8 Mg FFB per hectare per year, representing a high genetic gain and an excellent potential for the development of new cultivars. The estimates for $PROD_{ind}$ of the 15 best individuals (30.0 and 36.7 Mg FFB per hectare per year) were higher than those between 26.1 and 31.6 Mg FFB per hectare per year obtained by Lopes et al. (2012) while assessing IEH F1 (O×G) progenies for the selection of individuals for cloning, even though the plants were evaluated in their adult stage, which corresponds to the phase of higher productivity. The capitalization of all genetic effects on selection gain is the main factor contributing to the high selection gains of the individuals selected for cloning when using this strategy, since the genotype is fully reproduced and the allelic frequencies and gene combinations are not altered. Of the 15 individuals with the highest $PROD_{ind}$, 13 (87%) are RUB 1199, which is the progeny with the highest genotypic value for $PROD_{ind}$; these results are similar to those obtained by Gomes Junior et al. (2016) for the first 3.5 years of production (third to sixth year) in the same population as that assessed in the present study.

As the accuracy in the estimation of genotypic values is lower for individuals than for progenies, a longer period is necessary to reach a high selection accuracy in the evaluation of bunch production. According to Chia et al. (2009), for the selection of IEH O×G families, 4 consecutive years are required for the assessment of bunch production with a good repeatability (>85%), and at least 6 years for the selection of individuals with a good accuracy (>80%). In the present study, bunch production was evaluated for 5.5 years, and the C^2_{parc} and C^2_{int} genetic parameters indicate a good accuracy in the selection and cloning of the most productive individuals, which should undergo clonal assessment, with replicates, in different sites to validate their productive performance before being released as new cultivars. Therefore, although breeding programs can provide greater genetic gain, it is necessary to access clones before releasing them, which could take more than 10 years after the selection of individuals, considering the time required for in vitro micropropagation and for evaluating brunch production in the adult stage of the plant, or at least up to 8 years after planting in the field.

Considering the 15 best individuals for $PROD_{ind}$ (Table 5), the phenotypic values ranged from 207.9 to 256.6 kg per plant per year (29.7 to 36.7 Mg FFB per hectare per year), while the genotypic values ranged from 191.4 to 198.8 kg per plant per year (27.4 to 28.4 Mg

FFB per hectare per year). The best performing progeny, RUB 1199, accounted for 14 of the 15 individuals with the highest genotypic value, indicating its superiority to the others. The selection of IEH O×G individuals based on additive effects is interesting for the backcrossing strategy, which should be undertaken with the best performing IEH O×G individuals and elite oil palm materials as recurrent parents to establish caiaué resistance to lethal yellowing and improve oil palm productivity and fertility.

For selection among male parents only, the selection gain for the 5 best parents selected from the 13 tested was 10.1 kg FFB per plant per year (6.5%, 1.4 Mg FFB per hectare per year), and the new mean was 167.2 kg FFB per plant per year (23.9 Mg FFB per hectare per year) (Table 6). Of these selected parents, 3 belonged to the LM 13582 family (LM 2T progeny) and 2 to the LM 12252 family (LM 10T progeny), being represented by 17 progenies and 811 individuals in the experiment. This high number of individuals confers robustness to the genotypic value estimates of the male parents.

Selection based on the families and progenies of male parents resulted in two better families, LM 13582 (LM 2T progeny) and LM 12252 (LM 10T progeny), which presented a selection gain of 9.5 kg FFB per plant per year (6.0%, 1.4 Mg FFB per hectare per year), as well as an improved population, with a mean of 166.5 kg FFB per plant per year (23.8 Mg FFB per hectare per year) (Table 6). These families were represented by 7 male parents, 20 progenies, and 950 individuals in the experiment. The selection of the best progeny – LM 2T – resulted in a selection gain of 6.3 kg FFB per plant per year (4.0%, 0.9 Mg FFB per hectare per year) and in an improved population, with a mean of 163.4 kg FFB per plant per year (23.4 Mg FFB per hectare per year). This progeny was represented by 3 families, 6 parents, 15 progenies, and 712 individuals in the experiment.

Combining the studied Manicoré and La Mé populations – from which caiaué and oil palm originated – can lead to selection gains in the short, medium, and long terms through the selection of parents for seed propagation or of individuals for vegetative propagation.

Table 4. Phenotypic values (PV), genotypic values (GV), and selection gains (SG) for bunch production from the third to the eighth year after planting, used to classify the 15 best individuals among 39 progenies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids for use in vegetative propagation.

Clone order	Individual (line/plant)[(1)]	Progeny	PV	GV	GS	New mean	SG (%)
			(kg per plant per year)				
1	L124/P15	RUB 1205	256.6	204.2	47.2	204.2	30.0
2	L127/P17	RUB 1199	238.7	203.4	46.8	203.8	29.8
3	L113/P04	RUB 1199	232.6	201.9	46.1	203.2	29.4
4	L111/P25	RUB 1199	231.6	201.5	45.7	202.8	29.1
5	L124/P17	RUB 1199	234.0	201.5	45.5	202.5	28.9
6	L126/P19	RUB 1199	232.5	200.9	45.2	202.2	28.8
7	L125/P17	RUB 1199	225.4	198.0	44.6	201.6	28.4
8	L109/P24	RUB 1199	222.5	197.8	44.1	201.2	28.1
9	L113/P02	RUB 1199	220.9	197.2	43.7	200.7	27.8
10	L115/P02	RUB 1199	220.8	197.1	43.3	200.3	27.6
11	L109/P25	RUB 1199	216.8	195.6	42.9	199.9	27.3
12	L112/P05	RUB 1205	234.0	194.1	42.4	199.4	27.0
13	L115/P04	RUB 1199	212.9	193.9	42.0	199.0	26.7
14	L104/P07	RUB 1199	210.2	193.9	41.6	198.6	26.5
15	L124/P19	RUB 1199	214.1	193.4	41.2	198.3	26.3

[(1)]Identification of individuals according to line (L) and plant (P) numbers in the C22 commercial plot of Marborges Agroindústria S.A. (Moju, PA, Brazil).

Table 5. Phenotypic values (PV) and genotypic values (GV) for bunch production from the third to the eighth year after planting, used to classify the 15 best plants among 39 progenies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids for use as parents.

Order of parent	Individual (line/plant)[(1)]	Progeny	PV	GV
			(kg per plant per year)	
1	L127/P17	RUB 1199	238.7	198.8
2	L113/P04	RUB 1199	232.6	197.8
3	L111/P25	RUB 1199	231.6	197.5
4	L124/P17	RUB 1199	234.0	197.5
5	L126/P19	RUB 1199	232.5	197.0
6	L124/P15	RUB 1205	256.6	195.9
7	L125/P17	RUB 1199	225.4	195.0
8	L109/P24	RUB 1199	222.5	194.9
9	L113/P02	RUB 1199	220.9	194.4
10	L115/P02	RUB 1199	220.8	194.4
11	L109/P25	RUB 1199	216.8	193.2
12	L115/P04	RUB 1199	212.9	192.1
13	L104/P07	RUB 1199	210.2	192.0
14	L124/P19	RUB 1199	214.1	191.7
15	L104/P05	RUB 1199	207.9	191.4

[(1)]Identification of individuals according to line (L) and plant (P) numbers in the C22 commercial plot of Marborges Agroindústria S.A. (Moju, PA, Brazil).

Table 6. Phenotypic value (PV), genotypic value (GV), selection gain (SG), and new mean (NM) for bunch production based on the GV of the 39 progênies of caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) interspecific hybrids from the Manicoré (female) and La Mé (male) populations, respectively, evaluated for brunch production from the third to the eighth year after planting.

Progenies genealogy and representation considering male parents from La Mé (LM) population					PV	GV	SG	NM	SG[(1)] (%)
Parent	Parent family	Family origin	Number of progenies	Number of individuals	-----------(kg per plant per year)-----------				
RU 2693 P	LM 13582	LM 2T	5	239	173.8	170.5	13.5	170.5	8.6
RU 2692 P	LM 13582	LM 2T	4	189	174.4	170.4	13.4	170.5	8.6
RU 2700 P	LM 12252	LM 10T	5	240	168.9	166.3	12.0	169.1	7.7
RU 2691 P	LM 13582	LM 2T	2	96	173.8	164.5	10.9	167.9	7.0
RU 2733 P	LM 12252	LM 10T	1	47	184.8	164.1	10.1	167.2	6.5
RU 56 P	LM 12011	LM 10T	4	285	165.6	159.6	8.9	165.9	5.7
RU 2749 P	LM 13582	LM 2T	2	93	168.1	159.5	7.9	165.0	5.1
RU 2730 P	LM 13751	LM 10T	6	282	160.6	159.4	7.2	164.3	4.6
RU 2707 P	LM 12437	LM 2T	1	47	176.7	157.1	6.4	163.5	4.1
RU 53 P	LM 12785	LM 2T	1	48	172.1	153.3	5.4	162.5	3.5
RU 2710 P	LM 12011	LM 10T	6	372	143.8	143.8	3.7	160.8	2.4
RU 2729 P	LM 13751	LM 10T	1	48	158.1	141.3	2.1	159.2	1.3
RU 2698 P	LM 12252	LM 10T	1	46	146.9	131.8	0.0	157.1	0.0
Parent family	Family origin	Number of parents	Number of progenies	Number of individuals	PV	GV	SG	NM	SG (%)
					-----------(kg per plant per year)----------				
LM 13582	LM 2T	4	13	617	172.9	169.5	12.5	169.5	8.0
LM 12252	LM 10T	3	7	333	168.1	163.5	9.5	166.5	6.0
LM 13751	LM 10T	2	7	330	160.2	156.4	6.1	163.1	3.9
LM 12437	LM 2T	1	1	47	176.7	154.0	3.8	160.8	2.4
LM 12785	LM 2T	1	1	48	172.1	150.2	1.7	158.7	1.1
LM 12011	LM 10T	2	10	657	153.2	148.7	0.0	157.1	0.0
Origin	Number of families	Number of parents	Number of progenies	Number of individuals	PV	GV	SG	NM	SG (%)
					-----------(kg per plant per year)----------				
LM 2T	3	6	15	712	173.1	163.4	6.3	163.4	4.0
LM 10T	3	7	24	1,320	158.7	150.7	0.0	157.1	0.0

[(1)]SG was estimate considering only male parents selection, at the parent, family, and origin level.

DOI: 10.1590/S1678-3921.pab2019.v54.00819

Conclusions

1. Short-term genetic gains for bunch production in interspecific hybrids between caiaué (*Elaeis oleifera*) and oil palm (*Elaeis guineensis*) (IEH O×G) can be obtained if selection is restricted to male parents, while medium-term gains can be achieved through the selection of both male and female parents and cloning of F1 individuals.

2. Progenies of IEH O×G exhibit high genetic variability for bunch production from the third to the eighth year after planting.

3. By selecting improved IEH O×G individuals based on additive effects, selection gains for long-term bunch production can be obtained from backcrosses that use oil palm as the recurrent parent.

Acknowledgments

To Marborges Agroflorestal S.A., for providing the infrastructure for the experiments and for financial support; and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and to Fundação Amazônia de Amparo a Estudos e Pesquisas (Fapespa), for financial support.

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DOI: 10.1590/S1678-3921.pab2019.v54.00819