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Selection of triple-cross *Theobroma grandiflorum* genotypes, aiming at fruit production and resistance to *Moniliophthora perniciosa*

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ABSTRACT: In this study, we evaluated triple-cross *Theobroma grandiflorum* progenies from two successive hybridizations aiming to select families and individuals within them that aggregate high fruit production with resistance to the witches' broom disease, as well as to evaluate the possibility of incorporating the production methodology of triple-cross hybrids in the breeding program of the species. The study was conducted in a commercial area located in Tomé Açu, Pará, from 2007 to 2018, in a consortium with a black pepper plantation. Twenty-five progenies of *T. grandiflorum* were used, in a randomized block design, with five replicates and three plants per plot. The variables "number of fruit", "fruit production" and the occurrence rate of witches' broom, during eight harvests, were all analysed. Eight progenies with excellent production and low damage levels caused by witches' broom were selected. Within these, 16 plants were identified, which will be propagated vegetatively for clonal evaluations in different environments and later turn into parents of a new population. The obtained results served as an indication from the efficiency of the triple-crossing methodology in the breeding program of the species.

Key words: Amazonian fruit tree; cupuassu tree; mixed models; triple crossing

Seleção de genótipos tri compostos de *Theobroma grandiflorum*, visando produção de frutos e resistência à *Moniliophthora perniciosa*

RESUMO: Neste trabalho foram avaliadas progênies tri compostas de *Theobroma grandiflorum*, oriundos de duas sucessivas hibridações, objetivando selecionar famílias e, dentro delas, indivíduos que agregassem elevada produção de frutos com resistência à vassoura de bruxa, bem como, avaliar a possibilidade de incorporar a metodologia de produção de híbrido tri compostos no programa de melhoramento genético da espécie. O trabalho foi conduzido em uma área comercial em Tomé Açu, Pará, no período de 2007 a 2018, em consórcio com um plantio de pimenteira do reino. Foram utilizadas 25 progênies de *T. grandiflorum*, no delineamento de blocos casualizado, com cinco repetições e três plantas por parcela. Analisaram-se as variáveis "número de frutos", "produção de frutos" e a taxa de ocorrência de vassoura de bruxa, durante oito safras. Foram selecionadas oito progênies com excelentes produções e baixos níveis de danos ocasionados pela vassoura de bruxa. Dentro dessas progênies foram identificadas 16 matrizes, as quais serão propagadas vegetativamente, para avaliações clonais em diferentes ambientes e, posteriormente, se constituirão em genitores de nova população. Os resultados obtidos serviram como indício da eficiência da metodologia do cruzamento triplo no melhoramento genético da espécie.

Palavras-chave: fruteira amazônica; cupuaçuzeiro; modelos mistos; cruzamento triplo

Introduction

Among the diversity of fruit trees that are in the Amazon region, which contribute to the economic and social development of the region, the cupuassu (*Theobroma grandiflorum* (Willd. Ex Spreng.) Schum.) stands out, a species native of this same region that has been gaining space in the pulp market, mainly for producing juices, ice creams, jellies, jams and other derivatives (Pugliese et al., 2013). Moreover, its almond is suitable for oil extraction, used in both the pharmaceutical and cosmetic industries (Genovese & Lannes, 2010).

This species naturally occurs in understory conditions in the Amazon rainforest, with height varying from 15 to 20 meters and with reduced size when cultivated, due to the pruning management that the crop needs. It has simple and alternate leaves, in addition to the largest flowers of the genus (Santos et al., 2012), which, although hermaphrodites, they possess anatomical barriers efficient in hindering the direct access of pollen grains from the anthers to the stigma, with a hood that protect the stamens and the staminodes that surround the style-stigma. Furthermore, they also have a complex system of late self-incompatibility (Venturieri, 2011). Its fruit is a round/oval-shaped drupaceous berry with average size of 25 cm and average weight of 1.5 kg (Cerón et al., 2015).

The dawn of cupuassu cultivation in Brazil was in the 70s, appearing as one of the alternatives used by Japanese immigrants, set up mainly in the municipality of Tomé Açu, Pará, in order to replace the black pepper (*Piper nigrum* L.) crop plagued by fusariosis (Barros et al., 2009). These plantings were held with non-selected seeds from native cupuassus, homemade orchards and others. During the first years of attempting to domesticate the species, the yield was satisfactory despite the great variability between plants within crops. This was because the cupuassu draw on residues from the black pepper cultivation that previously occupied these areas. However, with the surge of the witches' broom disease, caused by the fungus *Moniliophthora perniciosa* Stahel Aime & Phillips-Mora (Alves et al., 2009), yield suffered a sharp drop, causing great discouragement to producers. As most plants had not been pruned at the early cultivation stages, they were all very tall, hindering the phytosanitary pruning.

In order to make the cultivation of this fruit tree feasible, Embrapa Eastern Amazon started in 1984 the cupuassu breeding program, by means of forming a collection of genotypes containing part of the species variability, especially including different sources of resistance to the disease. In 2002, Embrapa Eastern Amazon (CPATU) released the first cupuassu cultivars: BRS Coari, BRS Codajás, BRS Manacapuru and BRS Belém, which, besides having a good yield, also demonstrated resistance to *M. perniciosa*. Evolving alongside it, the breeding program was able to make available, in 2012, a seminal cultivar with genetic composition of improved population of the first cycle, named as BRS Carimbó. It maintained the resistance of previous cultivars, but having added greater fruit production and quality (Alves & Ferreira, 2012).

Using triple crossings aiming at incorporating different traits or the intensification of a specific one, in a single individual, is common in animal breeding and in the improvement of grains such as corn, soybean, sorghum and bean (Bacaxixi et al., 2011; Costa et al., 2012). In perennial species, the technique is mainly used in eucalyptus (Gomes et al., 2015); however, not as much in the breeding of fruit trees. In the breeding of cupuassu, this strategy is unprecedented, especially due to the long time taken for evaluating and select hybrids in the different phases.

In face of the above, it is important defining whether the triple-cross procedure originates different progenies, as for the main agronomic traits of the cupuassu, and incorporating this methodology into the breeding program of the species. Therefore, this study aimed to select triple-cross progenies and superior stock plants, concerning the fruit production and resistance to witches' broom, in an attempt to select efficient and sustainable genotypes for the producers.

Materials and Methods

The test was conducted in the period from 2007 to 2018, in the municipality of Tomé Açu, PA, on a private property, located at the coordinates 2°24'03.9" S and 48°00'02.4" W. The soil is medium-texture "Latossolo Amarelo" (Oxisol) type, with humid climate corresponding to the Ami type, as according to the Köppen classification. The mean temperature during the study period was of approximately 26.4 °C, with a relative humidity of 86% and mean annual precipitation of 2,964.5 mm. Figure 1 illustrates the history of rainfall and the relative humidity over the cupuassu crop years. During the eleven years of the experiment, the region experienced a very rainy period from December to May, and another one with little rainfall stretching from June to November (Figure 2).

The experimental area was initially planted with black pepper (*Piper nigrum* L.) and, after five years, a consortium with cupuassu progenies was established. The pepper trees were planted with spacing of 2 x 2 meters and density of 2,500 plants ha^{-1}, while the cupuassu was arranged in the spacing of 6 x 4 meters and density of 416 plants ha^{-1}, totaling 2,916 plants per hectare. During the production phase, fertilizations were with cattle manure (30 l $plant^{-1}$ $crop^{-1}$), supplemented by mineral nutrients, based on 1.5 kg of the 10-28-20 formulation per plant $crop^{-1}$.

The experimental design was in randomized blocks with 25 treatments, having five replicates and three plants per plot. At first, clones selected from the Germoplasm Active Bank were hybridized (Alves et al., 2017) by using the cupuassu controlled-pollination technique, as reported by Venturieri & Ribeiro Filho (1995). After evaluating and selecting the progenies, the most productive parents, who remained asymptomatic for *M. perniciosa* after 15 years of field exposure, were duly identified and selected. These parents were crossed with four released cultivars: BRS Coari (174), BRS Codajás (186), BRS Manacapuru (215) and BRS Belém (286), with attention to the non-coincidence of the parents, in order to avoid inbreeding

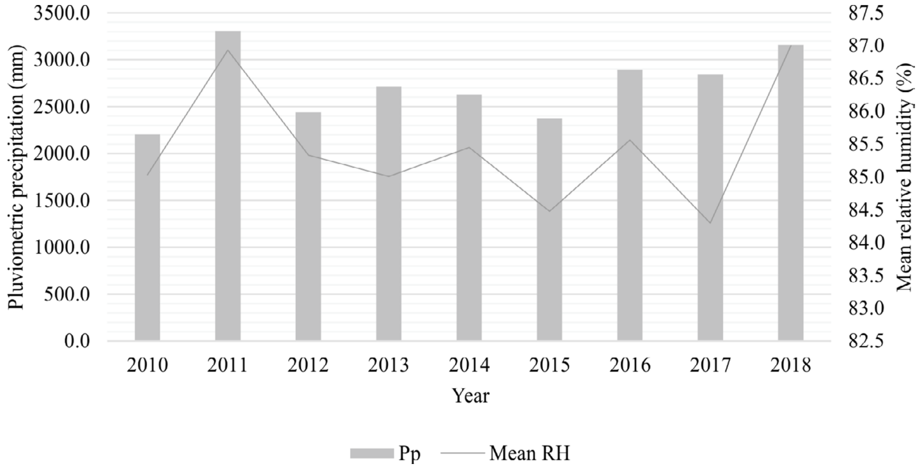

Figure 1. Annual means of pluviometric precipitation (mm) and relative humidity (%), during eight crops of an experiment for evaluating triple-cross *Theobroma grandiflorum* (cupuassu) progenies, in the municipality of Tomé Açu, Brasil. 2020.

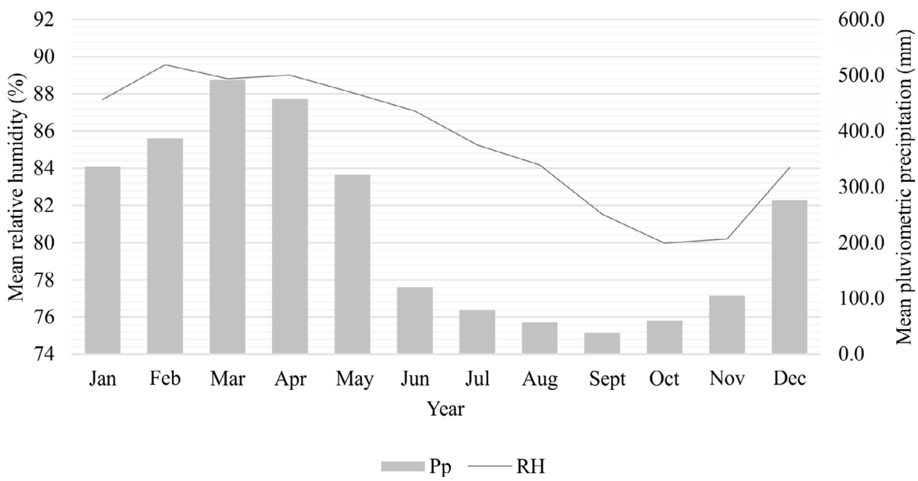

Figure 2. Monthly means, during the period from 2010 to 2018, of pluviometric precipitation (mm) and relative humidity (%), in an experiment for evaluating triple-cross *Theobroma grandiflorum* (cupuassu) progenies, in the municipality of Tomé Açu, Brasil. 2020.

and thus increase the hybridization-provided vigor (Maia et al., 2011). In the following crosses, it is important that the used genotypes are genetically distant and compatible. The compatibility rate is found by the ratio between the number of pollinated flowers and the number of fruit, so that when the setting rate is above 30%, it is considered compatible (Alves et al., 2017). The triple-cross progenies used in the present study were obtained in this manner and were constituted by the genetic contributions of three distinct genotypes.

The plants were evaluated individually, with three data collections every two months, recording the fruit amount produced per crop and the mean weight of these fruit. This enabled estimating the mean fruit production (kg) of each plant per crop. The evaluation of the witches' broom incidence in plants occurred at the same time, by recording the number of plants showing symptoms in each progeny, during all eight evaluated crops (from 2010/2011 to 2017/2018). These symptoms were identified when at least one branch possessed a totally misshapen phyllotaxis in a normal branch, which would wither after one month and remain stuck to the plant for up to two years (Alves et al., 2009).

The selection of the progenies was through the analysis of mixed models (REML/BLUP), in the SELEGEN software (Resende, 2016), where the components of variance and genetic parameters (REML method) were estimated and the genotypic values predicted (BLUP method), for the two production variables (number of fruit/plant and fruit production (kg plant^{-1})). The estimated genetic parameters were the following: genotypic variance, between plots variance, within plots variance and phenotypic variance; coefficient of determination of the plot effects; accuracy and heritabilities: within the plot, fitted to the progenies mean and narrow sense. The statistical model employed was $y = Xr + Zg + Wp + e$, where y is the data vector, r is the vector of the repetition effects (assumed as fixed) added to the general mean, g is the vector of individual genotypic effects (assumed as random), p is the vector of plot effects (assumed as random), and e is the vector of errors or residuals (random). Uppercase letters (X, Z and W) stand for the incidence matrices for the referred effects (Resende, 2007). The progenies were ranked by the genetic value of the two production variables studied and the ones among the ten best were selected regarding these variables, which had a rate of symptomatic plants for witches' broom lesser than 30%.

Subsequently, the selection was made at the individual level, where the matrices that composed the ten selected progenies were ranked, according to their genotypic value, for the two mentioned variables. In addition, some criteria was also considered for selection, such as asymptomatic plant and the maximum performance of two orthetes per progeny, so as not to restrict too much the genetic variability between the selected genotypes. The temporal distribution from the productive period of selected individuals was also characterized, where: plants that concentrated more production in the last months of the year (crop beginning) were classified as "early"; plants that concentrated production in the first four months (mid-crop) were classified as "regular"; and the plants that concentrated production in the period from May to July (crop end) were classified as "late".

Results and Discussion

The production evolution of the triple-cross progenies tested started with averagely 11 fruit/plant in the first crop (Figure 3). In other trials with progenies of primary hybrids in the same municipality, Tomé Açu, the production in the first crop reached a maximum of five fruit per plant, on average (Alves et al., 2018). Although the fruit production had a slow growth in subsequent years, it reached the seventh crop (2016/2017) averaging 30 fruit/plant, which corresponds to the production of about 50 kg of fruit plant^{-1}. Considering the used planting density (416 plants ha^{-1}), it will result in a yield of 20.8 t ha^{-1}. It represents almost twice the yield of 11 t ha^{-1} expected with the cultivar currently on the market, the BRS Carimbó (Alves & Ferreira, 2012), revealing that the tested genotypes are promising.

In addition to the genetic potential of tested genotypes, some environmental factors may explain the performance of these progenies. As the consortium was with black pepper, after fusariosis occurred in the area, the plants gradually died, thus leaving only the cupuassu under full sun, from the third year of field planting. Under these conditions, after the initial immaturity period, the cupuassu is able to express full production, if the additional requirements for water, nutrients and pest control are respected.

In the present experiment, the residues left by the black pepper and the organic fertilizers provided the necessary nutrition for the plants having vegetative vigor, without symptoms of nutritional deficiencies in their leaves, as well as to support the fruit production observed. The consortium had an irrigation system that was efficient in replacing water during the critical months, namely the last six months of the year (Figure 2), with no symptoms of water stress in the plants at any given time. In general, species from the genus *Theobroma* are not well adapted to conditions of water scarcity. In *T. cacao*, there is a decrease in the plant metabolism in such conditions, causing the stomatal closure and the paralysis of the assimilated photo production (Lozano & Fonseca, 2016). Still on the species, Carr & Lockwood (2011) emphasize the flowering inhibition and development of stunted fruit when the plant is subjected to water stress. Hence, in the present experiment, with light, nutrients and water in adequate proportions, there were ideal environmental conditions for the full production. In this standardized environment, the discrimination of genotypes was evident, allowing the identification of which progenies contributed the most for increasing the overall mean.

Estimating the variance components (Table 1) has revealed that approximately 17% and 16% of the genotypes performance regarding the number of fruit plant^{-1} and fruit production (kg plant^{-1}), respectively, can be attributed to their genetic composition. Rosado et al. (2012) emphasizes that there is a direct relation between the values found for genotypic variance and the possibility of successful selection. Despite the considerable influence of external factors, the data herein obtained can be considered as promising, in comparison with other studies with the species. Alves & Resende (2008), when studying this species, observed a little more than 12% of the genotypic variance composing the phenotypic variance.

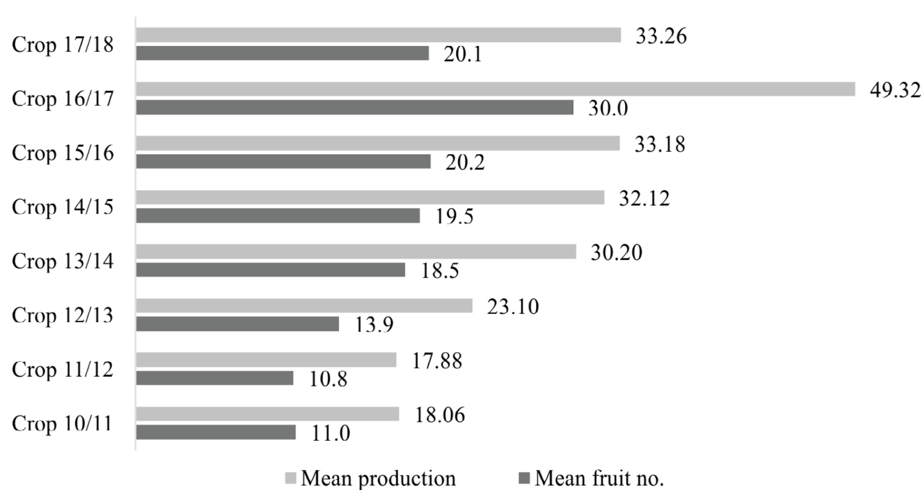

Figure 3. Evolution of the mean number of fruit and the fruit production per plant, in the first eight crops of the evaluation trail of triple-cross *Theobroma grandiflorum* progenies (cupuassu), in the municipality of Tomé Açu, PA, 2020.

Table 1. Estimation of genetic parameters and components of variance from tri-composed *Theobroma grandiflorum* (cupuassu) progenies, in the municipality of Tomé Açu, PA, 2020.

Variance components and genetic parameters	Number of fruit plant^{-1}	Fruit production (kg plant^{-1})
Genotypic variance	7.7	20.7
Variation between plots	0.7	0.95
Variance within the plot	36.3	103.3
Phenotypic variation	44.8	124.9
Coefficient of determination of the plot effects	0.01	0.007
Progeny selection accuracy	0.86	0.86
Individual heritability (narrow sense)	0.34 ± 0.12	0.33 ± 0.12
Mean progeny heritability	0.75	0.74
Additive heritability within the plot	0.21	0.2

Other parameters that provided evidence of the selection reliability were the coefficient of determination of the plot effects and the selection accuracy. The first one concerns the influence of plot effects on the total phenotypic variation. Their small values demonstrated that there was a similarity in the environmental conditions the plants were submitted to. According to Resende & Duarte (2007), the accuracy refers to the correlation between true and predicted genotypic values and, therefore, values close to 1 should always be sought. According to the classification proposed by these same authors, the accuracy found in the present research classifies as high, for both variables (0.86), reinforcing the reliability of the selection performed in the experiment.

Yet another genetic parameter of great importance in researching breeding is the heritability (Table 1), responsible for estimating the selection success, since it reflects the proportion of phenotypic variation that can be inherited. The individual heritability estimated here, in the narrow sense, was practically of the same magnitude between the two production variables and is compatible with the field data, when researching polygenic characters, where there is normally a strong environmental influence (Maia et al., 2011). Hence, we expected that the selection performed would be efficient in identifying the genotypes that could contribute in improving the yield of cupuassu orchards, as well as, increasing the breeding program, with the formation of a new base population through the recurrent selection. Alves & Resende (2008) and Souza et al. (2002) found heritability values (0.30 and 0.24, respectively) lower than those in the present study, when evaluating a smaller number of crops (four crops). According to Souza et al. (2002), this component may have significantly influenced the values they recorded. Another factor that may have influenced heritability was the genetic base range of the present population, since using genetically distant parents and a third genotype at the crossing, contributed to the variability increase. Pinto et al. (2013) used genetically similar parents on papaya, finding values around 0.20 for the evaluated traits (oligogenic and polygenic).

It is worth emphasizing that the mean heritability of the progenies was significantly higher, of more than twice the value of individual heritability. Maia et al. (2009), point out that in this case there is a decrease in experimental errors using means as evaluation units. Pinto et al. (2013) also observed a great difference between the two heritabilities, indicating that the progeny selection, in this case, is more viable. In the present study, we opted for selecting the progenies first, in order to capitalize the gains provided by this selection, reflected in the average heritability of progenies and, subsequently, to conduct the individual selection, at the plant level, only with those previously selected progenies. Therefore, we attempted to increase the selection accuracy, evaluating not only the performance of the individual, but also the family behavior, thus increasing the chances of selecting individuals that had both production and resistance genes.

The mean phenotypic and genotypic values in the first eight crops were, coincidentally, 19.6 fruit plant^{-1}, resulting in the production of 29.2 kg of fruit per plant (Table 2). Genotypic values that are close to phenotypic ones indicate a good genetic contribution to the manifestation of phenotypic character. This mean was much higher than the one found by Alves et al. (2018) in a experiment, also in Tomé Açu (10.3 kg of fruit plant^{-1}). However, in these said tests both the genotypes and the cultural treatments used were different from the present study, despite the same number of crops evaluated.

The ranking based on the genetic values of the response variables mean number of fruit plant^{-1} and the average fruit production per plant, revealed eight progenies standing out: 117, 120, 124, 129, 140, 165, 166 and 167 (Table 2), with progenies 165, 117 and 140 having very significant nominal values in relation to BRS Carimbó (Alves & Ferreira, 2012). Two parents, recurring mothers, seem to have contributed in the production genes increase of the progenies: 174, the code for BRS Coari, present in progenies 117, 120, 124 and 129, and clone 1074 used in progenies 165, 166 and 167. Furthermore, during the initial hybridization, the common presence of clone 186, cultivar released as the BRS Codajás, is found in seven out of the eight highlighted progenies, attesting to the influence of this genotype on the quality of the material. Alves et al. (2010), when selecting cupuassu progenies in the municipality of Belém-PA, noticed the same positive influence of clone 186, since the three selected progenies had this genotype as one of the parents. Normally, there is no perfect coincidence between these two variables results (number of

Table 2. Genealogy, phenotypic and genetic values related to the variables "number of fruits/plant" and "fruit production (kg plant^{-1})" and incidence rate of *Moniliophthora perniciosa*, in triple-cross progenies of *Theobroma grandiflorum* (cupuassu), in the municipality of Tomé Açu, PA, 2020.

Progeny	Genealogy	Number of fruit plant^{-1}		Fruit production (kg plant^{-1})		Incidence rate of *Moniliophthora perniciosa* (%)
		Phenotypic value	Genetic value	Phenotypic value	Genetic value	
117	**174 x (186 x 434)**	**24.4**	**23.1**	**39.8**	**37.0**	**7.7**
118	174 x (186 x 434)	18.1	18.4	38.0	35.4	0.0
120	**174 x (186 x 434)**	**24.1**	**23.0**	**36.4**	**34.4**	**26.7**
121	174 x (186 x 434)	20.3	20.1	34.8	33.3	26.7
123	174 x (186 x 554)	13.7	15.1	33.4	32.2	26.7
124	**174 x (186 x 554)**	**21.2**	**20.8**	**33.4**	**32.2**	**7.7**
127	174 x (186 x 1074)	19.9	19.7	32.4	31.4	28.6
128	174 x (186 x 1074)	14.2	15.6	31.1	30.3	15.4
129	**174 x (186 x 1074)**	**21.6**	**21.1**	**30.5**	**30.0**	**13.3**
130	174 x (186 x 513)	17.0	17.6	30.0	29.7	13.3
131	174 x (186 x 513)	18.7	18.9	29.8	29.6	20.0
132	174 x (286 x 513)	18.7	18.8	29.1	29.1	15.4
133	186 x (286 x 215)	15.5	16.8	29.1	29.1	7.7
135	186 x (174 x 286)	19.7	19.6	29.2	29.1	6.7
136	186 x (174 x 286)	12.9	14.6	29.1	28.9	0.0
137	186 x (286 x 513)	19.7	19.7	28.8	28.9	0.0
138	215 x (174 x 186)	19.1	19.2	27.6	28.0	26.7
140	**215 x (186 x 434)**	**23.3**	**22.2**	**27.3**	**27.8**	**16.7**
149	SEKÓ x (186 x 434)	19.8	19.5	27.4	27.7	9.1
152	SEKÓ x (186 x 554)	19.0	19.1	26.1	26.8	14.3
157	554 x (174 x 186)	20.0	19.7	24.8	26.1	7.1
161	1074 x (186 x 434)	19.9	19.8	24.8	25.9	63.6
165	**1074 x (174 x 286)**	**25.6**	**24.2**	**20.3**	**22.5**	**14.3**
166	**1074 x (186 x 554)**	**21.9**	**21.2**	**19.4**	**22.1**	**10.0**
167	**1074 x (186 x 554)**	**22.3**	**21.6**	**18.2**	**21.1**	**14.3**
	Mean	19.6	19.6	29.2	29.1	15.7
	C.V. %	21.28		24.98		

Rows in bold represent progenies that stood out both in number of fruit and in fruit production, according to the BLUP analysis.

fruit plant^{-1} and production of fruit plant^{-1}). There are plants with many fruit, but small fruits, and plants with few, albeit large, fruit (Alves et al., 2010). Hence, there is usually a need for complementarity of this information.

Progenies 117, 120, 124, 129, 140, 165, 166 and 167 also demonstrated having good resistance to *M. perniciosa*, with low infection rates, except for progenies 120 and 140 that showed symptoms of the disease above the average, compared the other selected progenies (Table 2).

For diversifying the sources of resistance to *M. perniciosa*, progenies 149 and 152 are worth mentioning for incorporating the genes from the Sekó clone, however, their yields are lower than the eight previously mentioned. The performance of progenies 118, 136 and 137 was also relevant, having no plants affected by the disease over the field years during the experiment. These progenies have in common parental 186 (BRS Codajás) that may have contributed to this behavior (Table 2). According to Alves et al. (2009), this clone is the one that promotes the highest nominal resistance rates in its descendants. These five progenies listed will be incorporated into the cupuassu breeding program, for the supply and diversification of *M. perniciosa* resistance genes. Through sequential crosses with resistant genotypes, the frequency of resistance genes in the population will increase and, consequently, decrease the records of infection by the etiological agent of witches' broom, increasing the durability of resistance of cultivars in the field. Therefore, the triple crossing may accelerate the pyramidation process of these genes.

Initially, the average incidence rate of *M. perniciosa* in the experimental area was lower than other areas with cupuassu in that municipality. This is because the property was located far from the cupuaçu production center in the municipality of T. Açu. With expansion of the area planted by the producer in the following years, there was a rapid increase in the inoculum source and the disease started to affect severely the plants, thus revealing the susceptible genotypes, which was great for for evaluation. In commercial plantations, the integrated management of the disease is recommeded to prevent it from spreading epidemically through the orchard and affecting the production (Pereira & Kavati, 2011).

After ranking the individuals by the genotypic values of the two production variables, in addition to resistance to *M. perniciosa*, two orthetes were selected from each of the eight previously selected progenies, totaling 16 individuals (Table 3). Selecting a restricted number of plants per progeny was due to the need to maintain genetic diversity among the stock individuals, mainly due to the genetic self-incompatibility of

Table 3. Mean values of the number of fruit, fruit production, genotypic value and classification of the greatest production period of the stock individuals selected in the experiment of triple-cross *Theobroma grandiflorum* (cupuassu) progenies, in the municipality of Tomé Açu, PA, 2020.

	Number of Fruit crop^{-1}			Fruit yield (kg crop^{-1})			
Future clone*	Genotypic value	Genetic gain	New mean	Genotypic value	Genetic gain	New mean	Classification
117.5.1	29.3	9.9	29.5	47.4	18.2	47.4	Late
117.5.3	29.6	10.0	29.6	42.1	15.0	44.1	Regular
120.3.2	26.2	8.3	27.9	38.4	11.7	40.8	Regular
120.4.1	22.9	5.0	24.6	38.5	11.8	41.0	Late
124.2.3	25.1	6.9	26.5	37.5	11.3	40.5	Late
124.3.2	23.6	5.6	25.2	36.8	10.8	39.9	Late
129.4.1	24.7	6.4	26.0	41.7	14.5	43.7	Regular
129.5.2	23.9	5.7	25.3	34.7	8.5	37.6	Regular
140.2.2	23.6	5.5	25.1	40.8	13.7	42.8	Early
140.4.3	25.1	6.8	26.4	39.8	13.3	42.4	Regular
165.3.2	26.6	8.8	28.4	44.9	17.0	46.1	Regular
165.4.3	27.8	9.3	28.9	42.2	15.7	44.8	Regular
166.2.3	23.9	5.7	25.3	34.0	8.0	37.1	Regular
166.3.3	22.3	4.6	24.2	31.0	5.5	34.6	Early
167.4.1	23.0	5.2	24.7	35.4	9.2	38.3	Regular
167.5.2	25.5	7.0	26.6	39.3	12.7	41.8	Regular

*Coding of individuals x, y and z, in which x corresponds to the progeny, y corresponds to the location block and z corresponds to the plant.

the species, common in the genus *Theobroma* (Lanaud et al., 2017). As these stock plants will be propagated vegetatively for new evaluation, in clonal tests, this variability will help in the compatibility between the genotypes (Abreu et al., 2009).

Computing the selection of the 16 stock plants, representing a selection intensity close to 6%, we would have an increase of 7 (seven) fruit to the initial population mean, in turn corresponding to the genetic gain of 35%. Fruit production would increase by 12.3 kg, representing a gain of 41% (Table 3). The variability that still exists between cupuassu genotypes offers significant gains with the selection, and would deserve to be directed towards new market niches too (Alves et al., 2010). The variability observed between the progenies studied here reflects the heterozygosity degree of the genes present in the parents, which segregate when they are continuously crossed. According to Yamada et al. (2009), the state of heterozygosity in which the plants are found, makes the selection of stock plants for cloning more interesting than the selection of individuals for the hybrid production, since the crossing performed in the latter case can segregate, providing undesirable combinations and originating unproductive and/or individuals susceptible to diseases. Only the direct exploration of heterosis, provided by the targeted crossing, has a positive effect on the commercially interesting traits such as resistance and production.

For the producer and the agro-industry, it is important that the crop is not focused in a short period of the year. This concentration hinders the logistics of processing, storage and marketing in the agro-industry. This is because there will be an excess supply of raw material in the crop and a shortage in the other months of the year, which implies additional costs with cold-chamber storage (Nogueira & Santana, 2009). Thus, it is providential that the commercial orchard is composed of planting materials that meet the start, the midpoint and the end of the crop, as the producer will be able to extend the cropping period and obtain fair prices. Therefore, in this research, during the genotype-evaluation phases, the characterization of the breeding season was held. Table 3 displays the classification of each stock plant for this variable, where 12.5% of these individuals were precocious, 62.5% were regular and 25% were late.

Conclusions

The triple-cross genotypes proved to be a good strategy for the cupuassu breeding, for gene pyramidation of both resistance to *M. perniciosa* and fruit production.

Eight selected progenies may already be recommended to producers for small-scale planting, which will help to reduce the time for the final release.

Sixteen stock plants with high fruit-production capacity and resistant to *M. perniciosa* were identified. Once cloned, they will need a new evaluation cycle, through competition from clones in different environments, before are incorporated into the breeding program or made available to producers.

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