

Genetic parameters, correlation and repeatability of agronomic characters of yellow passion fruit genotypes in three harvest cycles

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ABSTRACT: The genetic improvement of sour passion fruit has the main objective of obtaining genotypes with high fruit yield and quality. The determination of the ideal early selection is extremely relevant to reduce costs and time in the selection of promising genotypes for use in genetic improvement programs. In this context, this work aimed to determine the ideal selection phase through estimates of genetic parameters, phenotypic, genotypic correlations and analysis of repeatability. A total of 14 yellow passion fruit hybrids in Lençóis (Bahia State, Brazil) were evaluated in a randomized block design with five replications and nine agronomic traits from three harvests with five fruits evaluated per repetition. Genetic parameters, repeatability coefficient and phenotypic and genotypic correlations were estimated for each evaluation cycle. For most parameters, the traits changed according to the evaluation cycle. Most of the genetic parameters showed favorable genetic conditions for the selection in the first harvest. The correlations between the traits fruit weight, peel and seedless pulp weight, fruit length and diameter were more stable in the different harvests. Through the repeatability analysis based on the principal components of covariance and correlation, it was possible to estimate a sample of 13 fruits per hybrid for prediction with accuracy of 90% for the physical traits of sour passion fruit.

Key words: *Passiflora edulis* Sims, breeding, heritability, repeatability analysis, genotypic correlation, early selection.

INTRODUCTION

The genetic breeding programs of sour passion fruit (*Passiflora edulis* Sims) aims to obtain genotypes with high productive potential and fruit quality, such as high juice yield and content of soluble solids and low acidity. In addition, resistance is necessary to the main pathogens that shorten the lifespan of orchards in different regions of Brazil (Lima et al. 2018; Pereira et al. 2019; Santos et al. 2019).

For the selection of genetically superior genotypes, several morpho-agronomic traits are considered. Correlation analysis between traits contributes to the selection of promising genotypes, since the technique allows selecting traits that are difficult to measure but that have complex inheritance with another trait that is easy to measure (Oliveira et al. 2011; Alves et al. 2012; Malek et al. 2014). This strategy allows faster progress in relation to the use of direct selection (Carvalho et al. 2004; Moraes et al. 2005). The association of correlation analysis with determination of other genetic parameters of genotypic, phenotypic and environmental variation and heritability is fundamental to obtain information on the population (Moraes et al. 2005; Bergo et al. 2019) and to understand the action of genes involved in trait control (Silva et al. 2012).



The successive evaluation of a genotype is desirable, because the individual performance is expected to remain constant during the investigated period (Santos et al. 2010). However, the successive assessment of many characteristics over an extended period is time-consuming and expensive (Santos et al. 2010). Thus, repeatability analysis is of great importance, since it allows to determine the correlation of these measures of the genotype under evaluation and allows to predict the minimum number of measures to provide acceptable accuracy of information.

The estimate of the repeatability coefficients expresses the proportion of the total variance that is explained by the variations of the genotype. The correlation between the measures obtained from the same plant in time or space also indicates the maximum value that heritability in the broad sense can reach (Cruz et al. 2004; Ferreira et al. 2005). High values for the estimate of character repeatability indicate that it is possible to predict the real value with a relatively small number of measurements, so that the gain in accuracy with a greater number of measurements is irrelevant (Bruna et al. 2012). However, when the repeatability is low, a large number of repetitions will be necessary to reach a satisfactory determination value that will vary with the nature of each of the traits to be evaluated (Cruz et al. 2004; Neves et al. 2010).

Studying yellow passion fruit, Cavalcante et al. (2017, 2018) used two production cycle periods, but only three traits related to fruit production and weight. However, there are no studies evaluating more characteristics with an estimate of genetic components, correlation and repeatability in association with different cycle of harvests. This approach helps to understand the changes that can occur in these parameters as a function of the evaluation epoch, with implications for breeding genetics. In addition, the selection of the cycle where the environmental factors are less pronounced regarding phenotype and which has the genetic component as the predominant factor in the evaluated phenotype allows estimates of important genetic parameters with better precision, consequently resulting in superior selective response for the genotypes under the evaluated conditions. Furthermore, the genotypic observations according to the initial harvests can accelerate the selection process and consequently reduce the cost of breeding programs. This acceleration is particularly interesting for the selection of yellow passion fruit, since the lifespan of the crop is declining due to the high incidence and severity of diseases (Oliveira et al. 2013; Lima et al. 2018; Pereira et al. 2019). Under ideal conditions, the culture is maintained commercially for up to four years, but this falls to one year in the presence of diseases caused by viruses and fungi, such as fusarium wilt (Oliveira et al. 2013; Pereira et al. 2019). On the other hand, passion fruit propagated by seeds can start fruiting five to eight months after planting, which can allow more than one evaluation in the productive cycle of the crop. Thus, a study of the components of variance, correlation and repeatability of the characters of production and fruit traits can support the selection and recombination, aiming to accelerate the process of genetic improvement of the species. The objective of this study was to determine the most suitable harvest cycle for selection, based on genetic components of variance, phenotypic and genotypic correlation and repeatability of the agronomic characters of sour passion fruit hybrids evaluated in three harvest periods.

MATERIALS AND METHODS

Experiment location

The research was carried out in the municipality of Lençóis, state of Bahia, Brazil (12°17'37"S, 42°39'27"W, 700 m). The local climate is classified as Cwb mesothermal by the Köppen classification. The climate conditions of the evaluation period were average maximum temperature of 30 °C, average minimum of 18 °C, relative humidity of 68% and precipitation of 0.31 to 7.37 mm per day. The soil is classified as yellow red dystrophic latosol (oxisol) with clayey texture (Embrapa 1999) and has the following chemical attributes in the 0–20 cm layer: pH (H₂O) 6.50; P 18 (mg·dm⁻³); K 0.15; Ca 4.30; Mg 2.30; Al 0.0; H + Al 3.08; CEC 9.91 (cmol_c·dm⁻³); V (%) 69; O.M. 47.6 g·kg⁻¹ of soil.

Plant material and experimental design

Were evaluated 14 intraspecific hybrids of sour passion fruit (*P. edulis* Sims), 12 intraspecific hybrids of the HFOP-01 series to 12, from crosses between parents selected due to the higher productivity and physical and chemical attributes

of fruits of interest (Neves et al. 2013), and two commercial hybrids, BRS Sol do Cerrado (BRS-SC1) and BRS Gigante Amarelo (BRS-GA1). The experimental design used was randomized blocks, with 14 treatments, five replications and 12 plants per plot.

Ninety days after sowing, the seedlings produced under an anti-aphid screen were planted in the field with a simple wire at height of 2 m and planting spacing of 4.0×2.5 m. The plants were irrigated in an organic production system, according to the guidelines of the Embrapa production system (Embrapa 2018). Due to the presence of pollinating insects, no artificial pollination was carried out in the planting area.

Variables collected

The traits analyzed were total accumulated yield ($t \cdot ha^{-1}$), number of fruits per plant (NF), fruit weight (FW), length (FL) and diameter (FD), peel thickness (PT), peel weight (PW), seedless pulp weight (PuW) and juice yield (JY), given by the PuW/FW ratio in percentage. The evaluation was performed using an illustrated manual of the descriptors for *Passiflora* (<https://bit.ly/3oR0SYp>; Jesus et al. 2017). For each harvest, five fruits were analyzed per plot. To estimate productivity, the number of fruits in the plot was counted. All traits were evaluated at three harvest times: 184 (harvest 1 or H1), 334 (harvest 2 or H2) and 441 (harvest 3 or H3) days after planting.

Genetic parameters

The estimated genetic parameters were determined based on expected mean square of the analysis of variance (ANOVA), considering treatment as a random effect (Cruz et al. 2004). The estimated parameters were coefficient of genetic variation (CV_g), residual (experimental) coefficient of variation (CV_e), CV_g/CV_e ratio, phenotypic variance (σ_p^2), genetic variance (σ_g^2), environmental variance or residual variance (σ_e^2) and heritability (h^2).

Correlation

For correlation analysis, the phenotypic (r_f) and genotypic (r_g) correlations were estimated as described by Cruz et al. (2004). The magnitudes of the correlation coefficients were established according to the classification by Carvalho et al. (2004): $r = 0$ (null); $0 < |r| \leq 0.30$ (weak); $0.30 < |r| \leq 0.60$ (medium); $0.60 < |r| \leq 0.90$ (strong); $0.90 < |r| < 1$ (very strong) and $|r| = 1$ (perfect). All analyses were performed using the Genes program (Cruz 2013).

Repeatability analysis

To determine the repeatability coefficient, four methods were used: 1) ANOVA for each trait described and estimation of the components of variance associated with the genetic and residual effects; 2) principal component analysis based on the correlation matrix (PCCOR); 3) principal component analysis based on the covariance matrix (PCCOV) between each pair of measurements (Abeywardena 1972) and 4) structural analysis based on the correlation matrix (SACOR) between the accessions in each evaluation pair (Mansour et al. 1981). For repeatability analysis, the character measurements of the fruits within each plot were considered, using the average obtained in each of the five repetitions in order to check if there was consistency of the data obtained for the five fruits of each harvest.

The repeatability coefficient (R) was estimated through the results of ANOVA (Cruz et al. 2004). For each characteristic, the minimum number (n_0) of measurements necessary to predict the real value of the genotypes was determined, based on predetermined coefficients of determination (R^2) of 0.85, 0.90 and 0.95 (Cruz et al. 2004). For each characteristic, the determination coefficient (R^2) was calculated based on the average of n measurements and the estimation of the repeatability coefficients obtained according to one of the methods used. The repeatability was classified as follows: high repeatability ($r \geq 0.60$); medium repeatability ($0.30 < r < 0.60$) and low repeatability ($r \leq 0.30$) (Resende 2002).

RESULTS

Genetic parameters

The evaluations carried out over the three production harvests (H1, H2 and H3) of the 14 hybrids of sour passion fruit demonstrated variability for most traits within and between the evaluation harvest (Table 1). The CV_g ranged from 3.96 to 21.02% for the characteristics of FD and production (PR), respectively. Approximately 66.67% of CV_g values were above 10%, with considerable variability even in the case of previously selected individuals, thus allowing advances in new selection cycles. In general, the highest CV_g values were observed in the third harvest (H3), followed by the first (H1), but the pulp weight, number of fruits and productivity stood out in the second (H2) harvest (Table 1).

Table 1. Genetic parameters of nine physical and chemical traits of fruits from 14 hybrids of sour passion fruit analyzed at 184 (H1), 334 (H2) and 441 (H3) DAP.

Parameters	Harvest	FW	FL	FD	PT	PW	PuW	JY	NF	PR	
CV_g	H1	13.40	7.98	3.96	10.87	16.47	13.86	8.14	13.10	17.07	
	H2	12.93	7.70	4.45	9.92	12.90	16.26	5.25	19.29	21.02	
	H3	16.08	9.42	5.67	4.78	20.84	13.60	12.80	18.93	12.94	
CV_e	H1	11.65	6.00	4.21	11.21	13.28	17.77	14.03	26.73	33.47	
	H2	15.96	6.36	5.78	15.75	18.43	23.57	15.91	24.11	26.61	
	H3	18.48	22.98	5.73	15.42	17.81	34.00	32.00	22.27	25.88	
CV_g/CV_e	H1	1.15	1.33	0.94	0.97	1.24	0.78	0.58	0.49	0.51	
	H2	0.81	1.21	0.77	0.63	0.70	0.69	0.33	0.80	0.79	
	H3	0.87	0.41	0.99	0.31	1.17	0.40	0.40	0.85	0.50	
σ_p^2	H1	884.73	0.69	0.19	1.23	372.04	119.12	21.95	51.12	2.31	
	H2	1683.43	0.82	0.31	1.10	406.32	342.70	27.86	113.61	5.44	
	H3	1511.15	4.25	0.38	1.18	638.81	215.99	69.29	1276.40	28.78	
% of σ_p^2	σ_g^2	H1	57.05	63.77	47.37	48.78	60.75	37.84	25.19	19.41	20.78
		H2	39.62	59.76	38.71	28.18	32.67	32.35	10.05	39.29	38.05
		H3	42.95	14.59	50.00	8.47	57.86	13.55	14.04	41.76	20.29
	σ_e^2	H1	42.95	36.23	52.63	52.03	39.25	62.16	74.81	80.58	78.79
		H2	60.38	40.24	61.29	70.91	67.33	67.65	89.95	60.71	61.76
		H3	57.05	85.65	50.00	91.53	42.14	86.45	85.96	58.24	79.74
h^2	H1	86.92	89.82	81.66	82.34	88.56	75.27	62.73	54.64	56.83	
	H2	76.64	87.98	74.91	66.74	70.81	70.51	35.81	76.39	75.50	
	H3	79.01	45.83	82.99	32.21	87.28	43.94	44.97	78.19	55.97	

FW: fruit weight; FL: fruit length; FD: fruit diameter; PT: peel thickness; PW: peel weight; PuW: pulp weight; JY: juice yield; NF: number of fruits; PR: productivity. CV_g : coefficient of genetic variation; CV_e : residual (experimental) coefficient of variation; CV_g/CV_e : ratio between the genetic and experimental coefficient of variation (CV_g); σ_p^2 : phenotypic variance; σ_g^2 : genetic variance; σ_e^2 : environmental variance; h^2 : heritability.

The CV_e ranged from 34.00% (PuW in H3) to 4.21% (FD in H1), the majority being considered medium (10 to 20%). Lower CV_e values were observed in H1, except for NF and PR, in which the values were higher (Table 1). The lack of fruiting uniformity in the H1 hybrids resulted in a higher CV_e , showing the variability in the precocity of production among the evaluated hybrids.

The parameter heritability ranged from 32.21 to 89.82% for PT (H3) and FL (H1), respectively. The highest values were observed in H1 for FW, FL, PT, PW, PuW and JY. For FD, NF and PR, the highest values were observed in the third and second evaluations, (Table 1). In general, H1 and H2 concentrated the highest heritabilities (62.73 to 89.82%) of the characteristics.

Correlation

There were 44 significant phenotypic correlations, with coefficients ranging from -0.74 to 0.96. Of these, 20.4% were very strong correlations ($0.90 < |r| < 1.0$), 52.3% were strong correlations ($0.60 < |r| \leq 0.90$) and 15.9% were medium ($0.30 < |r| \leq 0.60$) (Table 2). Of the 44 significant phenotypic correlations, 9.09% had negative coefficients. On the other hand, genotypic correlations showed 58 significant correlations, with coefficients ranging from -0.85 to 1.00, with 5.2% being classified as medium correlation, 41.4% strong correlation, 19% very strong and 10.3% of perfect correlation ($r = 1.00$) (Carvalho et al. 2004).

For all harvests, there were positive and significant genotypic correlations between FW \times (FL, FD, PW and PuW); FL \times (FD, PW and PuW) and NF \times PR. The PT only showed significance with the traits FW, FL, FD, PW and PuW (in the third harvest); with NF (in the second harvest) and with PR (in the second and third). In addition to PT, PR showed significance for positive correlations ranging from 0.56 to 1.00 with the third (H3) and first (H1) harvest, respectively of the traits FW, FL, FD and PW. For NF, the third harvest showed a negative and significant genetic correlation for FW (-0.82), FL (-0.65), FD (-0.75), PW (-0.85) and PuW (-0.68), while the first and second harvests had few correlated characteristics, the exception being NF \times JY (-0.57) in the first harvest and NF \times FL (-0.73) and NF \times PT (-0.66) in the second harvest (Table 2).

Table 2. Estimation of phenotypic (upper diagonal) and genotypic (lower diagonal) correlations for nine traits of 14 hybrids of sour passion fruit analyzed at 184 (H1), 334 (H2) and 441 (H3) DAP.

	Harvest	FW	FL	FD	PT	PW	PuW	JY	NF	PR
FW	H1		0.94**	0.95**	0.10 ^{ns}	0.91**	0.72**	-0.19 ^{ns}	0.02 ^{ns}	0.65*
	H2		0.86**	0.90**	0.12 ^{ns}	0.94**	0.93**	0.41 ^{ns}	-0.33 ^{ns}	0.36 ^{ns}
	H3		0.62*	0.96**	0.53*	0.94**	0.66*	-0.21 ^{ns}	-0.70**	0.09 ^{ns}
FL	H1	0.98**		0.86**	0.20 ^{ns}	0.94**	0.60*	-0.30 ^{ns}	0.10 ^{ns}	0.64*
	H2	0.88**		0.68**	0.25 ^{ns}	0.85**	0.74**	0.18 ^{ns}	-0.61*	-0.02 ^{ns}
	H3	0.94**		0.53*	0.31 ^{ns}	0.69**	0.19 ^{ns}	-0.35 ^{ns}	-0.35 ^{ns}	0.21 ^{ns}
FD	H1	0.96**	0.90**		0.17 ^{ns}	0.82**	0.80**	0.00 ^{ns}	-0.01 ^{ns}	0.59*
	H2	0.92**	0.70**		0.00 ^{ns}	0.86**	0.89**	0.44 ^{ns}	-0.28 ^{ns}	0.34 ^{ns}
	H3	1.00**	0.76**		0.51 ^{ns}	0.94**	0.54*	-0.34 ^{ns}	-0.64*	0.11 ^{ns}
PT	H1	0.14 ^{ns}	0.23 ^{ns}	0.27 ^{ns}		0.40 ^{ns}	-0.15 ^{ns}	-0.39 ^{ns}	0.27 ^{ns}	0.21 ^{ns}
	H2	0.06 ^{ns}	0.31 ^{ns}	-0.11 ^{ns}		0.18 ^{ns}	-0.04 ^{ns}	-0.30 ^{ns}	-0.44 ^{ns}	-0.39 ^{ns}
	H3	0.97**	0.96**	0.99**		0.64*	0.20 ^{ns}	-0.23 ^{ns}	-0.70**	-0.43 ^{ns}
PW	H1	0.93**	1.00**	0.86**	0.46 ^{ns}		0.52 ^{ns}	-0.39 ^{ns}	0.14 ^{ns}	0.67**
	H2	0.97**	0.89**	0.87**	0.10 ^{ns}		0.82**	0.20 ^{ns}	-0.24 ^{ns}	0.39 ^{ns}
	H3	0.96**	1.00**	0.96**	1.00**		0.43 ^{ns}	-0.40 ^{ns}	-0.74**	-0.06 ^{ns}
PuW	H1	0.77**	0.69**	0.88**	-0.06 ^{ns}	0.60*		0.53*	-0.16 ^{ns}	0.37 ^{ns}
	H2	1.00**	0.76**	1.00**	-0.10 ^{ns}	0.88**		0.70**	-0.28 ^{ns}	0.39 ^{ns}
	H3	0.67**	0.33 ^{ns}	0.59*	0.56*	0.45 ^{ns}		0.58*	-0.49 ^{ns}	0.09 ^{ns}
JY	H1	-0.24 ^{ns}	-0.35 ^{ns}	0.01 ^{ns}	-0.38 ^{ns}	-0.43 ^{ns}	0.44 ^{ns}		-0.31 ^{ns}	-0.31 ^{ns}
	H2	0.66**	0.16 ^{ns}	0.84**	-0.50 ^{ns}	0.31 ^{ns}	0.76**		-0.06 ^{ns}	0.30 ^{ns}
	H3	-0.51 ^{ns}	-0.75**	-0.67**	-0.49 ^{ns}	-0.68**	0.27 ^{ns}		0.06 ^{ns}	-0.05 ^{ns}
NF	H1	-0.02 ^{ns}	0.10 ^{ns}	-0.09 ^{ns}	0.42 ^{ns}	0.21 ^{ns}	-0.32 ^{ns}	-0.57*		0.76**
	H2	-0.39 ^{ns}	-0.73**	-0.33 ^{ns}	-0.66*	-0.26 ^{ns}	-0.31 ^{ns}	0.04 ^{ns}		0.75**
	H3	-0.82**	-0.65*	-0.75**	-1.00 ^{ns}	-0.85**	-0.68**	0.21 ^{ns}		0.63*
PR	H1	0.76**	0.80**	0.67**	0.35 ^{ns}	0.87**	0.39 ^{ns}	-0.54*	0.62*	
	H2	0.34 ^{ns}	-0.1 ^{ns}	0.35 ^{ns}	-0.63*	0.41 ^{ns}	0.45 ^{ns}	0.67**	0.74**	
	H3	-0.08 ^{ns}	0.19 ^{ns}	-0.01 ^{ns}	-0.82**	-0.23 ^{ns}	-0.11 ^{ns}	-0.14 ^{ns}	0.63*	

FW: fruit weight; FL: fruit length; FD: fruit diameter; PT: peel thickness; PW: peel weight; PuW: pulp weight; JY: juice yield; NF: number of fruits; PR: productivity. *, **, ns significant at 1 and 5% and not significant by the T-test, respectively.

Repeatability

For each evaluated characteristic, five measurements were carried out in four blocks. There was variation in the repeatability coefficient for all estimation methods, ranging from $\hat{r} = 0.03$ for peel thickness in H3 to $\hat{r} = 0.66$ for FL, in the first harvest cycle (H1). The magnitudes of the repeatability coefficients (\hat{r}) were identical between ANOVA and SACOR and also identical between PCCOV and PCCOR. However, based on the repeatability and determination coefficients (\hat{r} and R^2), there was a slight increase in the estimate when using PCCOV and PCCOR (Table 3).

Table 3. Estimates of the repeatability coefficient (\hat{r}) and its determination coefficients (R^2) and number of measurements required considering R^2 values of 85, 90 and 95% based on data from fruit traits analyzed at 184 (H1), 334 (H2) and 441 (H3) DAP of 14 sour passion fruit hybrids.

Character	Harvest	ANOVA/SACOR					PCCOV/PCCOR				
		\hat{r}	R^2	N° of measurement R^2 (%)			\hat{r}	R^2	N° of measurement R^2 (%)		
				85	90	95			85	90	95
FW	H1	0.60	88.50	3.68	5.84	12.34	0.61	88.91	3.53	5.60	11.84
	H2	0.38	76.03	8.93	14.18	29.95	0.42	78.32	7.84	12.46	26.30
	H3	0.42	78.58	7.72	12.26	25.88	0.47	81.55	6.40	10.18	23.58
FL	H1	0.66	90.63	2.93	4.65	9.82	0.66	90.79	2.87	4.56	9.63
	H2	0.57	86.87	4.28	6.79	14.35	0.57	87.01	4.23	6.72	14.18
	H3	0.58	87.75	3.95	6.28	13.26	0.59	87.95	3.88	6.16	13.01
FD	H1	0.48	82.06	6.19	9.87	20.76	0.51	83.64	5.54	8.80	18.58
	H2	0.35	72.64	10.67	16.95	35.78	0.38	75.47	9.21	14.63	30.88
	H3	0.29	67.74	10.02	15.91	33.58	0.33	70.81	8.44	13.41	28.31
PT	H1	0.56	86.58	4.39	6.97	14.72	0.57	87.11	4.19	6.66	14.06
	H2	0.28	66.33	14.38	22.84	48.22	0.31	69.66	12.33	19.59	41.36
	H3	0.03	12.64	19.58	31.09	65.64	0.29	67.30	13.76	21.86	46.12
PW	H1	0.58	87.26	4.14	6.57	13.87	0.61	88.62	3.40	5.87	12.2
	H2	0.29	67.18	13.84	21.97	46.39	0.37	74.93	9.48	15.06	31.78
	H3	0.49	83.00	5.80	9.21	19.46	0.50	83.41	5.63	8.95	18.89
PuW	H1	0.42	78.52	7.74	12.31	25.98	0.46	80.98	6.66	10.57	22.32
	H2	0.32	69.83	12.24	19.44	41.03	0.35	73.40	10.26	16.3	34.42
	H3	0.16	49.10	22.73	36.09	76.21	0.23	60.16	21.50	34.13	72.05
JY	H1	0.19	55.49	22.73	36.09	76.21	0.25	62.80	16.78	26.65	56.27
	H2	0.17	50.77	27.47	43.63	92.12	0.24	61.26	17.91	28.45	60.07
	H3	0.20	55.49	22.73	36.09	76.21	0.21	56.86	21.48	34.13	72.05
NF	H1	0.18	53.02	25.10	39.86	84.16	0.25	63.23	16.48	26.17	55.25
	H2	0.37	74.64	9.62	15.28	32.27	0.40	77.00	8.46	13.44	28.37
	H3	0.36	73.66	10.13	16.09	33.97	0.44	79.74	7.20	11.43	24.14
PR	H1	0.30	68.20	13.21	20.98	44.29	0.33	71.37	11.36	18.05	38.11
	H2	0.34	71.93	11.05	17.56	37.06	0.37	74.72	9.58	15.22	32.14
		0.19	53.75	24.38	38.73	81.76	0.24	61.31	17.88	28.39	59.94

\hat{r} : repeatability coefficient; R^2 : genotypic determination coefficient; ANOVA: analysis of variance; PCCOV: principal components obtained from the phenotypic variance and covariance matrix; PCCOR: principal components obtained from the correlation matrix; SACOR: structural analysis based on the theoretical eigenvalue of the correlation matrix or mean correlation; FW: fruit weight; FL: fruit length; FD: fruit diameter; PT: peel thickness; PW: peel weight; PuW: pulp weight; JY: juice yield; NF: number of fruits; PR: productivity.

Among the evaluated harvests, mean repeatability (\hat{r}) and determination (R^2) coefficients per harvest were $\hat{r} = 0.46$ and $R^2 = 78.21\%$ for H1; $\hat{r} = 0.36$ and $R^2 = 72.67\%$ for H2, and $\hat{r} = 0.33$ and $R^2 = 67.27\%$ for H3, indicating greater accuracy

of the information obtained in the first harvest due to less environmental variation (Table 3). On the other hand, traits such as JY, NF and PR in general showed lower results for the coefficients of repeatability and determination. For these variables, the effect of the harvest was not as great as observed for the other traits (Table 3), which may be related to the greater environmental variance of the harvests for these traits (Table 1).

Based on the PCCOV and PCCOR estimates, the number of measurements necessary to predict the real value of the physical characteristics of passion fruit and productivity when analyzed with 90% accuracy was 13 fruits in the first harvest, 16 in the second and 18 in the third harvest (Table 3). The smallest numbers of fruits (< 10.0) necessary to predict the real value with 90% precision were observed for the traits FW, FL, FD, PT and PW when evaluated in the first harvest based on in the PCCOV and PCCOR methods (Table 3).

A high number of samples with 90% accuracy according to the PCCOV and PCCOR methods was necessary in the first harvest to predict important characteristics, such as JY (n = 26) and PR (n = 18) (Table 3). This effect was also associated with high environmental variance and low heritability of these characteristics, especially in the first harvest (Table 1). Despite this, pulp weight and productivity showed high correlation with fruit weight in the first harvest, which is a characteristic that is easy to measure and thus can be used in evaluations, especially when many genotypes are evaluated (Table 2).

DISCUSSION

The evaluation of genotypes in breeding programs is time-consuming and costly, so reduction of the evaluation period without compromising accuracy of the information is extremely relevant (Neves et al. 2010; Cavalcante et al. 2017, 2018; Mendes and Ramalho 2018). Passion fruit production is low in the first year, tends to increase in the second year and decreases again in the third year (Pimentel et al. 2008). The study of parameters such as correlations and repeatability in different harvests can contribute to the identification of the production phase that provides greater gains in selection, in addition to allowing better inference of the characterization information based on the data of fruit traits over multiple harvests.

In this study, the measurements were performed 184 (H1), 334 (H2) and 441 (H3) days after planting (DAP). The genetic parameters varied according to the harvests (H1, H2 and H3) and CV_e , phenotypic (σ_p^2) and environmental variance (σ_e^2) values increased with harvests, while for genetic variance (σ_g^2), CV_g/CV_e ratio and heritability (h^2) the values decreased from harvest H1 to H3 and for CV_g there was little variation (H1 to H3) for most characters.

The changes in the estimated values for the evaluated parameters reflect the most pronounced influence of environmental effects on the characters of H2 to H3, consequently contributing to the different values observed in the parameters in H1 to H3. A strong reduction in heritability in the third harvest was observed for the parameters FL, PT, PuW and PR (Table 1) due to the greater environmental variation (σ_e^2). However, the values of h^2 and CV_g showed the existence of genetic variability and a favorable condition for selection, especially for important characters such as observed for H1 regarding FW, FL and PW, showing lower CV_e and high values at median CV_g and heritability values above 80%. For number of fruits and productivity, the second and third harvests were more suitable for selecting superior individuals, respectively.

The values obtained were within the reported range of 4.13 to 28.38% for CV_e (Silva et al. 2012). According to Oliveira et al. (2008), values below 20.48% are considered to denote good experimental accuracy for sour passion fruit. The studied population of passion fruit hybrids has already undergone a selective process, but still showed high CV_g in the first harvest compared to similar studies (Moraes et al. 2005; Oliveira et al. 2008; Silva et al. 2012). This reflects the potential of these hybrids to follow the stages of genetic improvement for the development of cultivars.

The values observed for the coefficients of genotypic correlation exceeded those of phenotypic correlation (Tables 1 and 2), reinforcing the presence of genetic variability in the studied population (Table 1). This result is advantageous to the selection process, since the genetic effects overlap with the environmental effects in the manifestation of phenotype (Silva et al. 2012). For the variables FW, FL, FD, PW and PuW, the pairwise correlations were high and positive in the three evaluation harvests, indicating that the correlations between the traits were maintained between the different periods.

The results obtained suggest that an increase in fruit weight would imply gains in length, diameter, PW and PuW at any time of selection, but the negative impact on the number of fruits is more evident in the third harvest.

High positive genetic correlations were observed between FL and FD, as well as between FD and PW. This last correlation is interesting, since PW is associated with lower JY, which is undesirable ($r = -0.68$), so this correlation allows the selection for lower PW based on the measurement of FL in the field. This type of correlation has also been reported in other studies (Oliveira et al. 2008; Alves et al. 2012). However, in general, the variables PT, PR and NF only showed a significant positive correlation [NF or PT x (FW, FL, FD, PW and PuW)] in H3 and negative correlation [PR x (FW, FL, FD, PW and PuW)] in H1.

Therefore, depending on the harvest, there may be no correlation between the traits, which can interfere with the gains when the selection of one variable is used for gain or loss in another (indirect selection). In addition, the presence of negative or positive correlations between certain traits of agronomic interest implies the use of selection methods that take them into account when choosing superior genotypes (Greco et al. 2015). Changes in values and type of correlations need to be evaluated experimentally to verify whether this association is transient, i.e., whether selection based on the first cycle will promote a different response in relation to another in the following cycles.

The repeatability analysis was performed within each harvest (H1 to H3) in order to verify the consistency of the fruit characters measured within the plots. Repeatability studies of *P. edulis* are scarce (Santos et al. 2010; Neves et al. 2010), especially in association with other analyses for phase selection. In this study, it was possible to select traits based on the coefficients of repeatability (\hat{r}) and determination (R^2) and more reliable estimates were obtained for the principal components based on PCCOV, and the principal components based on the PCCOR in the H1 in relation to H2 and H3. The values of \hat{r} were medium to high (Resende 2002) and a value above 0.5 for the repeatability coefficient is considered reasonable for data reliability (Shimoya et al. 2002). Probably the low performance presented by the method based on ANOVA is also associated with the environmental variations that affected the characters evaluated. This observation has also been reported in other studies involving ANOVA (Neves et al., 2010; Santos et al. 2010; Vasconcelos et al. 2000).

Besides that, the low coefficients of repeatability in the second and third harvests may be related to environmental variation, which leads to less stability of the characteristic, causing a need to obtain a greater quantity of measurements to achieve accuracy of the results (Lessa et al. 2014). Due to the greater environmental variation observed in the last two harvests, the repeatability coefficient was lower regardless of the method used and consequently the number of samples necessary to obtain 90% accuracy was greater in the second and third harvests.

The minimum number of necessary measurements observed by Santos et al. (2010) for the characters pulp, peel and fruit weight were 18, 10 and 12, respectively. These values were higher than those observed in this study (10, 5 and 5, respectively) in the first harvest to predict the real value of the genotypes with 90% accuracy by PCCOV. Neves et al. (2010), using the same method, found that 15 and 16 measurements per genotype for fruit weight and pulp weight would be necessary to reach a determination coefficient of 90%. This result may be associated with the experimental conditions and the period of sampling and evaluation of the physical characteristics of the fruits, since an average increase of 32% was observed in the number of fruits necessary to obtain 90% accuracy in the third evaluation compared to the first by the PCCOV method (Table 3).

The genetic parameters differed significantly depending on the harvest, with high values for the first harvest, particularly genetic variance and heritability of the physical characteristics of fruits. This shows that the selection criteria, considering the three evaluation periods (harvests at 184 [H1], 334 [H2] and 441 [H3] DAP), can change, so the selection made at different times can result in different responses to selection.

Evaluations performed in the first harvest reduced the time spent in the breeding program to obtain superior individuals, meaning greater efficiency in the process of selection and validation of genetically superior genotypes (Santos et al. 2010). However, Pimentel et al. (2008) observed that the second year of production (450 to 660 DAP) expressed greater correlations than the first cycle (150 to 330 DAP), due to the unevenness in the initial development of plants under field conditions, which can interfere in productivity in the first harvest. However, in general, greater heritability, genotypic variance, genotypic correlation and repeatability (\hat{r}) and determination (R^2) coefficients were observed and less variance and number of samples

required for 90% accuracy in H1 (184 DAP) under the evaluation conditions of this study. This result is similar to that reported by Cavalcante et al. (2017), who obtained the highest average heritability (h^2) for fruit production in the first year of cultivation, while fruit number and fruit weight were high both in the first year and the full cycle.

The first harvest at 184 DAP under the conditions of this study can be used for the selection of superior individuals for gains in most of the characteristics related to the fruit by presenting low environmental variations and high heritabilities, accelerating the selection process. The correlations between the traits changed according to the evaluation cycle, however, the correlations between the traits FW, FL, FD, PW and PuW were more stable in the different harvests. Through the repeatability analysis based on the principal components of covariance and correlation, it was possible to estimate a sample of 13 fruits per hybrid for prediction, with accuracy of 90% for the physical traits of yellow passion fruit.

CONCLUSION

The evaluated genetic parameters showed different behavior depending on the time of evaluation of the characters of the fruits and production. The environmental component was more pronounced in the phenotypic expression of most of the characters in the harvests 334 (H2) and 441 (H3) DAP, thus contributing to the lowest estimate of genetic components in the evaluated population. With exception of NF (H3) and PR (H2), the evaluations carried out at 184 DAP (H1) showed the highest values of the genetic parameters. Due to the wide variability in the passion fruit sour hybrids (*P. edulis*), for better accuracy in the measurements of the evaluated characters, it is necessary to evaluate at least 13 fruits to predict the real value of the genotypes in the first harvest with 90% accuracy.

AUTHORS' CONTRIBUTION

Conceptualization: Jesus O. N., Lima L. K. S., Souza, P. U. and Girardi E. A.; Methodology: Lima L. K. S. and Jesus, O. N. Investigation: Souza, P. U. Writing – Original Draft: Jesus, O. N., Lima, L. K. S., Souza P. U. and Girardi E. A. Writing – Review and Editing: Jesus O. N. and Lima L. K. S.; Funding Acquisition: Jesus O. N.; Resources: Jesus O. N.; Supervision: Girardi E. A.

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Data sharing is not applicable.

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