

Desempenho e repetibilidade de características de frutos de acessos de *Physalis angulata* L..

Arsene Mariano Sebastien Toupe (✉ soloronny11@gmail.com)

Universidade Estadual de Feira de Santana <https://orcid.org/0000-0001-5318-8551>

Jefferson Souza Lima

State University of Feira de Santana: Universidade Estadual de Feira de Santana

Ian de Oliveira Souza

State University of Feira de Santana: Universidade Estadual de Feira de Santana

Erison Martins de Souza

State University of Feira de Santana: Universidade Estadual de Feira de Santana

Adriana Rodrigues Passos

State University of Feira de Santana: Universidade Estadual de Feira de Santana

Luiz Cláudio Costa Silva

State University of Feira de Santana: Universidade Estadual de Feira de Santana

Research Article

Keywords: Camapu, Groundcherry, Number of Measurements, Plant Breeding, Repeatability Coefficient

Posted Date: June 28th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2981707/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License. [Read Full License](#)

Version of Record: A version of this preprint was published at Genetic Resources and Crop Evolution on January 9th, 2024. See the published version at <https://doi.org/10.1007/s10722-023-01838-8>.

Abstract

The *Physalis angulata* L. species, better known in Brazil as camapu, is most found in the northern regions of the country. It is used for human consumption, in medicine and as an ornamental plant. Because of its potential economic and nutritional value, studies have carried out to know the genetic variability of fruit traits. Repeatability is the fraction of phenotypic variation that is due to permanent genetic and environmental factors. The estimation of repeatability coefficient allows breeders to estimate the ideal number of measurements for a trait. This work aims to evaluate the performance of *P. angulata* accessions and to estimate the coefficients of repeatability and minimum number of repetitions for fruit characteristics, in two environments and two seasons. The present work was conducted at the Horto Florestal Experimental Unity of Universidade Estadual de Feira de Santana, using seven accessions of *P. angulata* from the Germplasm Collection of LAGEM/UEFS. Four experiments were conducted, two in the experimental field and two in the greenhouse, in an entirely randomized design with 24 replicates, using five accessions in the first two experiments, and six accessions in the last two in each environment, totaling 120 and 144 experimental units, respectively. The characteristics number of fruits per plant (NFP), soluble solids content (SSC), longitudinal diameter (LFD) and transversal diameter (TFD) of the fruits, and average fruit mass (AFM) were evaluated. Data were submitted to analysis of variance (ANOVA) and estimates of repeatability coefficients were obtained by ANOVA, principal components (PC), and structural analysis (SA) methods. There was significant variance among accessions for the characteristics LFD, TFD, AFM and SSC in the experimental field, and for TFD, LFD NFP in the greenhouse. Heritability ranged from 61.63–91.91% in both environments. PC showed the highest estimates of repeatability coefficient. The repeatability and determination coefficients by PC analysis ranged from TFD ($r = 0.51$; $R^2 = 96.19\%$) to SSC ($r = 0.72$; $R^2 = 98.47\%$) in the field, and from NFP ($r = 0.40$; $R^2 = 93.92\%$) to LFD ($r = 0.51$; $R^2 = 79.38\%$) in the greenhouse. Twenty measurements can achieve 95% and 90% reliability for experimental field and greenhouse experiments, respectively, for the evaluated traits.

INTRODUCTION

The genus *Physalis* belongs to the family Solanaceae, which counts more than 2300 species (Jagatheeswari 2014; Medina-Medrano et al. 2015). Its center of diversity is in South and North America and is found particularly in tropical and subtropical countries around the world (Mexico, Colombia, Brazil, China, Japan and some African countries; Silva Junior et al. 2022). Several species of the *Physalis* genus are object of studies, such as *Physalis alkekengi* L., *Physalis angulata* L., *Physalis ixocarpa* Brot., *Physalis minima* L., *Physalis peruviana* L. and *Physalis philadelphica* Brot. (Fukushima et al. 2016 Shenstone et al. 2020). In Brazil, *P. angulata* has stood out in recent years because of its economic, food, medicinal and pharmacological potentials (Silva et al. 2005; Muniz et al. 2015).

P. angulata, commonly known as camapu in Brazil or groundcherry in English countries, is an herbaceous plant found in many regions in Brazil, including those that are arid or semiarid, growing spontaneously, being considered a weed in some regions (Stehmann and Knapp 2020; Balah and Balah, 2022). It has a high germination rate and a large number of seeds. The fruits are good source of vitamin C, minerals e many secondary phenolic compounds (Oliveira et al. 2011). *P. angulata* can be produced in small areas, and is a potential source of extra income for farmers (Ordoñez et al. 2022). In addition to the great nutritional value, camapu has several compounds with medicinal interest, the main one being physalin (Sholehah et al.; 2021).

The study of genetic diversity is an essential tool for identifying more divergent genotypes, and is also used for the formation of hybrids (Gonçalves et al. 2008). The species camapu is a facultative autogamous plant that has hermaphrodite flowers and has not yet been completely domesticated. Despite the potential of the species, research on genetic improvement of camapu is still incipient. In fact, there is still no genetic material with high productivity already developed (Trevisani, 2015).

Previously studies with *Physalis* species at the Universidade Estadual de Feira de Santana (UEFS) show that there is variability for many fruit traits. However, large residual variance has been observed in these studies, especially with *P. angulata* (Orellana et al. 2021; Farias et al. 2022). In this sense, the estimate of repeatability coefficient of characteristics of interest is a tool that can assist in breeding. Repeatability can be defined as the correlation between measurements on the same individual, whose evaluations were repeated in time and space (Kemptorne, 1973; Cruz et al. 2010). According to Falconer (1987), the repeatability coefficient represents the upper limit that heritability can reach. This coefficient allows to predict the number of measurements needed to reach a certain value of confidence for a given character in the same genotype, leading to a reduction in time and labor cost (Cruz et al. 2010).

In this sense, the objective of this work was to evaluate the performance of *P. angulata* accessions and to estimate repeatability coefficients and the minimum number of repetitions for fruit traits, in two locations and two years.

MATERIAL AND METHODS

The present work was carried out at Horto Florestal Experimental Unity, belonging to the Universidade Estadual of Feira de Santana (Horto Florestal/UEFS), located at Feira de Santana city, in the semiarid region of Bahia State, Brazil, whose geographic coordinates are 12° 16' 10.14" south latitude, 38° 56' 17.51" west longitude and 257 m altitude. The average annual temperature is 23.5°C, and the maximum temperature exceeds 35°C. Soil analysis was performed prior to the experiments.

Seven accessions (BASP-01; BASP-02; PEIT-01, BAAN-04; BALJ-01; BAFS-01; RJRJ-01) of *P. angulata* (Table 1) from the Germplasm Collection of the Laboratory of Molecular Genetics (LAGEM/UEFS) were used. The seeds of the accessions were stored at low temperature and humidity.

Table 1
Information about the *Physalis angulata* L. accessions used in the experiments.

Access name	City and State of Collection	Geographic Coordinates
BASP-01	Serra Preta-BA	Latitude 12° 2'12.93 South and Longitude 39° 16'8.69" West.
BASP-02	Serra Preta-BA	Latitude 12° 2'12.77 South and Longitude 39° 16'8.28" West.
PEIT-01	Itapetim-PE	Latitude 7° 22' 39" South and Longitude 37° 11' 26" West.
BAAN-04	Anguera-BA	Latitude 12° 09' 04" South and Longitude 39° 14' 47" West, altitude 235 meters.
BALJ-01	Lajedinho-BA	Latitude 12°22'00" South and Longitude 40°54'00" West, altitude 640 meters.
BAFS-01	Feira de Santana-BA	Latitude 12° 16' 24" South and Longitude 38° 57' 20" West, altitude 232 meters.
RJRJ-01	Rio de Janeiro-RJ	Latitude 22°54'10" South and Longitude 43°12'27" West.
BA: Bahia State; PE: Pernambuco State; RJ: Rio de Janeiro State.		

Four experiments were conducted, at two different times. Two experiments (one in the field and one in the greenhouse) started in August 23, 2021 and finished in January 25, 2022 (Exp1). Another two experiments (one in the field and one in the greenhouse) started in September 18, 2022 and finished in January 15, 2023 (Exp2).

The seeds of each accession were placed in petri dishes with distilled water and were sown 24h later in disposable cups containing local soil. Thinning was performed 15 days after sowing, with the most vigorous seedlings remaining. The seedlings were maintained under shaded conditions with daily manual watering in the early morning and late afternoon. The experiments were conducted in an entirely randomized design with 24 repetitions, spacing of 1.0 m between rows and 0.5 m between plants in both experimental field and greenhouse. The seedlings were transplanted after reaching about 20 to 25 cm in length.

In Exp1, 120 plants of five accessions (BASP-01, BASP-02, PEIT-01, BAAN-04 and BALJ-01) were transplanted to the experimental field, with drip irrigation. Fertilization was performed with urea (2.2 g/hole), potassium chloride (2.15 g/hole) and single superphosphate (11.25 g/hole), according to the recommendations for cherry tomato culture. After 45 days, top-dressing fertilization was carried out with urea (5.86 g/hole) and potassium chloride (4.3 g/hole). For phytosanitary control, virgin lime was used around the experimental areas, to combat African snails, Bordeaux mixture to combat powdery mildew, and a homemade solution made of 200 ml of 70% alcohol, 200 ml of vinegar and 1 liter of water, to control mites. In the greenhouse, 120 plants of the same accessions were transplanted in 10 L pots, each containing sieved local soil (6 L), vegetal substrate (2 L). Fertilizing and phytosanitary control was made as same as in experimental field.

In Exp2, 144 plants of six accessions (BASP-01, BAFS-01, RJRJ-01, PEIT-01, BALJ-01 and BAAN-04) were transplanted to the experimental field, with drip irrigation. Fertilization was performed with urea (4.31 g/hole), potassium chloride (6.43 g/hole) and single superphosphate (16.82 g/hole), according to the recommendations for cherry tomato culture. After 45 days, top-dressing fertilization was carried out with urea (5.78 g/hole) and potassium chloride (4.81 g/hole). In the greenhouse, 144 plants of the same accessions were transplanted, applying similar fertilization as in the field, in 10 L pots containing 6 L of sieved soil and 2 L of vegetal substrate. Phytosanitary control was carried out as the same as in Exp1.

Three harvests were made in all environments. In the field, the first 60 days after transplanting (DAT); the second, 70 DAT and the last 85 DAT. In the greenhouse, the first harvest occurred 50 DAT, the second 60 DAT and the last 65 DAT. The fruits from the three harvests were stored together. The evaluations of the fruits were performed after they reached the physiological maturity stage. Ten fruits with the largest size and with yellow calyx coloration (maturation point indicator) were evaluated from each plant for the following evaluations.

- Number of fruits per plant (NFP), making a count of the total amount of fruits per plant.
- Average fruit mass (AFM), measured with a precision scale and expressed in grams.
- Fruit longitudinal diameter (LFD), measured with a digital pachymeter and expressed in millimeters.
- Fruit transverse diameter (TFD), measured with a digital pachymeter and expressed in millimeters.
- Soluble solids content (SSC), determined by digital refractometer, and expressed in °Brix units.

The data was subjected to analysis of variance (ANOVA) and estimates of variance, heritability and coefficient of variance. The estimates of the repeatability coefficients were obtained by the methods of ANOVA; principal components (PC), based on the matrix of correlations (PC-cor) or covariances (PC-cov); and structural analysis (SA), based on the matrix of correlations. All analyses were performed with GENES software (CRUZ, 2013), following the statistical model below.

$$Y_{ij} = \mu + G_i + (E_p + GE_p)_i + (E_t + GE_t)_{ij}, \text{ where,}$$

- Y_{ij} : phenotypic value of the characteristic for the i-th individual at the j-th time;
- μ : general average;
- G_i : genotypic effect on the characteristic of the i-th individual;
- $(E_p + GE_p)_i$: permanent environmental effect on the characteristic in the i-th individual.

- $(E_i + GE_{ij})$: temporary effect, or localized effect, of the j-th environment on the i-th individual.

Repeatability coefficient was calculated by the following formula:

$$r = (\sigma^2_G + \sigma^2_E) / \sigma^2_p, \text{ where:}$$

r = coefficient of repeatability

σ^2_G = estimated between genotype variance

σ^2_E = estimate of experimental error variance

σ^2_p = estimated phenotypic variance

The number of measurements required to predict the true value of the genotype was calculated with the formula below.

$$N_0 = [R^2 \cdot (1-r)] / (1-R^2) \cdot r \text{ where:}$$

N_0 = minimum number of measurements required

R^2 = coefficient of determination

r = coefficient of repeatability

The coefficient of determination was estimated by the following formula:

$$R^2 = N \cdot r / 1 + r (N-1) \text{ where,}$$

R^2 = coefficient of determination

r = coefficient of repeatability

N = number of measurements performed

RESULTS

The summary of the analysis of variance of two experiments in two different seasons of *P. angulata* cultivation in experimental field (Exp1-EF and Exp2-EF) at Horto Florestal/UEFS are shown in Table 2. All the traits showed significant variation between the treatments except NFP in Exp1-EF and NFP and SSC in Exp2-EF.

Table 2

Summary of variance analysis for the characteristics longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), average fruit mass (AFM), number of fruits per plant (NFP) and soluble solids content (SSC), for 5 accessions (Exp1) and 6 accessions (Exp2) of *P. angulata* grown in experimental field. Feira de Santana (BA), 2023.

Exp1-EF						
	DF	MS				
Source of Variation		LFD (mm)	TFD (mm)	AFM (g)	NFP	SSC (°Brix)
Treatments	4	5.89*	9.12**	1.35**	5084.6 ^{ns}	18.59**
Residual	80	1.67	2.23	0.17	2355.5	4.26
Mean		13.65	12.86	1.82	79.8	13.58
CV		9.46	11.62	22.3	60.81	15.19
Phenotypic Var.		0.46	0.71	0.10	397.87	1.40
Environmental Var.		0.13	0.17	0.10	184.32	0.33
Genotypic Var.		0.33	0.57	0.90	213.55	1.12
Heritability (%)		71.65	75.50	87.73	-	77.06
Exp2-EF						
Treatments	5	3.89*	9.11**	0.76**	14357.7 ^{ns}	1.56 ^{ns}
Residual	129	1.23	0.73	0.06	9584.74	1.26
Mean		11.95	12.58	1.39	182.65	12.42
CV		9.30	6.82	18.36	53.60	9.04
Phenotypic Var.		0.17	0.41	0.03	656.20	0.07
Environmental Var.		0.05	0.03	0.003	438.05	0.05
Genotypic Var.		0.12	0.40	0.03	218.14	0.01
Heritability (%)		68.25	91.91	91.44	-	-
Exp1: Experiment 1; Exp2: Experiment 2; DF: Degrees of freedom; MS: Mean square; CV: Coefficient of variation; EF: Experimental field						
*significant at 5% probability; **significant at 1% probability; ^{ns} not significant						

The coefficient of variation (CV) of AFM showed a higher variation (22.3% in Exp1-EF and 18.36% in Exp2-EF), compared to the others. The lowest CV value was recorded with the traits LFD (9.46% in Exp1-EF) and TFD (6.82% in Exp2-EF). The mean for the LFD trait in Exp1-EF (13.65 mm) was higher compared to that of Exp2-EF (11.95 mm). However, for TFD, these means were similar (12.86 mm and 12.58 mm in Exp1-EF and Exp2-EF, respectively). We observed that AFM in Exp1-EF (1.82g) was higher than in Exp2-EF (1.39g). For the field experiments, SSC showed significant variation only in Exp1-EF, with an average of 13.58 °Brix and a coefficient of variation of 15.19%.

The values of heritability coefficient (h^2) ranged from 68.25% (LFD) to 91.91% (TFD), both at Exp2-EF. High values of heritability were found in Exp1-EF for TFD (87.73%) and SSC (77.06%), and in Exp2-EF for AFM (91.44%) and for TFD (91.91%).

The results of the analysis of variance of two experiments evaluated at different seasons in greenhouse (Exp1-GH and Exp2-GH) are presented in Table 3. All evaluated characteristics showed significant variation, except AFM in Exp1-GH and SSC in Exp2-GH. The lowest coefficient of variation was found for LFD (9.46%) in Exp1-GH, and for TFD (6.82%) in Exp2-GH. Exp1-GH showed the highest values of fruit diameters (LFD 12.29 mm and TFD 11.98 mm). For NFP, the highest mean value was found in Exp2-GH, with 97.04 fruits per plant and a coefficient of variation of 34.12%. The values of heritability coefficient ranged from 61.63% (TFD) to 78.74% (LFD), both at Exp2-GH. Tables 4 (experimental field) and 5 (greenhouse) present the results of the estimates of the repeatability coefficients (r) of Exp1 and Exp2. The repeatability coefficients and determination coefficients (R^2) estimated by the principal components, based on PC-cov and PC-cor matrices, presented the highest values in relation to those estimated by ANOVA and the structural analysis from the correlation matrices, for all traits. In the experimental field, the repeatability coefficients ranged from 0.28 to 0.72. The highest values of these coefficients in Exp1 and Exp2 of experimental field were recorded respectively with the characters SSC ($r = 0.72$; $R^2 = 98.47\%$) and TFD ($r = 0.51$; $R^2 = 96.19\%$).

Table 3

Summary of variance analysis for the characteristics longitudinal fruit diameter (LFD), transversal fruit diameter (TFD), average fruit mass (AFM), number of fruits per plant (NFP) and soluble solids content (SSC), for 5 accessions (Exp1) and 6 accessions (Exp2) of *P. angulata* cultivated in greenhouse, UEFS, Feira de Santana (BA), 2023.

(Exp2) of <i>P. angulata</i> cultivated in greenhouse, OLFS, Feira de Santana (BA), 2023.						
	DF	MS				
Exp1-GH						
SOURCE OF VARIATION		LFD (mm)	TFD (mm)	AFM (g)	NFP	SSC (°Brix)
TREATMENTS	4	11.05**	11.69**	0.17 ^{ns}	367.07**	16.62*
RESIDUAL	81	2.83	3.23	0.29	89.33	5.78
MEAN		12.29	11.98	1.25	14.39	9.23
CV		13.69	14.99	43.44	65.65	26.04
PHENOTYPIC VAR.		0.84	0.90	0.01	27.96	1.30
ENVIRONMENTAL VAR.		0.21	0.24	0.02	6.80	0.40
GENOTYPIC VAR.		0.62	0.64	0.00	21.15	0.80
HERITABILITY (%)		74.39	72.36	-	75.66	65.19
Exp2-GH						
TREATMENTS	5	8.78**	3.06*	0.22**	3660.12**	1.40 ^{ns}
RESIDUAL	134	1.89	1.17	0.05	1096.69	1.12
MEAN		12.02	11.20	1.21	97.04	12.06
CV		11.44	9.68	19.76	34.12	8.78
PHENOTYPIC VAR.		0.40	0.13	0.009	158.70	0.06
ENVIRONMENTAL VAR.		0.08	0.05	0.002	47.55	0.04
GENOTYPIC VAR.		0.30	0.08	0.007	111.14	0.01
HERITABILITY (%)		78.44	61.63	74.25	70.03	-
Exp1: Experiment 1; Exp2: Experiment 2; DF: Degrees of freedom; MS: Mean square; CV: Coefficient of variation; GH: Greenhouse						
*significant at 5% probability; **significant at 1% probability; ^{ns} not significant						

Table 4

Coefficients of repeatability (r) and of determination (R^2) and number of measurements required (N^0) for seven fruit traits from accessions of *P. angulata* in experimental field at Horto Florestal/UEFS, Feira de Santana, (BA), 2023.

	r	R ²		N ⁰ (80%)		N ⁰ (85%)		N ⁰ (90%)		N ⁰ (95%)		N ⁰ (99%)		
Estimation method	Longitudinal Fruit Diameter													
	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2
Anova	0.20	0.11	86	75.12	15.99	31.78	22.65	45.02	35.98	71.49	75.96	150.96	395.83	786.60
PC-covariance	0.47	0.32	95.54	92.13	4.47	8.20	6.40	11.61	10.07	18.44	21.26	38.94	110.78	202.94
PC-correlation	0.46	0.28	95.40	90.28	4.63	10.32	6.55	14.63	10.41	23.24	21.98	49.06	114.53	255.65
SA-correlation	0.23	0.12	88.16	77.46	12.88	27.92	18.25	39.56	29	62.83	61.21	132.65	318.96	474.07
	Transversal Fruit Diameter													
Anova	0.23	0.36	87.79	93.33	13.34	7.18	18.91	10.17	30.03	16.15	63.40	34.10	330.37	177.71
PC-covariance	0.51	0.51	96.26	96.19	3.73	3.79	5.28	5.38	8.39	8.54	17.71	18.04	92.30	94.01
PC-correlation	0.44	0.46	95.02	95.43	5.02	4.58	7.11	6.50	11.03	10.32	23.85	21.79	124.30	113.57
SA-correlation	0.27	0.36	90.26	93.34	10.36	6.84	14.67	9.69	23.31	15.40	49.21	32.51	256.42	169.40
	Average Fruit Mass													
Anova	0.38	0.35	93.64	92.69	6.51	7.56	9.22	10.71	14.64	17.02	28.09	35.94	161.11	187.27
PC-covariance	0.59	0.51	97.24	96.17	2.71	3.80	3.84	5.41	6.11	8.60	12.89	18.15	67.21	94.60
PC-correlation	0.55	0.49	96.76	95.89	3.21	4.10	4.55	5.82	7.28	9.24	15.25	19.51	79.50	101.67
SA-correlation	0.44	0.36	95.11	93.15	4.93	7.04	6.99	9.98	11.10	15.86	23.44	33.48	122.15	174.46
	Number of Fruits per Plant													
Anova	0.14	0.03	79.71	45.25	24.42	116.14	34.59	164.52	54.95	251.31	116	551.60	604.46	2875.46
PC-covariance	0.48	0.43	95.77	94.80	4.23	5.25	6.02	7.44	9.53	11.83	20.02	24.97	104.85	130.12
PC-correlation	0.36	0.34	93.30	92.56	6.88	7.71	9.76	10.92	15.53	17.35	32.72	36.63	170.50	190.90
SA-correlation	0.18	0.03	84.30	44.43	17.87	120.06	25.32	170.08	40.21	270.13	84.9	570.28	442.40	2971.50
	Soluble solids content													
Anova	0.21	0.02	87.10	32.85	14.21	196.16	20.13	277.89	32	441.36	68	931.77	351.77	4855.05
PC-covariance	0.72	0.34	98.47	92.77	1.48	7.48	2.10	10.59	3.33	16.82	7.05	35.52	36.73	185.07
PC-correlation	0.51	0.34	96.27	92.59	3.71	7.68	5.26	10.88	8.36	17.28	17.65	36.48	91.97	190.11
SA-correlation	0.28	0.03	90.70	46.74	9.83	109.37	13.93	154.95	22.13	246.08	46.73	519.52	243.51	2706.97
PC: principal components; SA: structural analysis														

By PC-cov measurement number estimation method in experimental field, approximately 7 to 21 measurements are needed for most of the evaluated traits in Exp1 for 95% reliability level, with the trait SSC having the smallest measurements number and LFD having the largest. In Exp2, 18 to 38 measurements are needed to reach 95% reliability, being AFM with the smallest measurement number and LFD with the largest. For PC-cor method, these measurements numbers range from 13 to 22 to reach 95% reliability, being AFM with the smallest and LFD with the largest measurement number in Exp1. In Exp2, they range from 20 (AFM) to 49 (LFD) to reach the same reliability.

In the greenhouse (Table 5), the repeatability coefficients ranged from 0.32 to 0.51. The highest values of the repeatability and determination coefficients in Exp1 and Exp2, estimated by the principal components (covariance and correlation), were recorded respectively for the characters SSC ($r = 0.41$; $R^2 = 94.54\%$) and LFD ($r = 0.51$; $R^2 = 79.38\%$). Highest values of this coefficient in Exp1 were recorded to the traits SSC (0.41) and NFP (0.40). In Exp2, the highest values were LFD (0.51), AFM (0.47) and NFP (0.42). The r values were higher in Exp2 comparing to Exp1. In Exp, we found numbers of measurements varying from 26 to 40 to reach 95% reliability level with SSC characteristic having the lowest number and TFD having the highest. For Exp2, these numbers ranged from 18 (LFD) to 30 (TFD).

Table 5
Coefficients of repeatability (r) and of determination (R²) and number of measurements required (N^o) for seven fruit traits from accessions of *P. angulata* in greenhouse at Horto Florestal/UEFS, Feira de Santana, (BA), 2023.

	r	R ²		N ⁰ (80%)		N ⁰ (85%)		N ⁰ (90%)		N ⁰ (95%)		N ⁰ (99%)		
Estimation method	Longitudinal Fruit Diameter													
	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2	Exp1	Exp2
Anova	0.21	0.14	86.04	79.42	14.71	24.86	20.85	35.22	33.11	55.90	69.90	118.10	364.30	615.40
PC-covariance	0.34	0.51	92.56	79.38	7.71	3.80	10.92	5.35	17.35	8.50	36.63	17.89	190.87	93.50
PC-correlation	0.36	0.33	93.34	98.30	6.84	8.01	9.69	11.30	15.39	18.01	32.53	38.02	169.41	198.09
SA-correlation	0.28	0.09	90.69	96.21	9.84	37.31	13.90	52.8	22.15	83.90	46.76	177.30	243.60	923.58
	Transversal Fruit Diameter													
Anova	0.20	0.07	86.04	63.44	15.56	55.31	22.05	78.36	35.02	124.41	73.94	262.71	385.31	1369
PC-covariance	0.32	0.38	91.97	93.81	8.32	6.32	11.86	8.96	18.83	14.23	39.76	30.05	207.17	156.60
PC-correlation	0.33	0.27	92.08	90.01	8.24	10.64	11.68	15.08	18.56	23.95	39.18	50.57	204.15	263.40
SA-correlation	0.24	0.02	88.62	40.76	12.32	139.51	17.46	197.61	27.73	313.81	58.54	662.59	305.07	3452.50
	Average Fruit Mass													
Anova	0.11	0.11	21.56	75.57	349.12	31.02	495.49	43.94	785.51	69.79	1658.21	147.35	8640.39	767.79
PC-covariance	0.38	0.47	93.87	95.58	6.26	4.43	8.87	6.28	14.09	9.97	29.74	21.06	155	109.83
PC-correlation	0.34	0.36	92.72	93.19	7.53	7.01	10.67	9.93	16.91	15.78	35.79	33.31	186.49	199.68
SA-correlation	0.05	0.08	56.18	69.54	74.8	42.03	106	59.55	168.59	95.41	355.59	199.60	1852.79	1040.50
	Number of Fruits per Plant													
Anova	0.25	0.10	88.95	73.36	11.91	34.85	16.88	49.37	26.80	78.41	56.59	165.51	294.89	862.59
PC-covariance	0.40	0.42	93.92	94.53	5.90	5.55	8.37	7.86	13.28	12.48	28.04	26.50	146.15	137.41
PC-correlation	0.39	0.35	94.2	92.85	6.23	7.38	8.79	10.46	13.81	16.61	29.49	35.07	153.65	182.73
SA-correlation	0.28	0.08	90.69	69.38	9.86	42.36	13.55	60.01	22.16	95.32	46.78	201.23	243.69	1048.50
	Soluble solids content													
Anova	0.20	0.14	85.88	26.93	15.77	260.35	22.35	368.81	35.51	585.79	74.94	1236.69	390.50	6443.71
PC-covariance	0.39	0.44	93.91	94.97	6.23	5.07	8.83	7.19	14.03	11.42	29.62	24.11	154.34	125.61
PC-correlation	0.41	0.38	94.54	83.74	5.54	6.40	7.83	9.07	12.47	14.41	26.32	30.42	137.17	158.47
SA-correlation	0.21	0.20	87.01	33.73	14.32	188.59	20.28	267.11	32.22	424.21	68.02	885.61	354.39	4666.49
PC: principal components; SA: structural analysis														

DISCUSSION

Of the five characteristics evaluated, only TFD and LFD showed significant variation in all environments. AFM showed significant variation in three environments, and NFP and SSC in two environments. Considering that four accessions were common in all experiments, we believe that excessive environmental variance was the main cause of not finding significant difference between the accession for AFM, NFP and SSC in some environments. Thus, there is potential for genetic improvement, but it is necessary to better control the environment, through improved cultural treatments, irrigation system and control of pests and diseases. Furthermore, the addition of new accessions from different origins can increase the genetic variability.

Fruits that present larger size and mass are more favored by commerce (Melo et al. 2017). Oliveira et al. (2011), evaluating physical, physicochemical characteristics and technological potential of camapu fruits, found mean values of 4.33 g, 21.7 mm and 18.6 mm, respectively, for the characteristics fruit weight, length and width. Tanan et al. (2018) found for *P. angulata* the average of 16.3 mm for transverse diameter and 15.4 mm longitudinal diameter. In the present study, mean values of close to 13 mm (TFD and LFD) and 1.4–1.8 g (AFM) were found in the experimental field, and value close to 12 mm (TFD and LFD) and 1.2 g (AFM) were found in the greenhouse. The differences found between these values in the all environments may be due to the environmental variation found in these locations, including attacks by powdery mildew on the plants in Exp1-GH, as well as the possible effect of the genotype x environment interaction.

Working with the same species in the same location, Silva et al. (2008) found an average of 8.5 mm (TFD), 8.6 mm (LFD) and 0.38 g (AFM), with coefficient of variation of 15.18%, 15.09% and 40.77%, respectively. However, Rufato et al. (2013) reported that the ripe fruit of *P. angulata* has an average diameter up to 15 mm, values higher than those found in the experiments of this study. Evaluating the fruits of *P. peruviana*, Rodrigues et al. (2014) found mean values of transverse and longitudinal diameters of 16.89 mm and 18.17 mm, respectively, in addition to a mean fruit mass of 2.843 g. It is notable that the fruit size of *P. peruviana* is larger than *P. angulata*.

Working on diallel analysis for morphoagronomic descriptors of *P. angulata* hybrids, Farias et al. (2022) found no significant genetic variance for weight of fruits per plant and NFP traits, but found genetic variation for plant height and SSC traits. The authors suggested that genetic variation within accessions and environmental variation may have been the reason for high residual variation in NFP. In the present work, NFP showed significant genetic variation in the greenhouse in both experiments, with a higher mean in Exp2. One of the factors that may have led to a better result in our study is the number and composition of the experimental plots. In the present study, the experiments were carried out with 24 repetitions with one plant per experimental plot, while Farias et al. (2022) used three repetitions with four plants per experimental plot. Our results suggest that is better to invest in a greater number of repetitions than experimental plots with more plants.

It can be seen that the AFM trait showed significant variation at 1% of probability in both experiments in the field. On the other hand, in the greenhouse, there was significant variation only in Exp2. This result indicates the possibility of selection among the evaluated accessions to advance the improvement of the species, based on this characteristic, although considerable residual variation is observed in some situations.

The average SSC character in this study varied from 9.23 °Brix (Exp2-GH) to 13.58 °Brix (Exp1-EF), according to Tables 2 and 3. However, there was no significant variation in Exp2. These results can be explained, besides the high variation in the locations of the experiments, in part, due to the way of storing *P. angulata* fruits before the evaluation of this characteristic in the second experiment, when the fruits were frozen and stored in freezer. In Exp1, the fruits were stored in refrigerator (without being frozen).

According to Lima et al. (2009), for the commercialization of physalis (*P. peruviana*) fruits, the minimum value should be 14° Brix. Evaluating *P. angulata* fruits, Farias et al. (2022) found SSC values ranging from 10.73 to 12.90 °Brix, while Sadyah et al. (2020) found values between 9.06 to 11.66 °Brix, and Golubkina et al. (2018) found values between 4.9 and 9.7 °Brix. Considering these studies, the average value of 13.58 °Brix found in Exp1-EF was the closest to 14 °Brix, indicating that the *P. angulata* species has the potential to reach the minimum SSC value required for *P. peruviana* commercialization, since several fruits presented values above 14 °Brix. It is noteworthy that the accession BAAN-04 showed an average of 15.21 °Brix in Exp1-EF, exceeding the minimum threshold for the market.

In breeding programs, the traits that have higher heritability coefficients are interesting and provide greater chance of gain by selection (Londero et al. 2006; Ramalho et al. 2012). However, the most important traits for the crop can be of low heritability. In this work, a high heritability in experimental field was found in Exp2 for the characters TFD (91.9%) and AFM (91.44%). In the greenhouse, LFD (78.44%) Exp2 and NFP (75.66%) showed the highest heritability (Exp1). The highest heritability values were found, in general, in the field experiments. Considering that these are probably quantitative traits, the values found in our study indicate great chances of gain with selection.

Few studies estimating heritabilities for *P. angulata* fruits are found in the literature. Farias et al (2022) found broad-sense heritability values for plant height (53%) and SSC (41%), after evaluating eleven vegetative and productive traits. This SSC value was considerably lower than those found in this work in Exp1 in the field (77.06%) and greenhouse (65.19%), indicating that increasing the number of repetitions can lead to increased heritability for fruit traits. Working with *P. peruviana*, Kumar et al. (2017) found high heritability values for the characters fruit diameter (96.89%), fruit per plant (82.72%) and plant height (51.27%). High heritability in tomato plants for the trait fruit per plant (84–99.5%) was also found by Basavaraj et al. (2015).

The different values of the CV found in the experiments in the two locations justify the need to estimate the coefficient of repeatability. The values of CV found in both environments, greenhouse and experimental field, for all characteristics, can be explained by the possible genetic variability within the accessions and the influence of the environment, as previously commented. Moreover, these accessions are still in the domestication stage and have not undergone the improvement process. A recent study classified the species as being facultative autogamous (Figueiredo et al. 2020), occurring intense visitation by bees during cultivation, indicating the possibility that the accessions are not homozygous lines, but have some level of heterozygosity. In addition, because the species is tetraploid, the elimination of heterozygotes during generations of self-fecundation is slower compared to diploid species. These facts increase the chance of genetic variability within the accessions.

Resende (2009) classified the repeatability coefficients: values less than or equal to 0.3% are considered low, between 0.3% and 0.6% average, and greater than or equal to 0.6% are high. According to this standard, in our study, the repeatability coefficient was low for ANOVA and structural analysis, for all characters evaluated, and medium for estimation by principal components in the most traits and environments (Tables 4 and 5). For the SSC in Exp1-EF, the repeatability coefficient was 0.72, estimated by PC-cov method, being considered high. In the greenhouse, the values found for repeatability coefficients can be classified as average by the principal components, and the highest value was found in LFD (0.51 in Exp2), estimated by the PC-cov method.

NFP is an important trait controlled by several genes and severely influenced by the environment. The repeatability values of this characteristic do not exceed 0.40, according to Lira Junior et al. (2014) in *Spondia purpurea*. This agreed to the experiments in the greenhouse, for which we found 0.40 in Exp1 and 0.42 in Exp2. For the experiments in the field, this character did not show significant variation. Similar values of r were found for NFP in tomato, varying from 0.3 to 0.52 (Gonzalo et al. 2022).

Only one study about repeatability in *Physalis* fruits was found in the literature. Silva et al. (2008), using PC-cor method to estimate repeatability coefficient in *P. angulata* found values between 0.2826 and 0.3765, for the characteristics number of seeds per fruit and volume of the internal cavity, respectively. The authors also estimated r for SSC (0.2389), AFM (0.2893) TFD (0.3233) and LFD (0.3233). These values were low compared to those found in this work. Studies with tomato (Abreu et al. 2006) and pout pepper (Lucio et al. 2022) showed repeatability coefficients close to the founds in our study.

A major application of the repeatability coefficient is to allow the estimation of the number of measurements required to reach a level of reliability in estimating the value of a genotype. The higher the value of the repeatability coefficient, the better the actual value of the individual can be predicted with a small number of repeated measurements; however, a large number of measurements is necessary when this value is low. With a 95% reliability in mind, in the experimental field, 7 to 21 repetitions are needed in Exp1 and 18 to 38 repetitions in Exp2. In the greenhouse, 13 to 22 replicates are needed in Exp1 and 20 to 49 replicates in Exp2. With 99% reliability, in the field, 67 to 124 repetitions were needed in Exp1, and 95 to 255 repetitions in Exp2. In the greenhouse, 137 to 207 measurements were needed in Exp1 and 94 to 200 measurements in Exp2. Thus, reaching 99% reliability proves to be unfeasible, but reaching 95% reliability may be feasible for some characteristics in the experimental field, such as LFD (21), TFD (18), AFM (13), and SSC (7). In the greenhouse, with 90% confidence, the minimum number of measurements is around 14 (AFM, TFD, SSC), 12 (NFP) and 11 (SSC).

The high number of repetitions required according to our study may be due to the fact that the accessions have not yet been fully domesticated, the possibility of genetic variation within accessions, and the environmental variation, as previously discussed. Indeed, the plants suffered several attacks of pests and diseases, including African snail (*Achatina fulica*), slugs, whitefly (*Bemisia tabaci*), mites (*Aceria anthocoptes*), powdery mildew, and other environmental factors. This set of factors justifies the residual variation obtained in both environments. Estimating the minimum number of repetitions is an alternative to achieve good estimates of genetic parameters with the efficient use of plant genetic resources.

According to the results found for repeatability coefficient by principal component analysis, in view of the standardization of the number of repetitions in studies with *P. angulata*, we found higher results in the estimation of the number of repetitions based on this method than the others (ANOVA, and structural analysis). Taking all the experiments together, we considered that 20 measurements can provide about 95% reliability for field experiments and 90% reliability for greenhouse experiments for all traits. Further studies on repeatability in *P. angulata* are suggested to increase the efficiency of the selective process in the genetic improvement of the species.

CONCLUSIONS

The characters TFD, LFD, AFM and SSC showed significant genetic variability in the experimental field in both experiments. In the greenhouse, all traits had significant variation in at least one experiment.

Heritability values ranged from 61.63% (TFD in Exp2-GH) to 91.91% (TFD in Exp2-EF). These values indicate good chances of success in genetic improvement of these traits.

The principal components method, based on the covariance or correlation matrices, estimated the highest repeatability coefficients in both environments, ranging from 0.51 (TFD) to 0.72 (SSC) in the experimental field, and from 0.40 (NFP) to 0.51 (LFD) in the greenhouse. We suggest the use of 20 repetitions as number of measurements required for the traits evaluated to achieve 95% and 90% reliability for experimental field and greenhouse experiments, respectively.

Declarations

Funding: COORDENAÇÃO DE APERFEIÇOAMENTO DE PESSOAL DE NÍVEL SUPERIOR (granting master's scholarship 8887.615881/2021-00 and doctoral scholarship 8887.648176/2021-00). FINAPESQ/UNIVERSIDADE ESTADUAL DE FEIRA DE SANTANA, term of grant 040/2021.

Conflicts of interest/Competing interest: We state that there is no conflict of interest submitting this manuscript

Availability of data and material: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code availability: Not applicable

Authors' contribution:

A. M. S. Toupe – experiment planning, experiment conducting, traits evaluation, data analysis and interpretation, and manuscript writing and review.

J. S. Lima – experiment conducting, traits evaluation.

I. de O. Souza – experiment conducting, traits evaluation.

E. M. de Souza – experiment conducting, traits evaluation, data analysis.

A. R. Passos – experiment planning, data interpretation, co-advising

Ethics approval (include appropriate approvals or waivers): Not applicable

Consent to participate (include appropriate statements): Not applicable

Consent for publication (include appropriate statements): Not applicable

References

1. Abreu FB, Silva DJH, Marim BG, Carneiro PCS, Juhasz ANP, de Luca CAC, Valente RF, Guimaraes MA (2006) Minimum number and best combinations of harvests to evaluate accessions of tomato plants from germplasm banks. *Gen Mol Bio* 29(1):112–116. <https://doi.org/10.1590/S1415-47572006000100021>
2. Balah MA, Balah AM (2022) Growth and ecological characteristics of *Physalis angulata* invasive weed species in several invaded communities. *Biologia* 77(2):325–338. <https://doi.org/10.1007/s11756-021-00944-1>
3. Basavaraj LB, Vilas DG, Vijaykumar R (2015) Study on genetic variability and characters interrelationship of quality and yield components in tomato (*Solanum lycopersicum* L.). *HortFlora Res Spectr* 4(2):108–115. <https://www.researchgate.net/publication/291345193>
4. Borém A, Miranda GV, Fritsche-Neto R (2017) Melhoria de Plantas. Universidade Federal de Viçosa, Viçosa-MG
5. Figueiredo MCC, Passos AR, Hughes FM, Santos KS, Silva AL, Soares TL (2020) Reproductive biology of *Physalis angulata* L. *Ciência Hortic* 267:109307. <https://doi.org/10.1016/j.scienta.2020.109307>. Solanaceae
6. Cruz CD, Regazzi AJ, Carneiro PCS (2010) Modelos biométricos aplicados ao melhoramento genético. Universidade Federal de Viçosa, Viçosa-MG
7. Cruz CD (2013) GENES - a software package for analysis in experimental statistics and quantitative genetics. *Acta ciência Agron* 35(3):271–376 Disponível em. <https://doi.org/10.4025/actasciagron.v35i3.21251>
8. Daher RF, Maldonado H, Pereira AV, Amaral AT, Pereira MG, Ferreira CF, Ramos SRR, Tardin FD, Silva MP (2004) Estimativas de parâmetros de repetibilidade de caracteres forrageiros em clones de capim elefante (*Pennisetum purpureum* Schum). *Acta Scient Agron* 26:483–490. <https://doi.org/10.4025/actasciagron.v26i4.1823>
9. Falconer DS (1987) Introdução à genética quantitativa. Universidade Federal de Viçosa, Viçosa-MG
10. Farias JWS, Orella JST, Batista ES, Cordeiro RC, Passos AR, Silva LCC (2022) Diallel analysis for morphoagronomic descriptors in *Physalis angulata* L. hybrids. *Genet Resour Crop Evol*. 69:1–10, <https://orcid.org/0000-0002-9917-2448>
11. Fukushima A, Nakamura M, Suzuki H, Yamazaki M, Knoch E, Mori T, Umemoto N, Morita M, Hirai G, Sodeoka M, Saito K (2016) Comparative characterization of the leaf tissue of *Physalis alkekengi* and *Physalis peruviana* using RNA-seq and metabolite profiling. *Frente Plant Sci* 7:1883. <https://doi.org/10.3389/fpls.2016.01883>
12. Golubkina NA, Kekina HG, Engalichev MR, Antoshkina MS, Caruso G (2018) Genotypic effect on fruit production and quality, antioxidant content and elemental composition of organically grown *Physalis angulata* L. and *Physalis pubescens* L. *Folia Hortic* 30(2):367–374. <https://doi.org/10.2478/fhort-2018-0032>
13. González OT, Torres JMC, Cano CIM, Árias ML, Arboleda AAN (2008) Morphologic characterization of forty six accessions of cape gooseberry (*Physalis peruviana* L.), in Antioquia (Colombia). *Rev Bras Frutic Jaboticabal* 30(3):708–715. <https://doi.org/10.1590/S0100-29452008000300025>
14. Gonzalo MJ, Maia LC, Nájera I, Baixela C, Giuliano G, Ferrante P, Granell A, Asins MJ, Monforte AJ (2022) Genetic Control of Reproductive Traits under Different Temperature Regimes in Inbred Line Populations Derived from Crosses between *S. pimpinellifolium* and *S. lycopersicum* Accessions. *Plants* 11(8):1069. <https://doi.org/10.3390/plants11081069>
15. Jagatheeswari D (2014) Morphological studies on flowering plants (Solanaceae). *Int Lett Nat Sci* 10:36–43
16. José RMM, Norma AA, Socorro GEM, José NUS, Lora NUS, Yollanda HA (2015) Phenolic Constituents and antioxidant properties of five wild species of *Physalis* (Solanaceae). *Bot stud* 56(24):1–13. <https://doi.org/10.1186/s40529-015-0101-y>
17. Kempthorne O (1973) An introduction to genetic statistics. State University Press, Ames
18. Kumar K, Sharma D, Trivedi J, Kumar D (2016) Genetic variability, heritability and genetic advance for fruit yield and yield attributes in cherry tomato (*Solanum lycopersicum* L. var. *cerasiforme*). *Environ Ecol* 34(2a):718–721
19. Lima CSM, Severo J, Manica-Berto R, Silva JA, Rufato L, Rufato AR (2009) Características físico-químicas de physalis em diferentes colorações do cálice e sistemas de condução. *Ver Bras Frutic* 31(4):1061–1068. <https://doi.org/10.1590/S0100-29452009000400020>
20. Lira Junior JS, Bezerra JEF, Moura MJM, Santos VF (2014) Repetibilidade da produção número e peso do fruto em cirigueira (*Spondia purpurea* L.). *Rev Bras Frutic* 36(1):214–220. <https://doi.org/10.1590/0100-2945-294/13>
21. Londero PMG, Ribeiro ND, Rodrigues JA, Filho AC, Antunes IF (2006) Herdabilidade dos teores de fibra alimentar e rendimento de grãos em populações de feijoeiro. *Pesq agropec bras* 41(1):51–58. <https://doi.org/10.1590/S0100-204X2006000100008>
22. Lucio ADC, Lambrecht DM, Diel MI, Tischler AL, Tartaglia FDL, Zemolin JA, Marques LE (2022) Repeatability and number of measurements for productive variables in vegetable crops experiments. *Hortic Bras* 40:247–254. <https://doi.org/10.1590/s0102-0536-20220301>
23. Medina-Medrano JR, Almaraz-Abarca N, González-Elizondo MS, Uribe-Soto JN, González-Valdez LS, Herrera-Arrieta Y (2015) Phenolic constituents and antioxidant properties of five wild species of *Physalis* (Solanaceae). *Bot stud* 56(1):24. [10.1186/s40529-015-0101-y](https://doi.org/10.1186/s40529-015-0101-y)

24. Melo MS, Benett CGS, Melo BS, Lourenço SLO, Barboza FS (2017) Análise físico-química de frutos de achachairu coletados em diferentes partes da planta. *Rev Agric Néotrop* 4(5):17–21. <https://doi.org/10.32404/rean.v4i5.2189>
25. Muniz J, Molina AR, Muniz J (2015) *Physalis*: productive and economic overview in Brazil. *Hortic Bras* 33(2). <https://doi.org/10.1590/s0102-053620150000200023>
26. Oliveira JAR, Martins LHS, Vasconcelos MAM, Pena RS, Carvalho AV (2011) Caracterização física, físico-química e potencial tecnológico de frutos de camapú (*Physalis angulata* L.). *Rev Bras de Tecnol Agroind* 5(2):573–583
27. Ordoñez MA, Morales REJ, López SJA, Salomón HG (2022) Leaf area and yield of *Physalis angulata* L. as a function of population density and slow-release urea. *Agrociencia* 56:74–87. <https://doi.org/10.47163/agrociencia.v56i1.2689>
28. Orellana JST, Farias JWS, Silva LCC, Passos AR (2021) Evaluation and selection in half-sib progenies of *Physalis ixocarpa* Brot. aiming to increase productivity. *Sci Hortic* 290:110531. <https://doi.org/10.1016/j.scienta.2021.110531>
29. Ramalho MAP, Ferreira DF, Oliveira AC (2012) Experimentação em genética e melhoramento de plantas. Universidade Federal de Lavras, UFLA-MG
30. Resende MDV (2009) Genética, biométrica e estatística no melhoramento de plantas perenes. Embrapa Florestas, Colombo, PR
31. Rodrigues FA, Penoni EDS, Soares JDR, Silva RAL, Pasqual M (2014) Caracterização física, química e físico-química de *physalis* cultivada em casa de vegetação. *Cienc Rural* 44(8):1411–1414. <https://doi.org/10.1590/0103-8478cr20130743>
32. Rufato ADe R, Rufato L, Lima CSM, Muniz J (2013) A cultura da *Physalis*. Série floricultura-Pequenas frutas. UDESC, Florianópolis, pp 143–193
33. Sadiyah H, Soegianto A, Waluyo B, Ashari S (2020) Preliminary characterization of groundcherry (*Physalis angulata* L.) from East Java Province, Indonesia based on morpho-agronomic traits. *Biodivers J* 21(2):759–769. <http://doi.org/10.13057/biodiv/d210244>
34. Shenstone E, Lippman Z, Van Eck JA (2020) review of nutritional properties and health benefits of *Physalis* species. *Plant Foods Hum Nutr* 75:316–325. <https://doi.org/10.1007/s11130-020-00821-3>
35. Sholehah DN, Hariyanto S, Purnobasuki H (2021) Fruit development of groundcherry (*Physalis angulata* L.) in dryland. *Aust J Crop Sci* 15(8):1186–1191. <https://doi.org/10.21475/ajcs.21.15.08.p3318>
36. Silva AHB, Osuna JTA, Branco A, Souza MF, Silva AB, Oliveira J (2008) Estimativa do coeficiente de repetibilidade para caracteres do fruto de *Physalis angulata* L. (Solanaceae). *Hortic. Bras.* 26(2):S1331-S1335
37. Silva Junior AD, Leal MHS, Oliveira GJA, Toroco BR, Zeist AR, Silva DF, Oliveira JNM, Youssef K (2022) Reproductive biology and hybridization of *Physalis* L. species. *Braz J Bot* 45(3):1037–1045. <https://doi.org/10.1007/s40415-022-00811-6>
38. Silva M, Simas S, Batista T, Cardarelli P, Tomassini T (2005) Studies on antimicrobial activity, in vitro, of *Physalis angulata* L. (Solanaceae) fraction and Physalin B bringing out the importance of assay determination. *Mem Inst Oswaldo Cruz* 100(7):779–782. <https://doi.org/10.1590/S0074-02762005000700018>
39. Stehmann JR, Knapp S (2020) *Physalis* in Flora do Brasil. Jardim Botânico do Rio de Janeiro. Available in: <https://floradobrasil2020.jbrj.gov.br/FB14697>
40. Tamara TT, Nascimento MN, Leite RS (2018) Produção e caracterização dos frutos de espécies de *Physalis* cultivadas no semiárido baiano. *Colloq Agrariae*. 14(3):113–121. DOI: 10.5747/ca. 2018.v14.n3.a233