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Characterization of physiological maturity of *Physalis peruviana* L. fruits

Caracterização da maturidade fisiológica de frutos de *Physalis peruviana* L.

Marília Hortência Batista Silva Rodrigues[1]*; Kilson Pinheiro Lopes[2]; Marinês Pereira Bomfim[2]; Natali Almeida Evangelista Pereira[4]; Joseano Graciliano da Silva[4]; Francisco Jean da Silva Paiva[5]; Adriana da Silva Santos[1]

Highlights

Determining the ideal time for harvesting the fruits is difficult.
Determining physical and chemical traits of fruits is essential for evaluating the fruit development.
Physalis peruviana fruits should be harvestedupon reaching physiological maturity.

Abstract

Physalis peruviana L. has great nutritional value and economic viability, representing an innovation for Brazilian horticulture. However, knowing the ideal point of harvesting fruits of this species is a key factor in this process that allows maximum post-harvest utilization, providing better quality and minimal losses when the fruit is harvested at physiological maturity. Therefore, this study was conducted to characterize the physiological maturity of *Physalis peruviana* L. fruits. The experiment was laid out in a completely randomized design in which the treatmentscorresponded to different stages of fruit and seed maturation (20, 27, 34, and 41 days after anthesis [DAA]), with four replicates. The analyzed variables consisted of colorimetry (lightness, chroma and hue angle) of calyx and fruit; fresh weight, diameter (transverse and longitudinal), firmness, pH, total soluble solids, titratable acidity, total soluble solids:titratable acidity ratio, vitamin C and phenolic compounds of fruits; and carotenoids and chlorophyll (a and b) of calyx. The obtained data were subjected to analysis of variance and polynomial regression. Fruits intended for consumption must be harvested after 35 DAA, at which time yellow color and excellent organoleptic and nutritional qualities were observed.

Key words: Maturation. Physalis. Quality. Solanaceae.

[1] Students of the Doctoral Course of the Graduate Program in Agronomy, Center for Agricultural Sciences, Federal University of Paraíba, UFPB, Areia, PB, Brazil. E-mail: marilia_agroecologa@hotmail.com; drica_pl@hotmail.com
[2] Profs. Drs., Graduate Program in Tropical Horticulture, Center for Science and Agri-Food Technology, Federal University of Campina Grande, UFCG, Pombal, PB, Brazil. E-mail: kilsonlopes@gmail.com; mpbfito@gmail.com
[3] Student of the Doctoral Course of the Post-Graduate Program in Phytotechnics, Center for Agricultural Sciences, Federal Rural University of the Semi-Arid, UFERSA, Mossoró, RN, Brazil. E-mail: natalipb@hotmail.com
[4] Student of the Graduate Program in Seed Science and Technology, Faculty of Agronomy Elisel Maciel, Federal University of Pelotas, UFPel, RS, Brazil. E-mail: joseano_agronomo@outlook.com
[5] Student of the Doctoral Course of the Graduate Program in Agricultural Engineering, Center for Technology and Natural Resources, UFCG, Campina Grande, PB, Brazil. E-mail: je.an_93@hotmail.com
* Author for correspondence

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Resumo

A Physalis peruviana L. apresenta grande valor nutricional e viabilidade econômica, tornando-se uma inovação para a horticultura brasileira. No entanto, conhecer o ponto ideal de colheita em frutos dessa espécie é um fator primordial nesse processo e que permite o máximo aproveitamento pós-colheita, proporcionando melhor qualidade e mínimo de perdas quando colhidos na maturidade fisiológica. Diante disto, objetivou-se caracterizar a maturidade fisiológica dos frutos de Physalis peruviana L. O experimento foi conduzido em delineamento inteiramente casualizado, onde o tratamento consistiu em diferentes estádios de maturação do fruto e da semente (20; 27; 34; e 41 dias após a antese), com quatro repetições. As variáveis analisadas consistiram em colorimetria do cálice e do fruto (luminosidade, cromaticidade e ângulo hue), massa fresca, diâmetro (transversal e longitudinal) do fruto, firmeza, pH, sólidos solúveis totais, acidez titulável, relação sólidos solúveis totais e acidez titulável do fruto, carotenoides, clorofila (a e b) do cálice, vitamina C e compostos fenólicos dos frutos. Os dados obtidos submetidos à análise de variância e regressão polinomial. Os frutos destinados ao consumo devem ser colhidos após os 35 DAA, momento em que observou-se coloração amarelo e ótimas qualidades organolépticas e nutricionais.
Palavras-chave: Solanaceae. Qualidade. Maturação. Fisális.

Introduction

Physalis peruviana L. is a species of the family Solanaceae.Popularly known as Cape gooseberry, goldenberry or physalis, it stands out due to its low production cost, which makes it accessible to small and medium producers. The possibility of cultivating physalis in small areas renders it an excellent alternative owing to the high economic return (C. S. M. Lima Lima, Gonçalves, Tomaz, Fachinello, & Rufato, 2010).

In Brazil, *P. peruviana* is consumed fresh as a fine fruit with potential for nutritional and pharmacological interest due to its natural bioactive substances, low acidity, considerable β-carotene, vitamin C,soluble solid, carotenoid, flavonoid, physalin and terpene contents, in addition to antibacterial properties beneficial to human health (Licodiedoff, Koslowski, & Ribani, 2013; Mezzalira, Villa, Piva, Santin, & Melgarejo, 2017).

Physalisis a climacteric fruit, that is, after harvesting, its metabolism accelerates and its respiratory rate also increases due to autocalytic ethylene production (Rufato, Rufato, Schlemper, Lima, & Kretzschmara, 2008).Thus, after being separated from the mother plant, the fruits continue to ripen, which allows their harvest even when still immature. Fruits are usually harvested when they are only physically connected to the plant, whose translocation of reserves has already ceased (Chitarra & Chitarra, 2005).

C. S. M. Lima, Galarça, Betemps, Rufato and Rufato (2012) studied the characterization of the harvest point in *P. peruviana* L. and observed that the fruit maturation stage has a direct influence on its physicochemical quality. The harvest can be performed when the calyx of the fruit has a yellowish green to brownish yellow color, as it coincides with the phase in which the fruits a have larger diameter and greater accumulation of total soluble solids. Therefore, all physicochemical traits of *P. peruviana* L. fruits are directly influenced by their maturation stage, in a way that if

harvested at the appropriate time of maturity, they will exhibit greater plant quality as well as have a longer postharvest life (Damatto, Goto, Rodrigues, Viventini, & Campos, 2010).

However, due to its indeterminate growth habit, this species produces vegetative and reproductive structures simultaneously. In this way, fruits can be found at different stages of maturation on the same plant, during its cycle (Pereira, Torres, Silva, Grangeiro, & Nenedito, 2014). This characteristic makes it difficult to determine the ideal harvest time for the fruits destined for sale. In this scenario, this study was conducted to characterize the physiological maturity of *P. peruviana* L. fruits grown in the semi-arid region of Paraíba, Brazil.

Material and Methods

Experiment site

The experiment was conducted in a greenhouse at the Experimental Farm of the Federal University of Campina Grande, Pombal campus, located in the municipality of São Domingos, west of Paraíba State, Brazil (6°48'41.7" S, and 37°56'13.8" W, 190 m asl). According to the Köppen climate classification, adapted to Brazil (Coelho & Socin, 1982), the climate is aBSh type (hot and dry semi-arid), with average precipitation of 700 to 900 mm year^{-1}, average annual temperature of 26.1 °C and average annual evaporation of 1000 to 1100 mm (Francisco & Santos, 2017).

Design and treatment

The experiment was laid out in a completely randomized design in which the treatments corresponded to different stages of maturation (20, 27, 34 and 41 days after anthesis [DAA]), with four replicates, each consisting of 25 fruits.

Seedling production and croptraining

Seeds extracted from fruits, in full maturation stage and healthy, were purchased in João Pessoa-PB. The fruits were opened with a no. 15 surgical blade and seeds were extracted manually, washed in running water under a sieve and disinfected with 2% sodium hypochlorite solution for five minutes to eliminate contaminants. Subsequently, the seeds remained 30 min on a sheet of paper towel to remove excess water. Sowing was performed at a depth of 0.5 cm, in 50-mL polypropylene containers that were properly perforated and filled with commercial substrate Basaplant®, whose chemical characteristics are shown in Table 1.

Table 1
Chemical and physical composition of the commercial substrate Basaplant®, used in seedling production (SSP) and in the cultivation (SCV) of Physalis peruviana L. UFCG, Pombal, PB, 2019.

	pH	P	$S\text{-}SO_4^{-2}$	K^+	Na^+	$H^+ + Al^{+3}$	Al^{+3}	Ca^{+2}
	Water (1:2.5)	-----mg dm^{-3}-----		----------$cmol_c$ dm^{-3}----------				
SSP	5.5	257.30	-	2.00	0.43	8.57	0.05	2.69
SCV	7.4	733.39	-	2.73	1.20	0.00	0.00	1.23
	Mg^{+2}	SB	CEC	OM	Sand	Silt	Clay	Texture class
	----------cmolc dm^{-3}---------			----------g kg^{-1}----------				
SSP	1.46	3.89	12.46	233.51	878	113	9	-
SCV	1.09	6.25	6.25	10.34	789	155	56	Sandy loam

P, K, in Mehlich 1 extractor; SB: sum of exchangeable bases; H + Al: 0.5 M calcium acetate extraction, pH 7.0; CEC: cation-exchange capacity; Al, Ca, Mg: 1 M KCl extraction; OM: organic matter, Walkley-Black.

Seedlings were produced in a greenhouse (dimensions 24 m length × 10 m width × 3.5 m ceiling height × 4.5 m central height, respectively) covered with a 120-μ-thick diffuser film with anti-UV materials. The seedlings were irrigated three times a day with a watering can, and upon showing four definitive leaves, which occurred 30 days after sowing, they were transplanted to plastic pots.

Twenty-five pots were used, each holding one plant. The pots had a capacity of 12 L and a hole at the bottom and were initially filled with 200 g of no. 1 gravel and 10 dm^3 of substrate composed of soil, sand and manure, at the 2:1:1 ratio, whose chemical and physical characteristics are shown in Table 1.

To determine the volume of water required, the following drainage lysymetry formula was used, following the methodology proposed by Bernardo, Soares and Mantovani (2006):Vi = (Va-Vd) / (1-LF), where Vi = volume to be irrigated; Va = volume applied; Vd = volume drained 24 hafter application; and LF = leaching factor (10%). The volume of water applied was determined according to the initial field capacity. Based on the above equation, only the undrained volume was applied during the entire course of the experiment, keeping the soil always near field capacity.

Chemical corrections of the substrate used in the pots were carried out after transplanting, based on the recommendations for the tomato crop (Filgueira, 2003; Thomé & Osaki, 2010) and the results of the chemical analysis of the substrate. At 21 and 35 days after transplanting (DAT), $MgSO_4$. $4H_2O$ and $CaSO_4$ (1 mol L^{-1}) were applied using 1.5 mL dm^{-3} of soil. Then, at 28 and 42 DAT, a mixed fertilizer containing N, P, K, Ca and S (10, 10, 10, 4 and 11%, respectively) was applied using 1.5 g dm-3 of soil. As mulch, each pot received 100 g of dry and crushed cv. Esmeralda grass to maintain soil moisture and temperature.

Crop training

Twenty-five pots containing one plant per pot were used. The position of the planting row adopted in the experiment was East-West, in accordance with Rodrigues, Penoni, Soares,

Silva and Pasqual (2013), spaced 1.5 m between lines × 1.0 m between plants. The plant training system was on a stake with two main branches, using three strands of galvanized wire spaced 0.5 m from the border of the pot, arranged longitudinally, for the proper training of the branches (Muniz et al., 2011). For this, formation pruning was performed from a height of 0.45 m and lateral branches were removed biweekly.

Additional cultural treatments

The plants were sprayed with the insecticides Evidence 700 WG (1 g L^{-1}) and Abamax (0.5 mL L^{-1}) for the control of silverleaf whitefly (*Bemisia argentifolii*) and red spider mite (*Tetranychus urticae*), respectively, as recommended for the tomato crop (Sistemas de Agrotóxicos Fitossánitarios, 2016). Manual weeding was also carried out to eliminate the weeds that appeared, preventing competition with the main crop. Once anthesis began, the plants were shaken manually to stimulate self-pollination. Each day, from transplant until the end of the experiment, the temperature and air relative humidity inside the nursery were measured with a thermohygrometer and the precipitation in the area was recorded (Figure 1).

Analyzed variables

Fresh weight: four replicates were weighed with ten fruits each, on an analytical precision scale (0.001 g);

Transverse (middle region) and longitudinal (from apex to base) fruit diameter: measured with a digital caliper, with results expressed in mm/fruit;

Fruit and calyx colorimetry: the fruits were separated from the calyces and the color of both was determined by reflectometry, using a Konica Minolta reflectometer, model CR-10, which was pressed so as to maintain a firm contact with the fruit surface for the reading. Based on the color reading by the CIE system, three colorimetric coordinates were obtained (*L**, *a** and *b**). The *L** coordinate refers to the level of lightness, representing how light or dark the sample is, ranging from zero (completely black) to 100 (completely white). The *a** coordinate defines the axis that varies between green (-60) and red (+60), with negative values reflecting the predominance of green and the positive ones, red. The *b** coordinate, with blue to yellow intensity, can vary from -60 (blue) to +60 (yellow). Readings were taken randomly at three points in the equatorial region of the fruit and the calyx, and the color parameters were expressed by the lightness (*L**), which determines the brightness; chromaticity (chroma), which is the ratio between the values of *a** and *b**, that is, its intensity; and angle hue (h^o), which can be 0 (red), 90° (yellow), 180° (green), 270° (blue) or 360° (black) (J. M. S. Pinheiro, 2009).

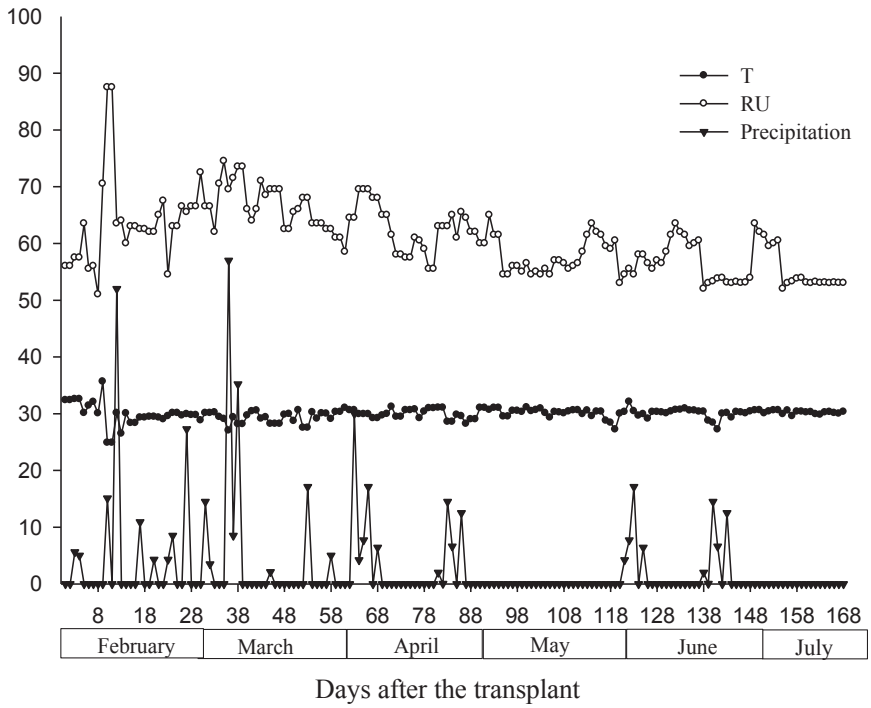

Figure 1. Mean values for temperature (T, °C), relative humidity (RH, %) and precipitation data over the course of the experiment (February to July) with *Physalis peruviana* grown in a protected environment in the semi-arid region of Paraíba, according to the number of days after transplanting. UFCG, Pombal, PB, 2019.

Pigment content: for the analysis of chlorophylls *a* and *b* and carotenoids, four 0.200-g samples of the *P. peruviana* L. calyx were weighed at 20, 27, 34 and 41 DAA, packed in aluminum foil envelopes and stored in a freezer until analysis. The pigments were extracted in 80% acetone and quantified by spectrophotometry, as described by Lichtenthaler (1987), with results expressed in mg 100 g^{-1}.

Firmness: determined using a digital penetrometer (Soil Control) with a 6-mm tip, by pressing it on the pulp, in the central region of the fruit. One reading was taken per fruit. Results were expressed in Newtons (N).

Potential of hydrogen: determined in one gram of *P. peruviana* L. pulp extract plus 10 mL of distilled water, using a digital benchtop pH meter (Instituto Adolfo Lutz [IAL], 2008).

Vitamin C: estimated by titration, using 2 mL of *P. peruviana* L. pulp extract plus 48 mL of 0.5% oxalic acid and titrating with Tillmans solution until it reaches a pink color, following method (365/IV), as described by IAL (2008). Data were expressed in mg $100g^{-1}$.

Titratable acidity: measured in 2 mL of *P. peruviana* L. pulp extract. The solution containing the sample was titrated with 0.1 N NaOH until it reached the turning point of the phenolphthalein indicator, which was confirmed by the pH range of the indicator of 8.2 (IAL, 2008). Data were expressed as a percentage of citric acid.

Total Soluble Solids: Titratable Acidity Ratio: obtained by dividing the soluble solid values by the titratable acidity values.

Phenolic compounds: estimated using the Folin and Ciocalteu method described by Waterhouse (2006), by mixing 500 µL of filtered juice of *P. peruviana* L. pulp extract with 1,625 µL distilled water, 125 µL Folin-Ciocalteu reagent and 250 µL calcium carbonate, followed by agitation and resting for 5 min. The standard curve was prepared with gallic acid; readings were taken in a spectrophotometer at 765nm and results expressed in gallic acid equivalent (GAE) mg $100g^{-1}$ of fresh weight.

Statistical analysis

Data were subjected to analysis of variance and polynomial regression using SISVAR 5.3 statistical software (Ferreira, 2014).

Results and Discussion

Results of analysis of variance for the evaluated variables are shown in Tables 2 and 3. There was a significant effect for all evaluated variables according to the treatment used, except for titratable acidity.

Table 2
Analysis of variance for the variables of lightness (*L), chroma (*C**) and hue angle (*h°*) of calyx and fresh weight (FFW), longitudinal diameter (FLD), transverse diameter (FTD) and firmness (FIRM) of fruits of *Physalis peruviana* L. harvested at different maturation stages. UFCG, Pombal, PB, 2019.**

		Mean square									
		Calyx			Fruit						
SV	DF	L*	C*	hº	L*	C*	hº	FFW (g)	FLD (mg)	FTD (mg)	FIRM (N)
Stage	3	327.83 **	100.99**	1138.02**	8366.60**	129.29**	1670.45**	2.43**	25.09 **	45.59**	54.23**
Residue	12	3.9738	6.0676	3.02	7.1639	2,7626	1.1191	0.02	0.64	0.37	1.5799
Total	15										
CV (%)		3.79	7.86	1.83	2.82	3.07	1.43	8.73	5.97	4.70	18.72
Mean		52.53	31.34	94.91	94.97	54.22	74.02	1.72	13.45	13.10	6.71

The values referring to calyxlightness (CL) rose linearly,with a 26% increase at 41 DAA when compared with that observed in the fruits harvested at 20 DAA (completely green) and reaching an estimated maximum value of 61.90 at 41 DAA (completely orange), as shown in Figure 2A. Fruit luminosity (FL) showed a quadratic trend during development, reaching minimum values of 58.39 at 35 DAA (Figure 3A). Lightness represents the brightness, clarity or reflectance of the surface, or even the amount of black, and is directly influenced by the color change of the fruits. These values demonstrate that the orange (ripe) fruits have greater brightness than green (unripe) fruits, as shown in Figure 3.

Table 3
Analysis of variance for titratable acidity (TA), pH, total soluble solids (TSS), total soluble solids/ titratable acidity ratio (TSS/TA), vitamin C (Vit. C) and phenolic compounds (PC) of fruit and carotenoid content (C) and chlorophylls *a* (Ca) and *b* (Cb) of calyx of *Physalis peruviana* L. harvested at different maturation stages. UFCG, Pombal, PB, 2019

		Mean square								
SV	DF	TA (%)	pH	TSS (ºBrix)	TSS/ TA	Vit. C (mg 100 g^{-1})	PC (mg 100 g^{-1})	C (mg. g^{-1})	Ca (mg. g^{-1})	Cb (mg g^{-1})
Stage	3	0.058^{ns}	0.77**	37.44**	15.26**	213.42**	1948.008 **	0.157**	6.68**	0.53**
Residue	12	0.038	0.01	0.6282	0.9498	0.7406	3.5604	0.0018	0.0135	0.0012
Total	15									
CV (%)		11.62	3.04	5.81	11.85	4.71	3.58	11.74	10.91	11.49
Mean		1.68	3.66	13.64	8.22	18.27	52.74	0.36	1.06	0.30

** significant at 1% (p<0.01); SV: source of variation; DF: degrees of freedom; CV: coefficient of variation. ns: not significant.

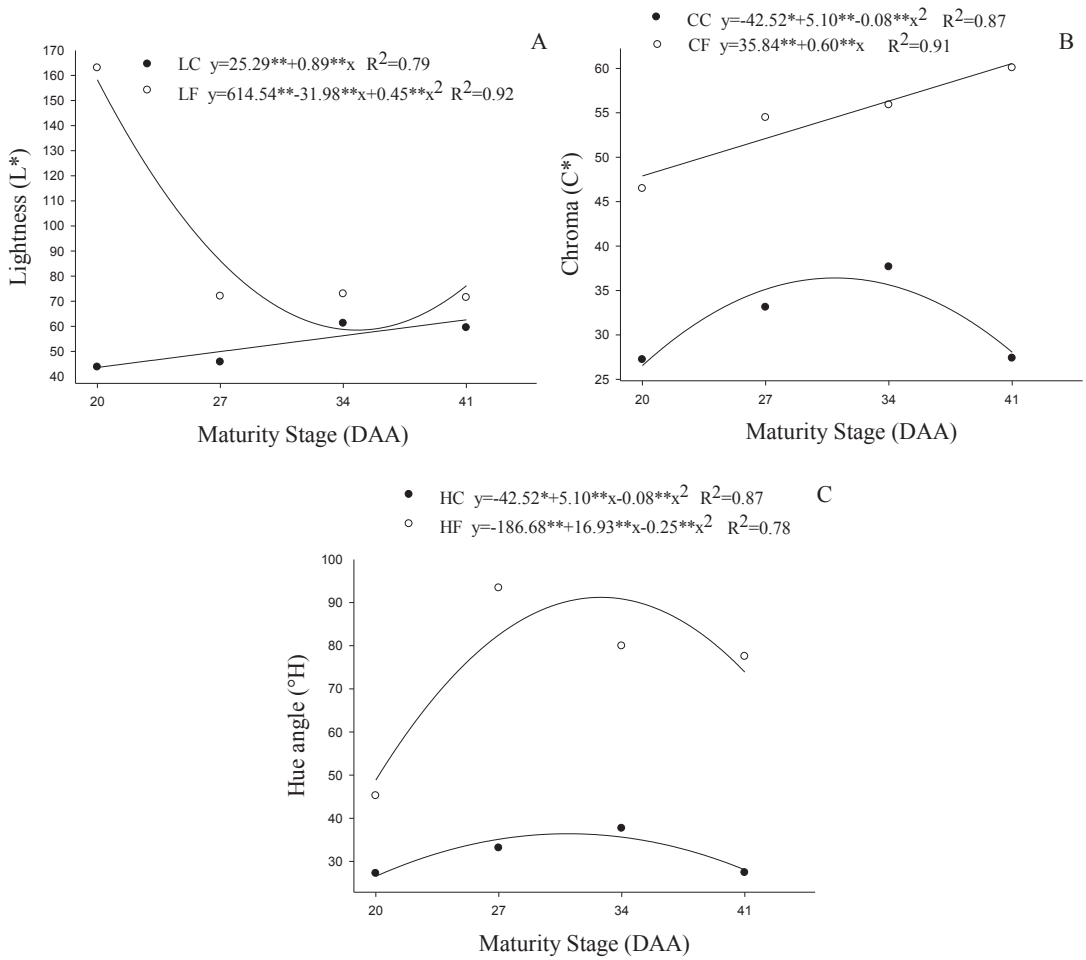

Figure 2. Lightness (A), chroma (B) and hue angle (C) of calyx (LC, CC and HC) and fruit (LF, CF and HF) of Physalis peruviana L. harvested at different maturation stages. UFCG, Pombal, PB, 2019.

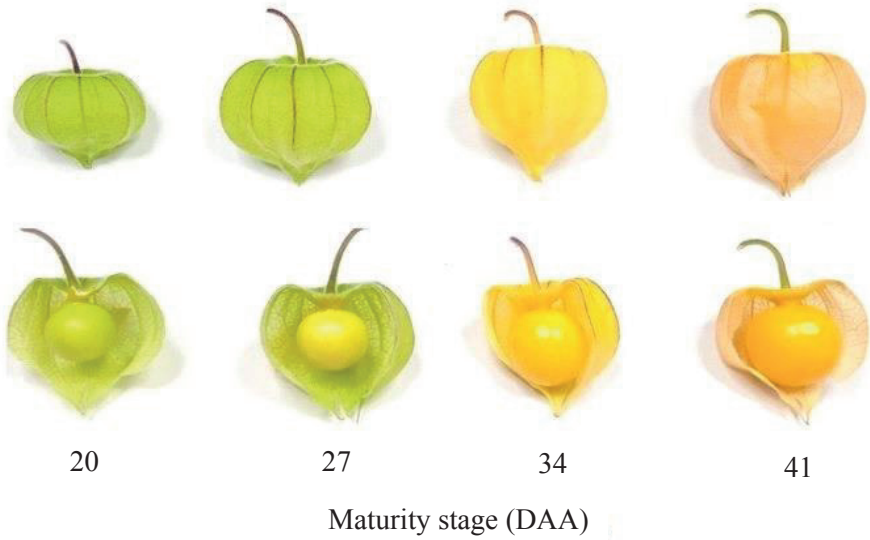

Figure 3. Visual aspect of the different maturation stages of calyx and fruit of Physalis peruviana L. at 20, 27, 34 and 41 DAA. UFCG, Pombal, PB, 2019.

Nevertheless, Licodiedoff et al. (2013) evaluated the flavonoid content and antioxidant activity of P. peruviana L. fruits harvested at two stages of maturation and observed a lightness value of 42.83 when the fruits were harvested with a yellowish green color and 41.40 when they were orange.

A similar result was reported by Tanan (2015), who characterized the physicochemical attributes of P. peruviana L. fruits with a yellow calyxand a found lightness value of 57.27.

Calyx chroma (CC) exhibiteda quadratic trend, with a maximum value of 36.41 at 31 DAA. Fruit chroma (FC), on the other hand, rose linearly, with a 22.62% increase at 41 DAA (orange) when compared with the fruits harvested at 20 DAA (green), reaching a maximum of 60.55 at 41 DAA (Figure 2B).

For this species, harvesting is usually performed when the calyx is a greenish yellow and the fruit is yellow (Severo et al., 2010). P. B. Silva (2013) studied the quality, bioactive compounds and antioxidant activity of P. angulata L. fruits and observed chroma values ranging from 45.34 to 51.23 when the fruits were completely green and completely yellow, respectively.

The hue angle of calyx (CH) and fruit (FH)behaved quadratically, reaching estimated maximum values of 36.41° and 91.21° at 31 and 33 DAA, respectively. A reduction in these values was also observed when the fruits were harvested at 41 DAA (Figure 2C). The hue angle expresses differences in color depending on the evaluated maturation stages. Therefore, this decrease of the hue value indicated that the green color slowly decreased as the fruits ripened, with an accentuation to the orange color.

According to Chitarra and Chitarra (2005), changes in fruit color during ripening are related to the rapid degradation processes of chlorophyll pigments caused by the disintegration of chromoplasts and their thylakoid membranes, which makes pre-existing pigments visible; and/or the synthesis of new pigments responsible for the

characteristic color of each species or each cultivar.

C. S. M. Lima et al. (2012) investigated physical, chemical and phytochemical traits of P. peruviana L. fruits throughout the development period and obtained a hue angle of 78° when the fruits had an orange to intense orange color. P. B. Silva (2013) observed a variation of 105.4 to 77.4 in the hue angle ofP. pubescens L. fruits, due to the influence of the fruit development process.

Fruit fresh weight showed a quadratic response, with a tendency to a gradual increase along the stages of maturation (Figure 4A), reaching an estimated maximum value of 2.39 g/fruit at 41 DAA. The increase in fresh weight that occurs with the advance of fruit development is attributed to the deposition of substances in the middle lamella of cell walls (Chitarra & Chitarra, 2005). F. A. Rodrigues (2011) conducted a physicochemical and anatomical characterization of P. peruviana L. fruits in the region of Lavras-MG and obtained a fresh weight of 2.84 g/fruit. However, a lower value was observed by J. G. Silva (2017), who examined the phenology and yield of P. peruviana L. under the conditions found in the semi-arid region of Paraíba State and obtained an average fresh weight of 1.78 g/fruit.

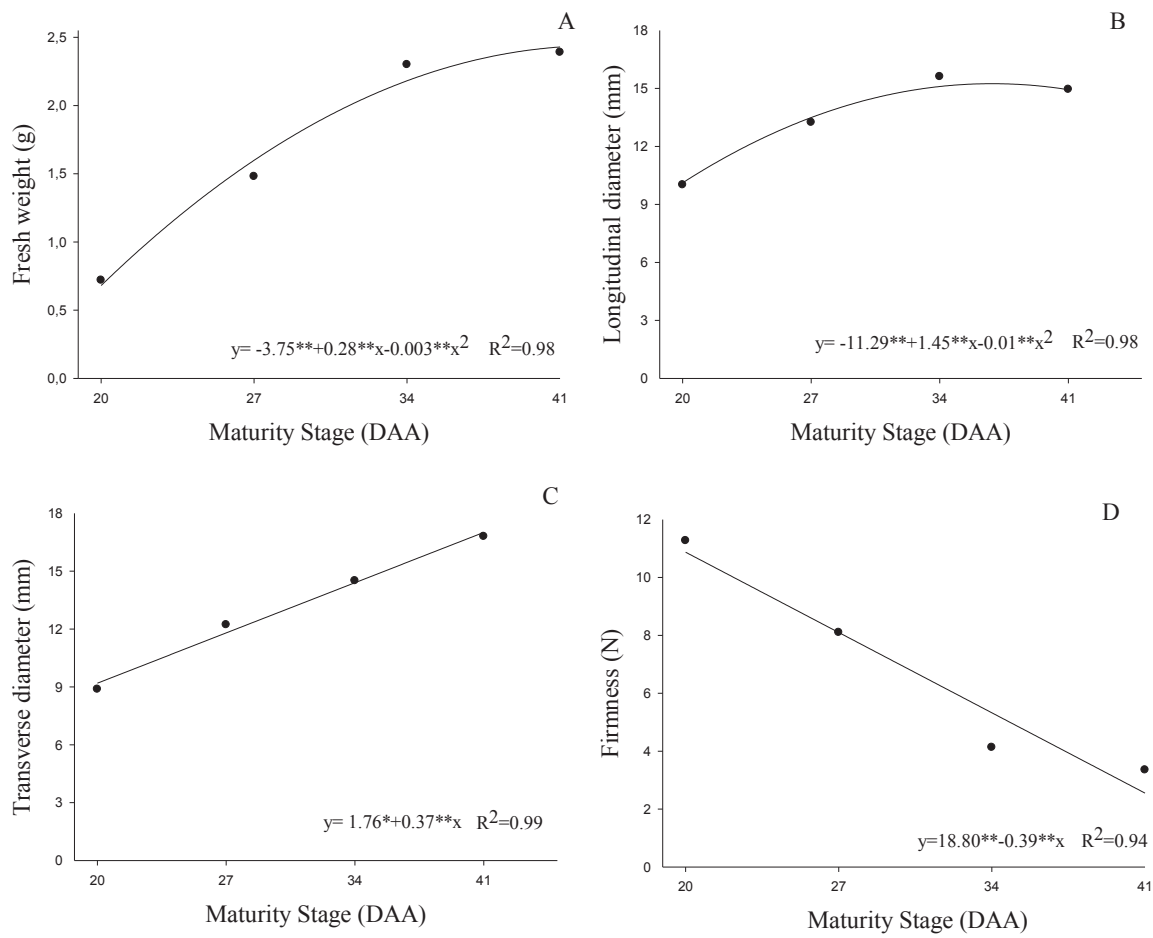

Figure 4. Fresh weight (A), longitudinal diameter (B), transverse diameter (C) and firmness (D) of *Physalis peruviana* L. fruits harvested at different of maturation stages. UFCG, Pombal, PB, 2019.

Figure 4B shows the changes in longitudinal diameter of P. peruviana L. fruits. There was a trend towards an increasing linear regression, with an estimated maximum value of 15.43 mm/fruit reached at 37 DAA, followed by a slight reduction until the 41st DAA.

D. M. Pinheiro (2008) reported that the maximum diameter of fruits may coincide with physiological maturity, resulting from the maximum increase in cell walls. F. A. Rodrigues, Penoni, Soares and Pasqual (2012) characterized the point of harvest of P. peruviana L. fruits picked at different maturation stages in the region of Lavras-MG and observed an increase in diameter from the green to the brownish yellow stage.

Transverse fruit diameter rose linearly with advance of the maturation stages, with a significant increase of 47% up to 41 DAA, when compared with the initial diameter (20 DAA), reaching a maximum value estimated at 17 mm/fruit (Figure 4C). This increase was due to the translocation of photoassimilates to form the fruit, as described by Chitarra and Chitarra (2005).

In contrast, F. A. Rodrigues et al. (2012) examined the harvest point of P. peruviana L. in the region of Lavras-MG and observed maximum values of 17.45 and 18.55 mm/fruit for transverse and longitudinal diameter, respectively, when the fruits were harvested with the calyx yellow. According to Sousa et al. (2011), the transverse and longitudinal diameters must be evaluated together, as they define the shape of the fruit.

The firmness of P. peruviana L. fruits decreased linearly, with a significant reduction of 70.27% at 41 DAA, when compared with the firmness of the fruits harvested at 20 DAA, reaching a minimum value of 2.55 N/fruit (Figure 4D).

This variable is related to biochemical changes in cell wall structures, cell cohesion and the maintenance of its integrity (C. S. M. Lima et al., 2012). Therefore, loss of firmness in plant tissues is caused by hydrolytic enzymes such as pectinmethylesterase, polygalacturonase, cellulase and other glucanohydrolases and transglucosidase,which act by attacking structural carbohydrates (Chitarra & Chitarra, 2005). P. B. Silva (2013) observed that firmness decreased by 28.68% due to the advance of maturation stages in P. pubescens L. fruits, reaching a minimum value of 11.80 N/fruit when they were completely ripe (yellow).

The pH of the P. peruviana L. fruits showed a quadratic behavior, with a minimum value of 3.21 estimated at 31 DAA. There was also a slight increase of 0.61 in pH for the fruits harvested at 41 DAA (Figure 5A). The low pH variation observed at the evaluated maturation stages is related to the low consumption of organic acids as an energy source, during the maturation process (C. S. M. Lima, Alves, Filgueiras, & Enéas, 2003). Likewise, P. B. Silva (2013) examined the quality, bioactive compounds and anti-toxicity activity of P. pubescens L. fruits and noted a low variation in pH, from 3.13 to 3.83, between the maturation stages of fruits harvested completely green and completely yellow, respectively.

J. A. R. Oliveira, Martins, Vasconcelos, Pena and Carvalho (2011) studied the physical and physicochemical characterization and technological potential of P. angulata L. fruits and found an average pH value of 4.11 when the fruits were harvested at the stage of maximum development known as “breaker”. However, values like this could be observed in fruits harvested at only 20 DAA, when they were totally green.

Total soluble solids (TSS)increased gradually as a result of fruit development, reaching a maximum (16.15° Brix) at 35 DAA. Nonetheless, a decrease of 1.05 was observed when they were harvested at 41 DAA (Figure 5B). According to Chitarra and Chitarra (2005), this increase is related to biosynthesis, excessive degradation of polysaccharides and excessive loss of water from the fruit. The reduction is caused by the start of senescence and intensification of respiratory activity in the fruits. This parameter is used as an indicator of fruit maturity and denotes the amount of sugars present in the juice (D. P. Rodrigues, 2016).

Rodrigues, Penoni, Soares, Silva and Pasqual, (2014) analyzed the physicochemical quality of P. peruviana L. fruits harvested at the complete maturation stage and obtained TSS of 13.81° Brix. C. S. M. Lima, Secero, Andrade, Affonso, Rombaldi and Rufato (2013) evaluated the physicochemical characterization of P. peruviana L. fruits harvested with a greenish yellow color and recorded a TSS value of 13.2° Brix.

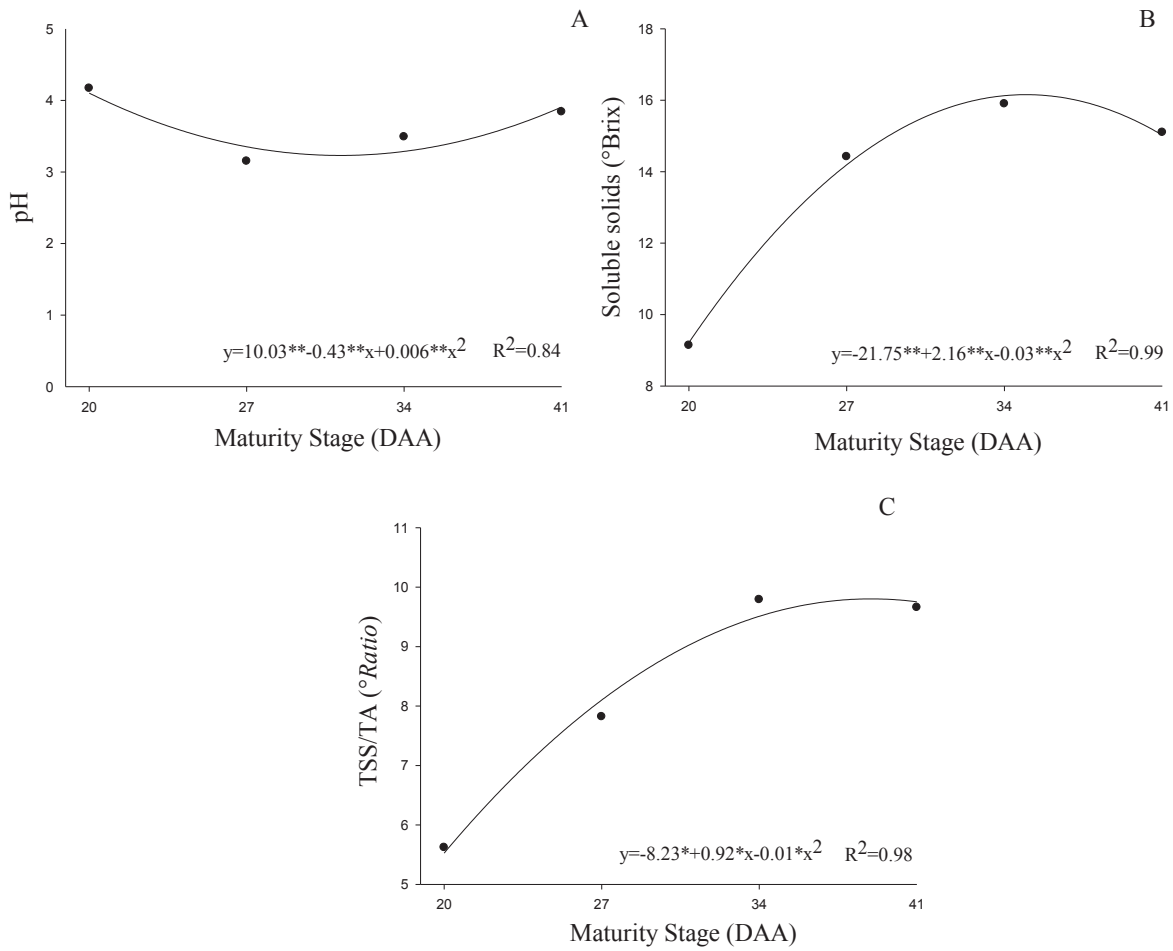

Figure 5. pH (A), total soluble solids (TSS, B) and total soluble solids: titratable acidity ratio (TSS:TA, C) of *Physalis peruviana* L. fruits harvested at different maturation stages. UFCG, Pombal, PB, 2019.

In view of the results of TSS/TA, a progressive increase in a quadratic trend was observed with the advancement of the fruit maturation stages, reaching values of up to 9.8 to 39 DAA (Figure 5C), followed by a decline. Although TA was not influenced by the fruit maturation stages, TSS was what significantly influenced this ratio. This increase in TSS/TA observed with the development of the fruits is a behavior resulting from the increase in total sugars and degradation of organic acids, given that this parameter expresses the fruit ripeness and quality index (Auler, Fiori-tutida, & Scholz, 2009).

Rodrigues et al. (2014) evaluated the TSS/TA ratio in P. peruviana L. fruits grown in a greenhouse in Lavras-MG when they showed a yellowish calyx and found a maximum value of 8.8. Licodiedoff et al. (2013) also found a lower value (8.6) when working with orange fruits (end of the maturation stage) of the same species, in the region of Vacaria-RS. On the other hand, C. S. M. Lima et al. (2013) evaluated the postharvest quality of P. peruviana L. in the climatic conditions of Capão Leão-RS, a region with an annual average temperature of 17.9 °C, and observed values higher than that obtained in the present study (15.73), when the fruits were harvested with a greenish yellow calyx.

The carotenoid concentration in the calyx showed a quadratic effect, reaching an estimated minimum of 0.18 mg g-1 at 41 DAA (Figure 6A). Accordingly, the carotenoid levels decreased throughout the maturation stages, i.e., there was degradation and, consequently, reduction of this pigment due to the development of the fruit, which was also related to the change in calyx color. In studies on the antioxidants of P. peruviana L., several authors have stated that these fruits are a significant source of carotenoids and phenolic compounds, which may vary depending on the fruit development stage as well as storage conditions (V. L. A. G. Lima et al., 2005; Ferreyra, Vinã, Mugridge, & Chaves, 2007; Veberic, Colaric, & Stampar, 2008; Severo et al., 2010).

Barroso, Souza, Rodrigues and Pelacani (2017) investigated the maturation of P. ixocarpa L. fruits grown in the experimental unit of the State University of Feira de Santana-BA and observed a decrease in the carotenoid content of the calyx with the advance of fruit development, which decreased from 0.35 to 0.07 mg g^{-1} when harvested at 15 and 55 DAA, respectively.

The chlorophyll *a* and *b* contentsin the calyx showed a quadratic response as a function of fruit development, both reaching an estimated minimum value of 0.00 at 41 DAA (Figure 6B). The observed reduction in these contents is related to the color change of the calyx, which varied from green to orange. Therefore, the highest levels were observed in the early stages of development (20 DAA), decreasing rapidly in the subsequent stages. Tanan (2015) also observed a high content of these pigments in calyces of immature fruits due to their photosynthetic activity, which provided the necessary photosynthesis for the development of the fruit.

A reduction in chlorophyll a and b values of the calyx as a result of the advance of fruit development was also observed by Barroso et al. (2017), who examined the maturation of *P. ixocarpa* L. fruits and described minimum chlorophyll a and b values of 0.09 and 0.26 mg g^{-1} in the calyx, respectively, in fruits harvested at 55 DAA.

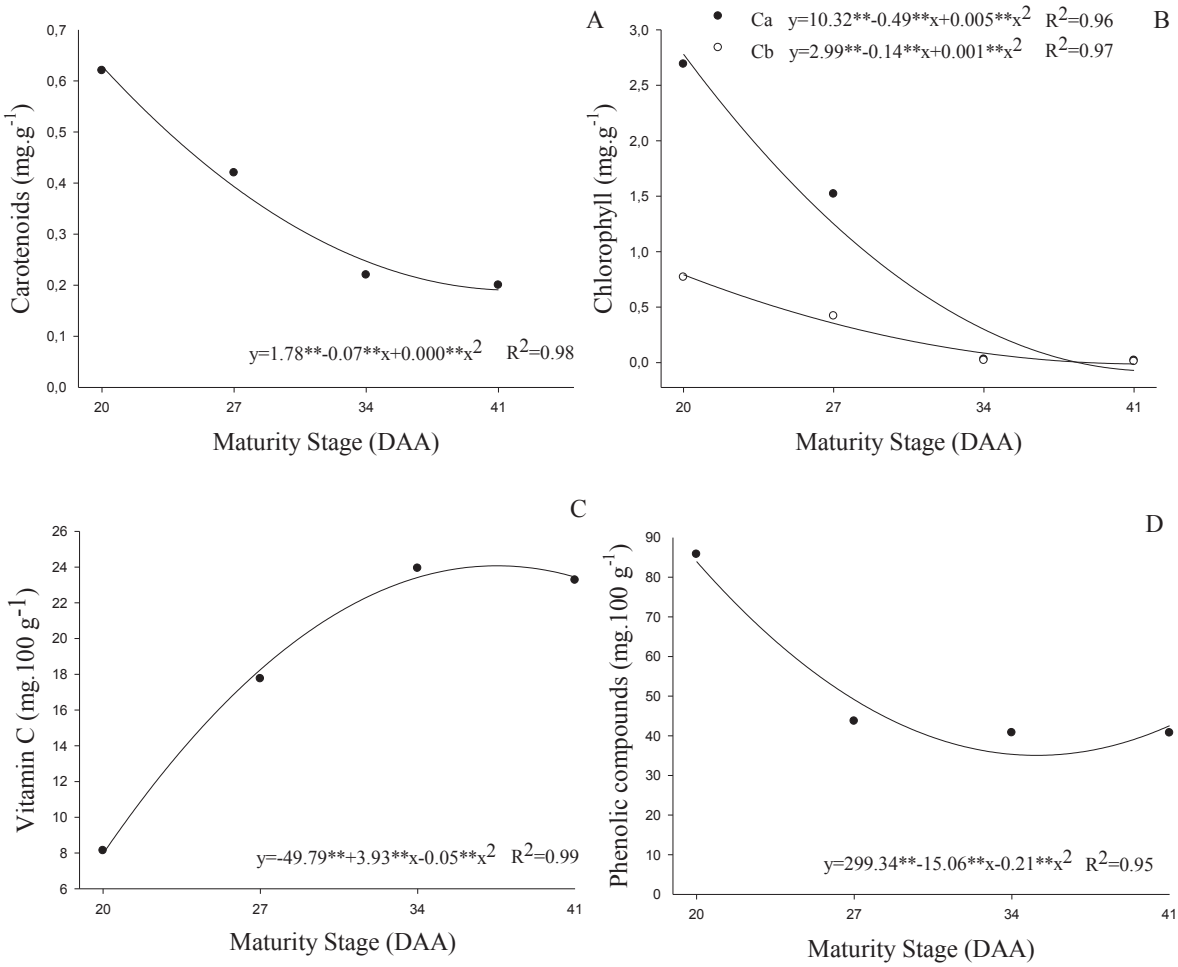

Figure 6. Carotenoids (A) chlorophylls a and b (B) of calyx and vitamin C (C) and phenolic compounds (D) of fruit of *Physalis peruviana* L. harvested at different maturation stages. UFCG, Pombal, PB, 2019.

A similar result was observed by Tanan (2015), who investigated the chlorophyll a and b contents of the calyx of *P. peruviana* L. and obtained a variation from 1.6 and 0.97 (15 DAA) to 0.09 and 0.26 mg g^{-1} (55 DAA), respectively. Therefore, these pigments decrease with the advance of the fruit ripening process.

Vitamin C showed a quadratic response, reaching an estimated maximum value of 24.07mg $100g^{-1}$ at 38 DAA. There was also a decrease at 41 DAA to 23.27 mg $100g^{-1}$ (Figure 6C). During the fruit ripening process, vitamin C increases in the initial stages of development until reaching full maturity. However, when excessively ripe, this content decreases as a consequence of the disarrangement of the cell wall, which causes this vitamin oxidize due to the action of the enzyme called ascorbic acid oxidase, which has a greater activity in ripe fruits (Mokady, Cogan, & Lieberman, 1984; Dhillon, Singh, Kundal, & Minhas, 1987; Vazquez-Ochoa & Colinas-Leon, 1990).

S. F. Oliveira (2016) studied the physicochemical properties and bioactive

compounds of *P. peruviana* L. fruits harvested from commercial crops in the northern region of Portugal and reported a vitamin C content of 26.7 mg $100g^{-1}$. According to that author, these values are slightly below the approximately 43 mg 100 g^{-1} mentioned in the literature in ripe fruits of this species (Puente, Pinto-Muñoz, Castro. & Cortés, 2011).

Data on the phenolic compound contents of *P. peruviana* L. fruits are shown in Figure 6D. There was a decrease in this variable as the fruit ripened, in a quadratic fashion, reaching an estimated minimum of 35.06 mg $100g^{-1}$ at 35 DAA. The maximum phenolic compound content was observed in the fruits harvested at 20 DAA. The decrease observed in this variable is due to the advance of fruit maturation and the use of these compounds as an energy source in the cellular respiratory process and also as a carbon source in the synthesis of sugars (Giehl et al., 2008; Gonzáles-Aguilar, Ayala-Zavala, Rosa, & Alvarez-Parrilla, 2010; Gruz, Ayaz, Torun, & Strmad, 2011).

Values higher than those found in the current study were observed by Bolzan (2013) and Rockenbach et al. (2008), who obtained 52 and 57.9 mg $100g^{-1}$, respectively, in the pulp of *P. peruviana* L. Severo et al. (2010) and C. S. M. Lima et al. (2012) evaluated the phenolic compounds content of ripe *P. peruviana* L. fruits and also observed values higher than those found in this study: 169.19 and 187.59 mg $100g^{-1}$, respectively.

Conclusion

The maturity of *Physalis peruviana* L. fruits in the semi-arid conditions of the Brazilian Northeast is reached after 35 DAA, when the calyx and the fruit are yellow, larger in diameter and exhibit greater accumulations of total soluble solids and higher total soluble solids:titratable acidity ratio, phenolic compounds and vitamin C.

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