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Development and maturation of cape gooseberry fruits

Fábio Oliveira Diniz[1]*, Bruno Ewerton da Silveira Cardillo[2], Ana Dionisia da Luz Coelho Novembre[3]

[1]Instituto Federal do Piauí, Uruçuí-PI, Brasil
[2]Sementes Biomatrix, Sorriso-MT, Brasil
[3]Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba-SP, Brasil
*Corresponding author, e-mail: fabio.diniz@ifpi.edu.br

Abstract

The cultivation of *Physalis peruviana* L. is an economic alternative, particularly for small farmers. However, there is a lack of available information on its cultivation under Brazilian edaphoclimatic conditions. Therefore, this study aims to evaluate the development and maturation of the fruits of *P. peruviana* according to the moment of flowering of the plant and the age of the fruit, in Piracicaba, São Paulo. A randomized block design with four replicates was used, and the treatments were arranged in a 2 × 4 factorial design, the first factor consisting of two moments of flowering of plants, 55 and 105 days after transplantation (DAT) and the second, represented by the age of the fruits, 45, 60, 75, and 90 days after anthesis (DAA). The physicochemical characteristics of 15 fruits from each repetition were evaluated immediately after harvesting. The necessary thermal accumulation from anthesis to the physiological maturity of the fruit is variable between the moments of flowering of the plant. Fruits harvested at 75 DAA, originating from the first moment of flowering (55 DAT), and at 60 DAA, originating from flowers issued at 105 DAT, present parameters (mass, size, color, and flavor) that characterize physiological maturity and have a quality standard that makes them suitable for marketing.

Keywords: fruit formation, fruit quality, *Physalis peruviana* L., point of harvest, Solanaceae

Introduction

Physalis peruviana L., from the Solanaceae family, originates from the Andean region and, because of its adaptation to climatic differences, is grown in several countries. In Brazil, commercial cultivation is relatively recent, stimulated by an appreciation of the fruit, considered exotic, and its unique functional and sensory qualities (Muniz et al., 2014; Fischer et al., 2014; Shenstone et al., 2020).

The plant has undetermined growth, with uninterrupted flowering throughout the cycle, and the ripe fruit is a globose berry with mass of 4–10 g, yellow-orange in color, completely enveloped by the calyx, which besides from protecting it, is a source of carbohydrates in the initial days of its development (Fischer & Lüdders, 1997).

Visual assessment of the calyx color is the main indicator of maturation and the timing of the harvest of *P. peruviana* fruits, whereas the color of the epidermis of the fruit is used as a parameter for postharvest classification. However, evaluation of the calyx coloration to determine the level of maturation is more reliable when performed in association with physicochemical characterization of the fruits (Rodrigues et al., 2012; Rodrigues et al., 2021).

On the other hand, the genetic variability of the species and its interaction with the environment in which it is cultivated leads to variations in the point of harvest and quality attributes of the fruit (Herrera et al., 2011; Lagos-Burbano et al., 2021).

Studies of other parameters, such as the age of the fruit and the moment of flowering, may add to our information about the development and maturation processes because despite the influence of climatic factors on the transformations which occur during maturation, these are possibly under genetic control. As a result, the interval between anthesis and ripening is

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relatively constant under similar climatic conditions (Lima et al., 2012; Avendaño et al. 2022; Barroso et al., 2022).

Knowledge of the fruit development process is important for defining the appropriate harvest time and for adopting technologies aimed at maintaining a useful postharvest life (Chitarra & Chitarra, 2005). In this context, the postharvest quality of *P. peruviana* fruits is compromised when they are harvested at early or advanced stages of ripening (Valdenegro et al., 2012; Balaguera-López et al., 2016; Olivares-Tenorio et al., 2017).

In view of the above, the objective was to evaluate the development and maturation of the fruits of *P. peruviana* according to the moment of flowering of the plant and the age of the fruit in the edaphoclimatic conditions of the municipality of Piracicaba, São Paulo.

Materials and Methods

The study was conducted from March to October, in 2016 and 2017, in the municipality of Piracicaba (22°42'32.01" S; 47°37'41.03" W, 546 m), São Paulo. According to Köppen's classification, the climate is of the Cwa type, humid subtropical, with a dry winter and a rainy summer.

In the first year of cultivation (2016), the physalis seedlings were formed from seeds acquired from a farmer located in the municipality of Camanducaia, Minas Gerais, whereas the seedlings of the second experiment (2017) were formed from seeds produced in the experiment conducted the previous year. The seedlings were produced in polyethylene trays, with 50 cells each, filled with Basaplant® commercial substrate, in addition to subsoil and coconut fiber, at a ratio of 3:2:1 (v/v/v). The seedlings were kept in a shaded nursery with 50% shade and were transplanted 60 days after sowing once they had reached a height of approximately 15 cm.

The soil of the experimental area had a clay-like texture, was prepared with two gradings, and was fertilized according to soil analyses. One hundred and twenty-six plants were cultivated, spaced 1.0 m apart and a distance of 2.5 m between rows. Each row consisted of 14 plants, which represented the blocks, in a total of four. The remaining rows of plants were considered borders of the experimental plot. In each plant, four main branches were defined and trained at a height of 1.6 m from the ground using the "X" system (Muniz et al., 2011). Irrigation was provided by drip tubes with a flow rate of 1.6 $L.h^{-1}$ per emitter, spaced 30 cm apart.

As experimental treatments, two moments of plant flowering were considered: 55 and 105 days after transplantation (DAT). In each of these moments, the flowers were labeled at the time of anthesis and the respective fruits harvested 45, 60, 75, and 90 days afterwards (DAA).

Meteorological data were recorded and the average temperatures were used to calculate the thermal sum (accumulated degree-days, DD), considering the interval of transplantation of seedlings to the respective markings of flowers and fruit harvests, according to the methodology adopted by Salazar et al. (2008) and the other climate variables are summarized in **Figure 1**.

At the end of the predetermined periods, 15 fruits were harvested from each block and immediately submitted to laboratory evaluations. Initially, they were evaluated for morphology using radiographic images. For this, the fruits were placed on a transparent acrylic sheet (210 × 297 mm), which was placed inside a digital apparatus (Faxitron X-Ray, model MX-20 DC-12) 57.2 cm from the source of X-ray emission. The intensity of the radiation and the time of exposure of the fruits to X-rays were determined automatically by the equipment. The images were then transferred to a computer and analyzed individually using software program ImageJ 1.5®. The results were presented as calyx and fruit area

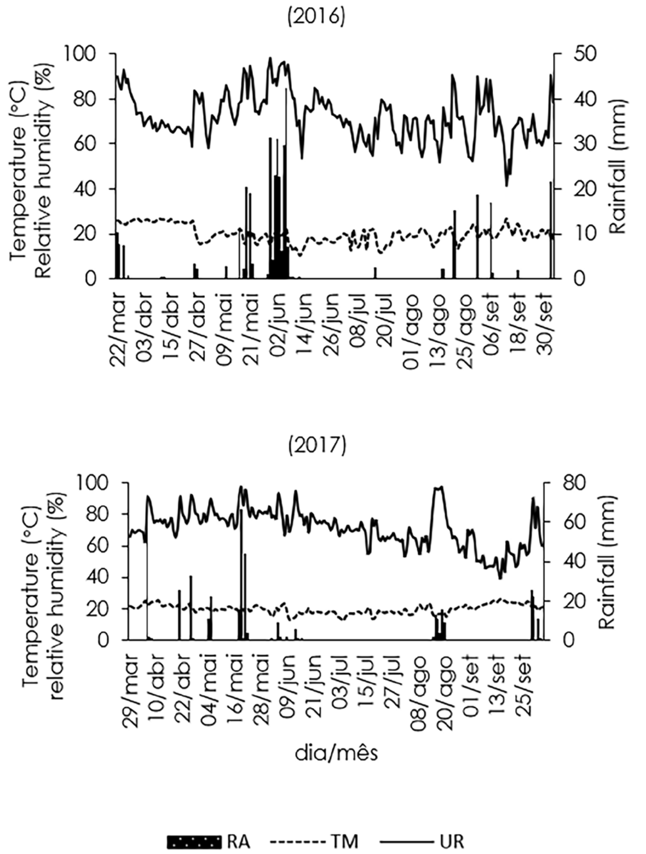

Figure 1. Average data on air temperature (TM), relative humidity (RH) and rainfall (RA) during the cultivation of *Physalis peruviana* L. in the years 2016 and 2017. Obtained at the USP/ESALQ Meteorological Station

(mm^2), fruit/calyx area ratio (%), and circularity of the calyx and fruit, which determines how circular the calyx and fruit are on a scale of 0–1.

To determine the polar and equatorial diameters (mm), a digital caliper with 0.01 mm grading was used and a digital scale with accuracy of 0.01 g was used to determine fruit mass with and without calyx (g). Based on the mass data, the relationship between the mass of fruit without the calyx and the mass of fruit with the calyx (%) were calculated; to determine the color of the calyx and the epidermis of the fruit, two readings were performed on opposite sides in the equatorial region of the calyx and epidermis of the corresponding fruit with a Minolta® colorimeter (Model CR-300) and the values of the Hue angle (h°) were noted.

Next, the fruit juice was extracted by crushing the fruits in a sieve, and the following evaluations were carried out: soluble solids (SS) content, determined by means of an Atago PR-101 Palette digital refractometer, expressed in °Brix at 20 °C; titratable acidity (TA), determined from 10 g of homogenized juice to which 90 mL of distilled water was added to read the pH of the sample; then potentiometric titration performed with 1 N NaOH to calculate the amount of citric acid, expressed as a percentage (Carvalho et al., 1990). Based on the soluble solids and titratable acidity values, the ratio (SS/TA) was determined. To evaluate the ascorbic acid content, 5 g of the juice was placed in an Erlenmeyer flask containing 25 mL of 1% oxalic acid. Titration with DCFI solution was performed, and the results were expressed in milligrams of ascorbic acid per 100 g of the juice (Carvalho et al., 1990).

The experimental design was randomized blocks, with four replications. The treatments were arranged in a 2 × 4 factorial scheme, represented by the two moments of flowering of the plants (55 and 105 DAT) and the age of the fruits (45, 60, 75, and 90 DAA). The data were submitted to analysis of variance and comparisons between the means by the Tukey test ($p < 0.05$).

Results and Discussion

Meteorological data records showed that in the first year of the experiment (2016) rainfall was more frequent, especially between May and the beginning of June, with an accumulation of 377.3 mm, equivalent to 90% of the rainfall occurring in the second year (2017). The average temperature and relative humidity for the 2 years were 19.9 °C and 72%, respectively (Figure 1).

These climatic conditions, which occurred during the cultivation period, are consistent with those suitable for the cultivation of *P. peruviana* plants because the optimum temperature is between 8 °C and 20 °C. Lower temperatures compromise the development of the plants, whereas higher temperatures hinder flowering and fruiting (Salazar et al., 2008). In addition, according to Fischer & Melgarejo (2022), rainfall of 1,000–1,800 mm that is well distributed throughout the year and relative air humidity between 70% and 80% are favorable for the vegetative and reproductive development of the plants.

P. peruviana is a rustic plant and can be grown in broad agroecological conditions (Fischer et al., 2014). Aparecido et al. (2019), through climate risk zoning, demonstrated that 10% of the area in the southeastern region of Brazil is climatically suitable for the cultivation of this species.

Table 1 shows the sums of thermal units in accumulated DD of the periods between seedling transplantation and the moments of flower marking (55 and 105 DAT) and of transplantation and harvests (45, 60, 75, and 90 DAA).

On average, at 55 DAT, plants accumulated 887 DD and at 105 DAT, they acquired 1,430 DD. Therefore, the two moments of flower marking were distinguished by an interval of 50 days and an average accumulation of 543 DD.

Considering the flowers marked at 55 DAT and that most of the variables analyzed indicate the physiological maturity of the fruits at 75 DAA, there was an average accumulation of 886 DD before harvest. For fruits originating from flowers issued at 105 DAT, there was a tendency to anticipate maturity at 60 DAA, with the average thermal sum equivalent to 744 DD, between anthesis and harvest, i.e., fruits originating from the first flowers (55 DAT) required more time and thermal accumulation to reach maturation than the fruits of flowers issued at 105 DAT. These results were possibly influenced by different temperatures throughout the plant development because the average temperatures were 17.4 °C in 2016 and 17.6 °C in 2017 in the period of development of fruits harvested at 75 DAA (55 DAT), whereas the average temperatures were similar, 18.7 °C, in the 2 years in which the research was conducted, i.e., the temperatures occurring during the development of the fruits from the second moment of flowering were 1 °C higher in relation to the first flowering during the development of fruits harvested at 60 DAA (105 DAT).

In relation to the coloration of the calyx and epidermis of the fruit, there was interaction between the factors “moment of flowering” and “age of the fruit” in the 2 years of this study (**Tables 2 and 3**).

The highest values of the hue angle (h°) are

Table 1. Accumulated degree-days (DD) in the intervals from transplantation to the moments of flower marking (55 and 105 days after transplantation, DAT) and from transplantation to harvesting of fruits of *P. peruviana* L., carried out at 45, 60, 75, and 90 days after anthesis (DAA). Years 2016 and 2017

Flower. (DAT)	Ac. degree-days (DD)	(DAA)			
		45	60	75	90
		2016			
55	955	1.443	1.639	1.835	2.020
105	1.483	2.101	2.262	2.514	2.678
		2017			
55	818	1.325	1.488	1.710	1.898
105	1.377	1.912	2.086	2.371	2.578

Table 2. Means of the hue angle (h°) of the calyx and epidermis of the fruits of *Physalis peruviana* L. harvested at 45, 60, 75, and 90 days after anthesis (DAA) for two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2016

Flower. (DAT)	(DAA) 45	60	75	90	Mean
		h° calyx			
55	111,2aA	107,4 aB	77,1 aC	72,6 aD	92,1
105	110,2aA	88,4 bB	70,9 bC	73,6 aC	85,8
Mean	110,1	97,9	74,0	73,1	-
		h° epidermis			
55	110,8aA	94,6 aB	75,5 aC	75,5 aC	89,1
105	110,1aA	78,6 bB	76,5aBC	75,0 aC	85,0
Mean	110,4	86,6	76,0	75,2	-
$CV_{h° calyx}$ = 2,2%; $CV_{h° epidermis}$ = 1,3%					

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test (p < 0.05); CV = Coefficient of variation

Table 3. Means of the hue angle (h°) of the calyx and epidermis of the fruits of *Physalis peruviana* L. harvested at 45, 60, 75, and 90 days after anthesis (DAA) for two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2017

Flower. (DAT)	(DAA) 45	60	75	90	Mean
		h° calyx			
55	113,6 aA	112,9 aA	82,0 aB	72,9 bC	95,4
105	110,6 bA	95,4 bB	76,2 bC	76,5 aC	89,7
Mean	112,1	104,2	79,1	74,7	-
		h° epidermis			
55	110,0 aA	89,5 aB	78,4 aC	77,3 aC	88,8
105	107,6 aA	82,6 bB	78,0 aC	76,0 aC	85,1
Mean	108,8	86,1	78,2	76,7	-
$CV_{h° calyx}$ = 2,1%; $CV_{h° epidermis}$ = 2,1%					

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test (p < 0.05); CV = Coefficient of variation

represented by the green color; values that are less than 90° are represented by yellow and yellow-orange color. In this case, the green calyx and epidermis were observed in the fruits of 45 DAA (h° ≥ 110), whereas the yellow and "straw yellow" calyx and yellow-orange epidermis were observed in fruits starting at 75 DAA (**Figure 2.A-D**), with h° ≤ 82. Mazorra et al. (2006) point out that at the beginning of the growth of the fruit of *P. peruviana*, the calyx is green with purple stripes for more than 50 days, after which it begins to take on a chlorotic appearance, before turning straw yellow.

The lowest mean calyx and epidermis h° values were determined in fruits harvested from 75 DAA onward. However, the fruits harvested at 60 DAA, from the flowers marked at 105 DAT, presented lower values than the fruits obtained from the first flowers (55 DAT). This result suggests that there is an anticipation of the change in the green to yellow color of the fruits produced from the second moment of flowering, possibly reflecting the influence of higher temperatures.

In absolute values, the mean of h° of the fruit epidermis was lower than that of the calyx, especially for the fruits harvested at 60 DAA, which may indicate that the change from green to yellow begins first in the epidermis of the fruit and later in the calyx.

The fruit harvested from the 75 DAA (55 DAT), the epidermis of which presented an average h° of 77.0, similar to the h° value of 77.86 obtained by Rodrigues et al. (2014), which corresponds to yellow fruits. Other studies suggest that harvesting can be carried out once the color of the calyx is greenish-yellow (Lima et al., 2009; Rodrigues et al., 2012), which corresponds to the 60 DAA (105 DAT) fruits, with an average h° of the calyx of 91.9. This possibility of early harvesting is due to the fact that it is a climacteric fruit (Valdenegro et al., 2012).

Regarding the physical characteristics of the mass and diameter of the fruit, there was interaction between the factors (**Tables 4 and 5**). Analogous to the results of the colors of the calyx and epidermis, the fruit which were harvested starting at 75 DAA and originating from 55 DAT flowers had greater masses and diameters, whereas in fruits originating from 105 DAT flowers, the largest masses and diameters occurred starting at 60 DAA.

In regard to the fruit mass without calyx/fruit mass with calyx (FM/FMC) ratio, the values were similar in fruits harvested from 75 DAA onwards. From this mass ratio, it is observed that the fruit mass at 75 DAA (55 DAT) represents more than 92% of the mass of the calyx-fruit set, whereas the fruit harvested at 60 DAA, originating from the second moment of flowering (105 DAT), contributes at least 85% of the mass of the calyx-fruit set.

The contribution of the calyx mass to the combined calyx-fruit mass decreases as the maturation process progresses because it is known that at the beginning of fruit development, the calyx has an important function in the nutrition of the fruit, presenting greater retention of water and chlorophyll at this stage and contributing to an increase in fruit mass (Fischer & Lüdders, 1997). According to Mazorra et al. (2003), there is an accelerated increase in the fresh weight of the calyx in the first 15 days, which reaches its maximum value and stabilizes from the 20th day, declining sharply from 80 days onward, which coincides with the parchment-like "straw" state due to

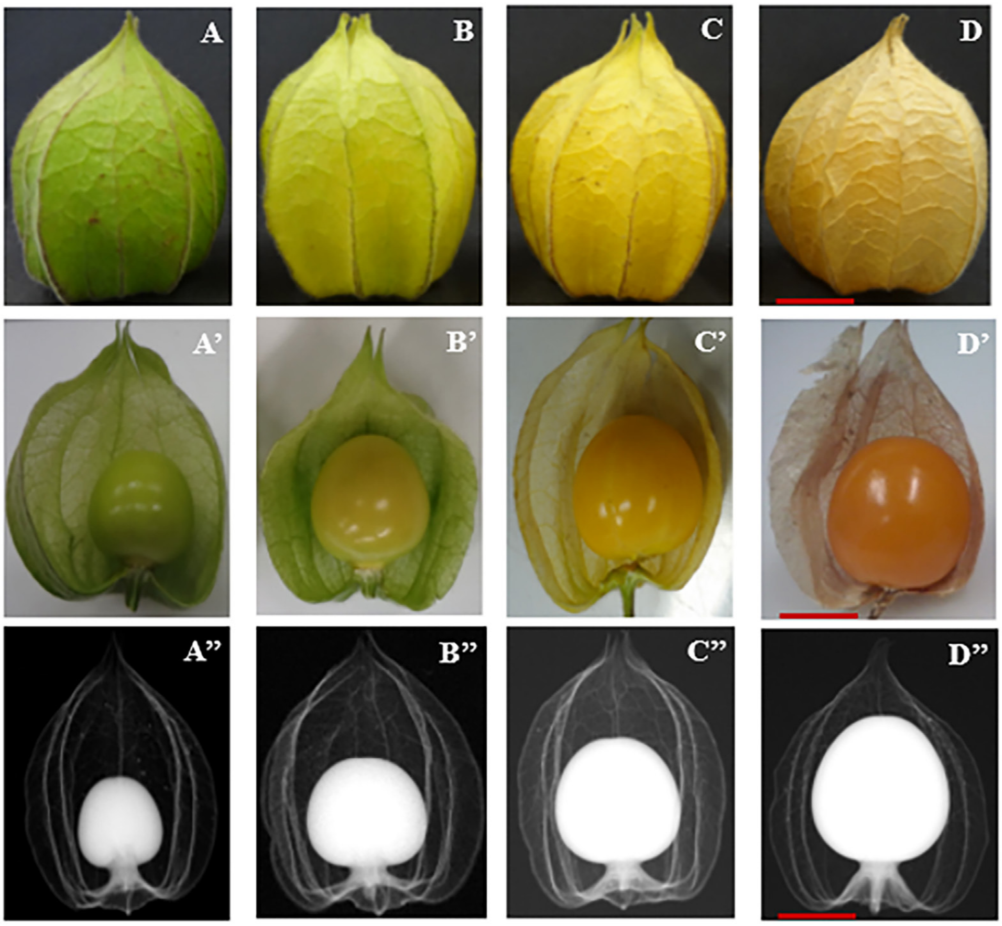

Figure 2. Images of the fruits of *Physalis peruviana* L. harvested 45, 60, 75, and 90 days after anthesis (A, B, C, D); detail of the fruit inside the calyx (A', B', C', D'); radiographic images of the fruits inside the calyx (A", B", C", D"). Bars = 1 cm

Table 4. Mean fruit mass with calyx (FMC) and without calyx (FM), ratio (FM/FMC), polar diameter (PD) and equatorial diameter (ED) of *Physalis peruviana* L. fruits harvested at 45, 60, 75, and 90 days after anthesis (DAA) in two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2016

Flower. (DAT)	(DAA) 45	60	75	90	Mean
			FMC (g)		
55	2,88 aC	4,15 bB	5,78 aA	4,66 aB	4,37
105	3,19 aC	5,37 aA	4,97 bAB	4,65 aB	4,55
Mean	3,04	4,76	5,38	4,66	-
			FM (g)		
55	2,17 aD	3,43 bC	5,44 aA	4,49 aB	3,88
105	2.51 aB	4,74 aA	4,73 bA	4,39 aA	4,10
Mean	2,34	4,09	5,08	4,44	-
			FM/FMC (%)		
55	75 bC	83 bB	94 aA	96 aA	87
105	79 aC	88 aB	95 aA	94 aA	89
Mean	77	86	95	95	-
			PD (mm)		
55	15,52 bC	17,45 bB	20,04 aA	19,35 aA	18,09
105	16,44 aB	19,61 aA	19,73 aA	19,07 aA	18,71
Mean	15,98	18,53	19,89	19,21	-
			ED (mm)		
55	15,79 bD	18,50 bC	21,39 aA	19,57 aB	18,81
105	16,64 aC	20,37 aA	20,07 bA	19,07 aB	19,04
Mean	16,22	19,437	20,73	19,32	-

CV_{FMC} = 6,8%; CV_{FM} = 6,2%; $CV_{FM/FMC}$ = 1,5%; CV_{PD} = 1,9%; CV_{ED} = 2,4%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation

Table 5. Mean fruit mass with calyx (FMC) and without calyx (FM), ratio (FM/FMC), polar diameter (PD) and equatorial diameter (ED) of *Physalis peruviana* L. fruits harvested at 45, 60, 75, and 90 days after anthesis (DAA) in two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2017

Flower. (DAT)	(DAA) 45	60	75	90	Mean
			FMC (g)		
55	3,00 aC	4,46 aB	6,95 aA	6,60 aA	5,25
105	2,90 aB	4,08 bA	4,08 bA	3,28 bB	3,58
Mean	2,95	4,27	5,51	4,94	-
			FM (g)		
55	2,29 aC	3,82 aB	6,41 aA	6,35 aA	4,72
105	2.22 aC	3,45 bAB	3,85 bA	3,11 bB	3,16
Mean	2,25	3,64	5,13	4,73	-
			FM/FMC (%)		
55	77 aD	86 aC	92 bB	96 aA	88
105	77 aC	85 aB	95 aA	95 aA	88
Mean	77	86	94	96	-
			PD (mm)		
55	16,35 aD	18,28 aC	21,00 aB	21,64 aA	19,31
105	16,13 aC	18,14 aB	19,04 bA	17,92 bB	17,81
Mean	16,24	18,21	20,02	19,78	-
			ED (mm)		
55	16,15 aC	18,78 aB	22,38 aA	22,32 aA	19,91
105	15,84 aC	18,10 bA	18,55 bA	17,16 bB	17,40
Mean	16,00	18,41	20,47	19,74	-

CV_{FMC} = 5,5%; CV_{FM} = 6,1%; $CV_{FM/FMC}$ = 1,3%; CV_{PD} = 1,4%; CV_{ED} = 2,1%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation dehydration. Lima et al. (2009) also demonstrated an inverse response of the mass of the calyx in relation to the mass of the fruit because there was a reduction in this floral whorl as the fruit ripened.

In relation to the data obtained in 2016, fruits harvested at 60 DAA, originating from flowers marked at 105 DAT, presented greater mass and polar and equatorial diameters than those harvested at 55 DAT. The opposite occurred at 75 DAA, with the fruits at this age having greater mass and diameters when originating from the flowers issued at 55 DAT. In addition, from 75 DAA (55 DAT) and 60 DAA (105 DAT) there was no more increase in mass and diameters. Avedaño et al. (2022), studied the development of cape gooseberry fruit ecotype Colombia, in the Departament of Boyaca, Colombia, and observed a rapid increase in polar and equatorial diameter between days 36 and 45 after anthesis, with a stabilization at 50 DAA, being the physiological maturity of the fruits between 60 and 65 DAA.

These results confirm the indications of the acceleration of fruit maturation resulting from the second moment of flowering and admit the hypothesis of maturity from this period, in which mass and diameter stabilization occurs, corroborating the findings of Chitarra & Chitarra (2005) who report that there is no increase in the size of the fruit after maturation, making this the ideal stage for harvesting the fruits.

The similarity between the results of 2017 and 2016 is evidenced by the stabilization of the mass (with and without the calyx) and the equatorial diameter of the fruits at 75 DAA (55 DAT) and 60 DAA (105 DAT). In addition, fruits at 75 DAA formed from flowering at 105 DAT presented smaller masses and diameters than those of the same age originating from the first moment of flowering (55 DAT). It is possible that this reduction in size (masses and diameters) is also a reflection of the lower source/drain ratio because, according to Criollo et al. (2014), the increase in the number of secondary branches causes a reduction in the mass and diameter of the fruit of *P. peruviana*.

The mean values of FMC (4.08–6.95 g) and fruit diameters (18.10–22.38 mm) starting at 75 DAA (55 DAT) and 60 DAA (105 DAT) are identical to those obtained in other Brazilian regions considered suitable for the crop, such as 6.8 g and 18.5 mm in Minas Gerais (Silva et al., 2013), 9.6 g and 17.2 mm in Rio Grande do Sul (Lima et al., 2009), and 3.4 g and 17.3 mm in Santa Catarina (Muniz et al., 2011). It should be noted that the fruits of *P. peruviana* are marketed inside the calyx, which is harvested with a fragment of the peduncle (stalk). However, in the present study, the peduncle was cut close to the calyx; if maintained, the mass of the fruit-calyx set could be greater.

The variables contained in **Tables 6 and 7** were obtained from the radiographic images of the fruits (Figure 2.A''–D''). The absence of interaction between the factors was observed only in relation to the area and circularity of the calyx, relating to the data obtained in 2016. These variables were influenced only by the age of the fruits because the fruits harvested at 45 DAA and 60 DAA presented the largest calyx areas of 895.4 mm^2 and 890.37 mm^2, respectively, whereas the smallest area was seen in fruits harvested at 90 DAA (765.72 mm^2).

Regarding the circularity of the calyx, the effect was similar as the 45 DAA and 60 DAA fruits differ from the others because they have the highest circularity indices of 0.59 and 0.56, respectively, giving them their rounded "globular" shape. The calyx has active metabolic activity at the beginning of fruit development and there is degradation of chlorophyll, dehydration of tissues, reduction of turgescence, and loss of globular shape as the fruit ripens. Consequently, there is a reduction of the area and a decrease in the circularity of the calyx in fruits in the more advanced stages of maturation (75 and 90 DAA). The data on the calyx area of the fruits produced in 2017 did not vary throughout development, which did

Table 6. Mean area (AC) and circularity (CC) of the calyx; area (AF) and circularity (CF) of the fruits and AF/AC ratio (%) of the fruits of *Physalis peruviana* L. harvested at 45, 60, 75, and 90 days after anthesis (DAA) at two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2016

Flower.	(DAA)				Mean
(DAT)	45	60	75	90	
		AC (mm^2)			
55	889,55	898,22	879,45	754,11	855,33 a
105	901,25	882,53	811,03	777,32	843,03 a
Mean	895,40 A	890,37AB	845,23	765,72C	-
		CC			
55	0,61	0,56	0,44	0,42	0,51a
105	0,58	0,55	0,45	0,34	0,48a
Mean	0,59A	0,56 A	0,45B	0,39B	-
		AF (mm^2)			
55	177,43bD	231,03bC	326,00aA	276,10aB	252,64
105	194,35aC	294,13aAB	302,54bA	272,10aB	266,01
Mean	185,89	262,58	314,27	274,54	-
		CF			
55	0,55aC	0,59aBC	0,62bB	0,75aA	0,63
105	0,56aB	0,61aB	0,75aA	0,79aA	0,68
Mean	0,55	0,60	0,68	0,77	-
		AF/AC (%)			
55	20,0aC	25,8bB	37,3aA	36,6aA	30,0
105	21,6aC	33,4aB	37,3aA	35,2aAB	31,8
Mean	20,8	29,6	37,3	35,9	-

CV_{AC} = 4,0%; CV_{CC} = 9,6%; CV_{AF} = 4,2%; CV_{CF} = 4,6%; $CV_{AF/AC}$ = 3,8%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation

Table 7. Mean area (AC) and circularity (CC) of the calyx; area (AF) and circularity (CF) of the fruits and AF/AC ratio (%) of the fruits of *Physalis peruviana* L. harvested at 45, 60, 75, and 90 days after anthesis (DAA) at two moments of plant flowering, at 55 and 105 days after transplantation (DAT). Year 2017

Flower. (DAT)	(DAA) 45	60	75	90	Mean
AC (mm²)					
55	887,10 aA	939,41aA	931,21aA	898,95aA	916,66
105	847,51 aA	791,03bA	779,35bA	672,11bB	772,50
Mean	872,29	865,22	855,28	785,53	-
CC					
55	0,56 aA	0,55 aA	0,46aB	0,31aC	0,47
105	0,59 aA	0,58 aA	0,35bB	0,29 aB	0,45
Mean	0,57	0,56	0,40	0,30	-
AF (mm²)					
55	190,59 aC	252,29 aB	366,30 aA	361,64aA	292,70
105	192,36 aC	238,38 aB	269,88 bA	222,76bB	230,84
Mean	191,47	245,33	318,10	292,20 B	-
CF					
55	0,51 aB	0,58 aAB	0,55 bAB	0,66aA	0,58
105	0,52 aB	0,58 aB	0,74 aA	0,72aA	0,64
Mean	0,51	0,58	0,64	0,69	-
AF/AC (%)					
55	21,3 aC	26,9 bB	39,4 aA	40,3aA	31,9
105	22,7 aC	30,1 aB	34,7 bA	33,2bA	30,2
Mean	22,0	28,5	37,0	36,7	-

CV_{AC} = 4,8%; CV_{CC} = 8,6%; CV_{AF} = 4,2%; CV_{CF} = 10,9%; $CV_{AF/AC}$ = 4,3%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation

not allow characterization of the difference in the area. However, the indices of circularity of fruits at 45 DAA (0.51) and 60 DAA (0.58) were similar to those observed in 2016.

Conversely to what was observed with the calyx, the area and the circularity of the fruits increased as soon as the fruit was developed. The largest fruit area was reached starting at 75 DAA and from this stage onward, the shape was rounded, resulting in the highest circularity indices of over 0.55.

The percentage ratio of the calyx area occupied by the fruit (AF/AC) was higher in the fruits harvested starting at 75 DAA, regardless of the moment of flowering, which can be explained by the physical alterations occurring in opposite directions in the calyx and fruit. The calyx grows more and reaches its maximum size in the first 25 days, i.e., before the fruit, providing space for the growth of the fruit within it (Mazorra et al., 2003). Therefore, while there is a stoppage in the growth of the calyx, the fruit increases in mass and diameters, as was observed in this study up to 75 DAA (55 DAT) and 60 DAA (105 DAT). From then on, the calyx tended to turn yellow and dehydrate, causing reduced turgor and, consequently, a reduction in area.

Apparently the calyx has no metabolic function after harvest, but it protects the fruit and can even prolong the life of the fruit during storage, by reducing respiratory intensity and losses in weight and coloration. Furthermore, the fruits are marketed with the calyx intact, as they are often used for ornamentation in cooking.

In terms of the qualitative attributes of the fruits (**Tables 8 and 9**), there was significant interaction in all variables, with the exception of the pH of the fruits of the year 2016. These values were influenced by the factors in isolation, which increased significantly starting at 75 DAA, especially in the fruits from the second fruiting moment (105 DAT).

SS and the ratio increased and TA decreased with fruit maturation. Therefore, the fruits harvested starting at 75 DAA (55 DAT) and 60 DAA (105 DAT) presented the characteristics and patterns necessary for harvesting and marketing, similar to those observed in fruits harvested with yellow calyx and "straw" color (Lima et al., 2009; Rodrigues et al., 2014; Silva et al., 2013).

Singh et al. (2012) studied the development of *P. peruviana* fruits until the 8th week after anthesis and verified a linear decrease in the water content and proportional weight of the calyx, a decrease in chlorophyll content and an increase in carotenoids, a decrease in acidity, and an increase in soluble solids. These results confirm the changes typical in the evolution of maturation: the degradation of chlorophyll, making pre-existing pigments visible, and/or the synthesis of new pigments, the synthesis of sugars and the reduction of acidity (Balaguera-López el al. 2024).

Table 8. Mean pH, soluble solids (SS), titratable acidity (TA), ratio (SS/AT), and vitamin C (Vit. C) content of *Physalis peruviana* L. fruits harvested at 45, 60, 75, and 90 days after anthesis (DAA) in two moments of plant flowering at 55 and 105 days after transplantation (DAT). Year 2016

Flower. (DAT)	(DAA) 45	60	75	90	Mean
pH					
55	3,64	3,57	3,76	3,85	3,70 b
105	3,65	3,70	3,88	3,97	3,80 a
Mean	3,64 C	3,63 C	3,82 B	3,91 A	-
SS (°Brix)					
55	6,8 bD	11,4 bC	14,3 bB	16,3 bA	12,2
105	8,1 aD	14,0 aC	15,9 aB	18,7 aA	14,2
Mean	7,4	12,7	15,1	17,5	-
TA (% citric acid)					
55	2,60 bB	3,18 aA	1,91 aC	1,91 aC	2,40
105	3,10 aA	2,02 bB	1,92 aBC	1,75 aC	2,20
Mean	2,85	2,60	1,91	1,83	-
ratio (SS/TA)					
55	2,6 aB	3,6 bB	7,5 aA	8,6 bA	5,6
105	2,6 aD	6,9 aC	8,4 aB	10,7 aA	7,2
Mean	2,6	5,3	8,0	9,7	-
VIT. C (mg ascorbic acid.100 g⁻¹)					
55	14,78 bC	47,52 aA	39,77 aB	47,43 aA	37,38
105	36,53 aC	42,54 bB	38,28 aC	45,90 aA	40,81
Mean	25,66	45,03	39,02	46,66	-

CV_{pH} = 1,4%; CV_{SS} = 3,4%; CV_{TA} = 5,6%; CV_{ratio} = 9,2%; $CV_{VIT.C}$ = 4,2%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation

Table 9. Mean pH, soluble solids (SS), titratable acidity (TA), ratio (SS/AT), and vitamin C (Vit. C) content of *Physalis peruviana* L. fruits harvested at 45, 60, 75, and 90 days after anthesis (DAA) in two moments of plant flowering at 55 and 105 days after transplantation (DAT). Year 2017

Flower. (DAT)	(DAA) 45	60	75	90	Mean
			pH		
55	3,67 aB	3,54 aC	3,82 bA	3,79 bA	3,70
105	3,65 aC	3,57 aD	3,92 aB	4,05 aA	3,80
Mean	3,66	3,55	3,87	3,92	-
			SS (°Brix)		
55	7,9 bC	13,8 bB	16,3 bA	16,1 bA	13,5
105	9,7 aC	14,3 aB	17,1 aA	16,9 aA	14,5
Mean	8,8	14,0	16,7	16,5	-
			TA (% citric acid)		
55	3,13 bA	3,10 aA	2,28 aB	1,91 aC	2,60
105	3,36 aA	2,10 bB	1,74 bBC	1,73 bC	2,23
Mean	3,25	2,58	2,01	1,82	-
			ratio (SS/TA)		
55	2,5 aD	4,5 bC	7,2 bB	8,4 bA	5,6
105	2,9 aC	6,9 aB	9,8 aA	9,7 aA	7,3
Mean	2,7	5,7	8,5	9,1	-
			VIT. C (mg ascorbic acid.100 g^{-1})		
55	21,37 bC	51,28 aAB	47,53 aB	53,02 aA	43,30
105	37,82 aB	53,53 aA	48,95 aA	51,19 aA	47,83
Mean	29,59	52,31	48,24	52,11	-

CV_{pH} = 1,0%; CV_{SS} = 2,5%; CV_{TA} = 3,5%; CV_{ratio} = 5,9%; $CV_{VIT.C}$ = 5,9%

Means followed by the same lowercase letters in the column and uppercase in the row do not differ from each other through the Tukey test ($p < 0.05$); CV = Coefficient of variation

The fruits produced at the second moment of flowering (105 DAT), regardless of the maturation stages, had higher soluble solids than those produced at the beginning of flowering (55 DAT) of the plants. Lima et al. (2012) evaluated the characteristics of *P. peruviana* L. fruits throughout the harvest period in two planting seasons and verified that the highest SS and ratio levels occurred in plants 240 days after seedling transplantation. Bravo et al. (2015), analyzing fruits of *P. peruviana* harvested in the months of June and August, found that those harvested in the second moment had more soluble solids than those harvested in the first moment, suggesting that this was caused by increased temperature and higher evapotranspiration.

According to Beckles (2012), several pre-harvest factors, including high solar radiation and high temperatures, positively influence sugar levels of Solanaceae fruits. This affirmation can be considered in this study because when fruits from flowers issued at 105 DAT were harvested, some plants had fewer leaves, which favored an increase in the incidence of sun rays on the fruits. Furthermore, according to Chitarra & Chitarra (2005), organic acids are used as substrates in the respiratory process during maturation and, because a part of these is translocated from roots or leaves to fruits, partially defoliated plants have less acidic fruits than those of normal plants.

Regarding ascorbic acid content, the lowest values were obtained in younger fruits (45 DAA) and in plants flowering at 55 DAT. In general, there was variation in the content during maturation, with ascorbic acid content increasing in 60 DAA fruits, reducing in 75 DAA fruits, and further increasing in 90 DAA fruits. Although they studied the development of *P. peruviana* fruits for only 8 weeks, Singh et al. (2012) found that the content of ascorbic acid increased between the 2^{nd} and 4^{th} weeks (5.9–8.4 mg.100 g^{-1}) and between the 6^{th} and 7^{th} weeks after anthesis (8.7–10.7 mg.100 g^{-1}).

Bravo et al. (2015) also found an increase in the ascorbic acid content and then a subsequent reduction with the advance of maturation, this variation is attributed to the antioxidant role of ascorbic acid, which increases with an increased respiratory rate in climacteric fruits.

Given the above, it can be stated that there is an increase in the mass and diameter of the fruit up to 75 DAA (55 DAT), after which changes occur in the color of the calyx (h° ≤ 95.4) and the epidermis of the fruit (h° ≤ 78.4), which change from green to yellow, accompanied by changes in the flavor of the fruit. With the increase in SS (> 14.0 °Brix), there is an increase in pH (≥ 3.76), a decrease in TA (≤ 2.28%), and an increase in the ratio (≥ 7.2). In this phase, the fruit has a circular shape (circularity ≥ 0.55), occupies more than 37% of the calyx area, and contributes to at least 92% of the mass of the calyx-fruit set. In fruits originating from flowering at 105 DAT, most of these typical maturation changes are noticeable at 60 DAA.

Conclusions

Fruits harvested at 75 DAA, from the first moment of flowering (55 DAT), and 60 DAA, from flowers issued at 105 DAT, present parameters (mass, size, color, and flavor) that characterize physiological maturity.

The necessary thermal accumulation from anthesis to physiological maturity of the fruit varies between the moments of flowering of the plant; 886 DD for fruits at 75 DAA (55 DAT) and 744 DD for fruits at 60 DAA (105 DAT).

The fruits of *P. peruviana* produced in Piracicaba, São Paulo, have a quality standard that makes them suitable for marketing.

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