100 Chilean J. Agric. Anim. Sci. (2026) 42(1):100-112.
https://doi.org/10.29393/CHJAAS42-9PSQP40009

ISSN 0719-3890 online

POSTHARVEST QUALITY AND SEED PERFORMANCE OF *Physalis peruviana* FRUITS DURING MATURATION

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ABSTRACT

Physalis peruviana **has attracted increasing research interest due to its production and fruit quality characteristics. This study aimed to determine the optimal harvest point to maximize fruit yield and seed quality in *P. peruviana* during maturation. Five harvest points were established based on the calyx color (V: green, VA: yellow-green, A: yellow, AP: straw-yellow, and P: straw) to evaluate various quality variables. Measurements were conducted at three evaluation time points: at harvest, 10 days after harvest (DAH), and 20 DAH. Fruit color darkened over time during storage across all harvest points, whereas saturation remained constant. An increase in fruit height was observed with fruit maturation in the three periods analyzed. Fruits harvested at the fully ripe point (P) showed a reduction in height over the storage period. Fruit mass, with and without calyx, differed significantly at harvest point V. Total soluble solids (TSS) increased with maturation and storage time, whereas total titratable acidity (TTA) decreased, resulting in an increase in the maturation index. Regarding fruit quality parameters, the optimal harvest points correspond to VA, A, and AP calyx coloration. Freshly extracted seeds had higher water content and dry mass at harvest point V, while higher germination was observed at point A. The highest number of seeds per fruit occurred at point AP. In dried seeds, seedling emergence and emergence speed index were recorded greater values at point A, with increased germination between A and AP harvest points. The most frequently detected fungal pathogens belonged to the genera *Aspergillus*, *Cladosporium*, and *Fusarium*. Harvest point A (yellow calyx) was identified as the optimal harvest stage for *P. peruviana* seed production.**

Keywords: cape gooseberry, harvest point, germination, organic agriculture.

Received: August 11, 2025 Accepted: April 16, 2026

INTRODUCTION

Physalis peruviana L. is a member of the Solanaceae family and is considered a rustic and shrubby species that may behave as either an annual or perennial, depending on soil and climate conditions (Muniz et al., 2014; Diniz and Novembre, 2019). Its fruits are characterized by their distinctive flavor and appearance and are covered by a calyx composed of thin leaves that protect them from herbivores and adverse environmental conditions (Silva et al., 2013). The ripe fruit of *P. peruviana* is a fleshy berry, typically spherical or ovoid, approximately 2 cm in diameter, with a strong aroma and yellow-orange color (Fischer, 2000; Silva et al., 2013).

The fruit of *P. peruviana* is considered a functional food due to its rich medicinal and nutraceutical properties and associated health benefits (Puente et al., 2021). It contains vitamins A, B complex, and C, as well as withanolide-type compounds known as physalins, which have been studied for their potential to inhibit tumor cell growth (Fischer, 2000; Zhang et al., 2020; Mohammed et al., 2024). Due to these distinctive characteristics, physalis fruits have attracted increasing interest in recent years, driving both scientific research and market growth. Consequently, cultivation of this commercially important species has expanded into new regions, including Brazil (Fischer et al., 2014).

For the maturation and harvesting of *P. peruviana* fruits, the primary indicator is visual assessment of calyx coloration, whereas fruit epidermal color is used as a parameter for postharvest classification (Diniz and Novembre, 2019). However, fruit color is not used as a harvest indicator because the calyx remains completely closed, preventing its visualization (De Souza et al., 2022). Therefore, calyx and fruit coloration are more reliable when evaluated in conjunction with other physical, chemical, and biochemical quality characteristics (Balaguera-López et al., 2024).

Quality is a set of characteristics encompassing measurable technical aspects that differentiates individual components of a given product (Malik et al., 2014). In horticultural products, quality can be assessed through physical, chemical, nutritional, and sensory parameters, including integrity, color, freshness, and texture, which can be influenced by factors such as cultivar, soil type, climate, production system, and harvest point (Fischer et al., 2021). Therefore, it is essential to conduct physicochemical, postharvest, and sensory evaluations during fruit development to accurately characterize the maturation process and distinguish developmental stages, thereby maximizing postharvest shelf life and use while minimizing losses for the producer.

Although physalis cultivation is gaining popularity worldwide, studies on its propagation and seed quality remain scarce (Diniz and Novembre, 2019). Therefore, further research on the primary propagation method for this species is essential, as clarifying technical aspects for obtaining high-quality seeds minimizes the risk of losses during seedling establishment, thereby increasing the likelihood of successful crop development (Da Silva et al., 2020).

In general, seed development occurs concurrently with fruit development (Carvalho and Nakagawa, 2012; Barroso et al., 2022), and in fleshy fruits, seed physiological maturity often coincides with the onset of calyx color change (Rodrigues et al., 2021). According to Pérez-Camacho et al. (2012), seed physiological quality is related to harvest timing. When harvested prematurely, before the seeds have reached maturity, they exhibit lower germination and vigor than mature seeds (Rodrigues et al., 2021).

This study aimed to evaluate the postharvest and physicochemical characteristics of *Physalis peruviana* L. fruits during maturation to determine the optimal harvest point for optimal fruit utilization and high-quality seed production, considering physiological and sanitary attributes.

MATERIAL AND METHODS

The experiment was conducted in the experimental area of the Organic Agriculture Laboratory at UFSCar, Federal University of São Carlos, in the city of Araras, São Paulo, Brazil (latitude 22.307077° South, longitude 47.378148° West, and altitude 696 m). The soil of the area is classified as Latosolic Dystrophic Red Argisol (Yoshida; Stolf, 2016), and the mean temperature during the experiment (March-September 2023) was 20 °C.

Seedlings were produced from *P. peruviana* seeds extracted from commercial fruit. Four physalis seeds were sown in each cell of five 128-cell polyethylene trays. After germination, the plants were watered daily by hand with tap water on a sieve-type watering can. At 58 days after sowing (DAS), 256 seedlings were transplanted to the experimental field with a 0.8 m line spacing and 0.5 m plant spacing. Organic compost resulting from the composting of pruning waste was applied to fertilize the plants (98 and 160 DAS), and the soil was mulched with dry grass mulch to maintain organic matter and soil moisture. Irrigation was carried out every three days. When necessary, pest and disease management was carried out in accordance with the specific requirements of organic farming, with spraying of a *Bacillus thuringiensis* solution (commercial product DimyPel, 5 g L^{-1}) for biological control of fruit- and stem-boring lepidopteran insects (178 and 199 DAS). Flowering began at 111 DAS, fruit ripening occurred at 156 DAS, and harvesting began at 217 DAS.

Physicochemical and postharvest analyses

The physicochemical and postharvest analyses were performed at the Sensory Analysis Laboratory of the Center for Agricultural Sciences at the Federal University of São Carlos (UFSCar), Araras, São Paulo, Brazil. Five harvest points were established based on calyx color as a morphological marker: green (V), yellow-green (VA), yellow (A), straw-yellow (A), and straw (P) (Fig. 1). For each point, 40 fruits were harvested. Analyses were conducted at three evaluation time points: at harvest, 10 days after harvest (DAH), and 20 DAH.

The fruits were stored in open plastic boxes at room temperature (±25 °C) for evaluation at 10 and 20 DAH. Fruit size (height and diameter, cm) was determined in 16 randomly selected fruits (four replicates of four fruits) at each harvest point using a Vernier caliper (model 530-104, Mitutoyo, Japan; 200 mm). Fruit mass with and without calyx (g) was determined using a semi-analytical balance (model BL320H, Shimadzu, Japan; readability: 0.001 g). Based on these measurements, fruit mass loss was analyzed between the day of harvest and 10 days of storage.

Instrumental color was obtained from four randomly selected fruits at each harvest point using a portable spectrophotometer (model CM-25d, Konica Minolta Sensing Americas Inc., USA.). Two readings were taken on opposite sides of the fruit epidermis for each fruit. According to Ferreira and Spricigo (2017), L* indicates lightness (0 = black and 100 = white), and Chroma (C*) represents color saturation. The hue angle (h) graphically represents 0° and 360° as red, 90° as yellow, 180° as green, and 270° as blue.

Ten fruits from each harvest point were used to obtain a solution to determine pH using a benchtop pH meter (EEQ9003-110, Edutec Astral, Brazil). Total soluble solids (TSS, °Brix) were measured using a digital refractometer (AK181, Compact Brix Akso, Brazil), and total titratable acidity (TTA) was assessed by neutralization titrimetry. Three analytical replicates were performed for each measurement. TSS and TTA were determined according to the methodology described by Instituto Adolfo Lutz (IAL, 2008). The maturation index (MI = TSS/TTA) was calculated based on the relationship between TSS and TTA values.

For the physicochemical and postharvest analyses, the experiment was conducted in a completely randomized design with a 5×3 split-plot arrangement (five harvest points evaluated at three different times). Data were subjected to

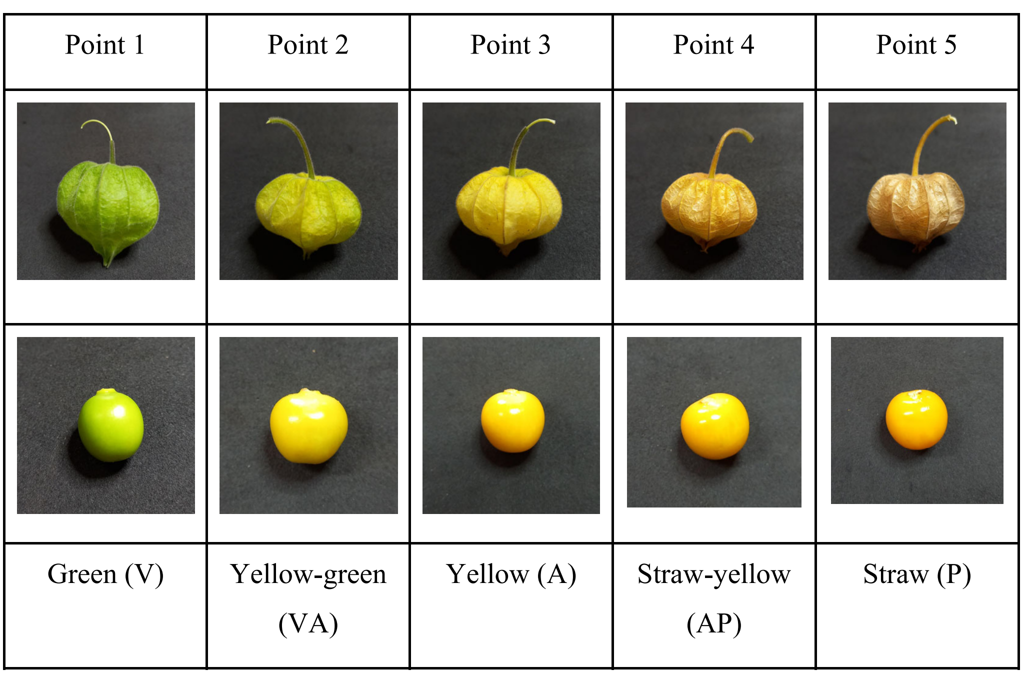

Fig. 1. Harvest points of *Physalis peruviana* fruits established using calyx color as a morphological marker.

analysis of variance (ANOVA) with a significance level of $p \leq 0.05$. When interactions between factors were significant, means were compared using Tukey's test in R software (R Core Team, 2023).

Seed quality analysis

Seed quality assessments were performed at the Organic Agriculture Laboratory (LAO) of the Center for Agricultural Sciences at the Federal University of São Carlos (UFSCar), Araras, São Paulo, Brazil.

Twenty *P. peruviana* fruits were randomly harvested from each of five harvest points based on calyx color as a morphological marker: green (V), yellow-green (VA), yellow (A), straw-yellow (AP), and straw (P) (Fig. 1). Five fruits from each harvest point were used for manual seed counting. Seeds were extracted using a sieve under running water, and residual pulp was removed with tweezers.

After seed extraction, analyses of water content, seed dry matter mass, and germination were performed on both freshly extracted seeds and seeds dried for 7 days in a cold, dry chamber (10 °C and 40% relative humidity). Water content and dry matter were determined using two replicates of seeds per harvest point. Samples were weighed using a semi-analytical balance (BL320H, Shimadzu, Japan; readability: 0.001 g) and dried in a forced-air oven (SAE 64L, 7Lab, Brazil) at 105 °C for 24 h (Brasil, 2009a).

Germination tests were performed on both freshly extracted and dried seeds, with four replicates of 50 seeds per harvest point. Seeds were placed on two sheets of Germitest paper moistened with water at 2.5 times the paper weight and arranged in plastic Gerbox-type boxes with lids (Brasil, 2009a). The boxes were maintained in a B.O.D. incubator at 25 °C, and evaluations were performed at 7 and 14 days (Diniz et al., 2020). Seedling emergence, emergence speed, and sanitary quality tests were performed only on the dried seeds.

Seedling emergence and emergence speed were evaluated using 128-cell polyethylene trays filled with vermiculite as substrate, with one seed sown per cell. Four replicates of 50 seeds were used, totaling 200 seeds per treatment. Trays were irrigated daily. Emergence was recorded daily by counting the number of seedlings that emerged until stabilization, which occurred at 17 DAS. The emergence speed index (ESI) was calculated according to the equation proposed by Maguire (1962).

Sanitary quality tests were conducted using sterilized Petri dishes with two sheets of filter paper moistened with distilled water (Brasil, 2009b). Four replicates of 50 seeds were used for each harvest point. The plates were maintained in B.O.D. incubator at 25 °C for 7 days, after which fungal occurrence was assessed using a magnifying glass and, when necessary, a microscope.

The experimental design for seed analyses was completely randomized, considering five treatments (harvest points). Data were subjected to analysis of variance (ANOVA) at a significance level of $p \leq 0.05$. When significant differences among treatments were found, means were compared using Tukey's test in R software (R Core Team, 2023).

RESULTS AND DISCUSSION

Physicochemical and postharvest analyses

There was a significant interaction between storage time and harvest points for all fruit color parameters (data not showed). The luminosity parameter (L*) was higher at points V, VA, and A than at P at 0 DAH (Table 1). At 0 DAH, L* values also differed from those at 10 and 20 DAH for all harvest points, except for point V, which did not differ from 10 DAH. Only harvest points V and A showed significant differences in L* values between 10 and 20 DAH, indicating a darkening of fruit color at these points. At 20 DAH, no significant differences in fruit luminosity were observed among harvest points. Overall, these results indicate that fruit color darkened during storage across all harvest points.

Luminosity (L*) decreased with maturation and storage time, attributed to oxidation, moisture loss, and browning associated with ascorbic acid degradation (Álvarez-Herrera et al., 2024; Weber et al., 2024). The L* values of *P. peruviana* fruits at all harvest points at 0 DAH are closer to those of lighter-colored fruits, contrasting with previous studies in which fruits showed an increase in luminosity as they ripened (Lima et al., 2009; Rodrigues et al., 2021).

At 0 DAH, C* values indicated that fruits from more advanced harvest points had significantly more vivid colors than fruits harvested at point V (Table 1). However, during storage, differences in color saturation among harvest points were no longer observed, resulting in similar color saturation. Color intensity in *P. peruviana* does not follow a predictable pattern and may vary depending on maturation and storage conditions (Silva et al., 2018; Rodrigues et al., 2021).

The hue angle (h) values indicated a predominantly yellowish coloration of the fruits. However, fruits from harvest point V at 0 DAH presented the highest hue value, indicating a color closer to greenish-yellow (Table 1). The later the harvest point, the riper the fruits, the lower

Table 1. Color (L*, C*, and h) of the epidermis of *Physalis peruviana* fruits at different harvest points and days after harvest (0, 10, and 20 DAH).

Parameters	Time (DAH)	Harvest point					CV (%)
		V	VA	A	AP	P	
L*	0	68.64 Aa	68.78 Aa	69.73 Aa	67.45 Aab	63.84 Ab	$CV_1 = 4.29$
	10	69.48 Aa	59.07 Bb	60.78 Bb	59.10 Bb	56.74 Bb	$CV_2 = 3.14$
	20	57.11 Ba	55.75 Ba	54.43 Ca	56.59 Ba	54.18 Ba	
C*	0	51.17 Bb	62.06 Aa	61.19 Aa	61.97 Aa	62.61 Aa	$CV_1 = 4.24$
	10	55.56 ABa	56.65 Ba	61.20 Aa	58.84 ABa	59.88 Aa	$CV_2 = 5.19$
	20	59.09 Aa	61.33 ABa	58.57 Aa	56.33 Ba	57.31 Aa	
h	0	91.44 Aa	72.42 Ab	71.27 Abc	68.56 Abc	66.88 Ac	$CV_1 = 3.38$
	10	80,78 Ca	68,43 Ab	65,77 Bbc	62,27 ABbc	63,66 ABc	$CV_2 = 3.44$
	20	68,21 Ca	63,45 Bb	61,44 Cb	62,77 Bb	61,10 Bb	

Means followed by the same uppercase letter within columns and lowercase letter within rows do not differ significantly according to Tukey's test at 5% significance level. V= green, VA= green-yellow, A= yellow, AP= yellow-straw, P= straw.

the hue values, indicating fruits with a color closer to orange. All subsequent harvest points differed significantly from the hue values, and therefore, from the hue of the fruits at point V. The same was observed at 10 and 20 DAH; fruits harvested at point V were more greenish-yellow than those harvested at other harvest points, which is expected due to the ripening process, in which fruits tend to degrade chlorophyll and acquire an orange/reddish coloration due to carotenoid synthesis (Ramos et al., 2021; Barroso et al., 2022; Weber et al., 2024).

Fruits harvested at point V were significantly shorter in height than those harvested at more advanced ripening stages at 0 DAH (Table 2). Point V also had the lowest height values in the other two storage periods analyzed; however, significant differences in height were observed only between fruits harvested at this point and those harvested at point P at 10 DAH, and only for AP at 20 DAH. In general, an increase in fruit height was observed with fruit maturation in the three periods analyzed. At each harvest point, the fruits generally decreased in size during storage, likely due to water loss (Agudelo-Sánchez et al., 2023; Álvarez-Herrera et al., 2024; Lima et al., 2024). This loss is associated with postharvest transpiration, a factor that contributes to fruit deterioration and quality decline (Álvarez-Herrera et al., 2024).

TSS increased with maturation and storage time (Table 2). From the VA point onward, TSS levels increased and did not differ between 0 and 10 DAH. Higher TSS levels with advancing fruit maturation may be associated with increased sugar content (Diniz and Novembre, 2019; Wen et al., 2020; Barroso et al., 2022). Furthermore, the increased concentration of soluble solids during storage may be associated with fruit deterioration and fermentation, contributing to increased perishability (Balaguera-López et al., 2017).

TTA decreased with storage time and at different harvest points, showing an inverse relationship with TSS (°Brix), which increased with storage time and fruit ripening. As a result, the MI increased as ripening progressed and with increasing storage time at each harvest point.

As a climacteric fruit (Trinchero et al., 1999), *P. peruviana* continues to ripen after harvest. As expected for these types of fruits, soluble solids and, therefore, sugar content tend to increase, while organic acid content tends to decrease as the fruit ripens (Barroso et al., 2022; Weber et al., 2024). The MI values at the harvest points VA, A, and AP increased significantly after harvest, reaching levels comparable to those observed at the fully ripe point (P) both at harvest and during subsequent storage. These results indicate that VA, A, and AP points may be suitable for harvest based on this parameter. The values obtained for ripe fruits were within Colombian legal standards (≥9) (Icontec, 1999; Codex, 2005).

Fruit mass with and without calyx, as well as fruit diameter, were significantly affected by harvest points (Table 3).

Fruit mass, both with and without calyx, reached the lowest values at the harvest point V, which differed significantly from the remaining harvest points (Table 3). No significant differences were observed among the other harvest points. A similar trend was observed for fruit diameter, which was also lower at point V, differing from the other harvest points from point A onward, indicating that more advanced ripening stages are

Table 2. Height, total soluble solids (TSS), total titratable acidity (TTA), and maturation index (MI) of *Physalis peruviana* fruits at different harvest points and days after harvest (0, 10, and 20 DAH).

Parameters	Time (DAH)	Harvest points					CV (%)
		V	VA	A	AP	P	
Height (cm)	0	1.35 Ab	1.63 Aa	1.59 Aa	1.62 Aa	1.67 Aa	CV_1 = 6.73
	10	1.27 Ac	1.41 Bbc	1.47 ABab	1.59 Aa	1.63 Aa	CV_2 = 5.30
	20	1.27 Ab	1.37 Bab	1.43 Bab	1.51 Aa	1.35 Bab	
TSS (°Brix)	0	8.20 Bb	12.78 Ca	12.40 Ba	13.15 Ba	13.22 Ba	CV_1 = 3.91
	10	10.57 Ab	13.55 Ba	13.15 Aa	13.67 ABa	13.90 Aa	CV_2 = 2.95
	20	10.65 Ac	14.28 Aab	13.58 Ab	14.09 Aab	14.46 Aa	
TTA (g citric acid/100 g sample)	0	0.81 Aa	0.77 Aab	0.76 Aab	0.73 Ab	0.59 Ac	CV_1 = 5.04
	10	0.74 Ba	0.69 Bab	0.73 Aab	0.68 Bb	0.59 Ac	CV_2 = 3.56
	20	0.65 Ca	0.58 Cb	0.57 Bb	0.51 Cc	0.50 Bc	
MI (TSS/TTA)	0	10.16 Cc	16.49 Cb	16.35 Bb	17.85 Cb	22.60 Ba	CV_1 = 7.20
	10	14.39 Bc	19.62 Bb	18.10 Bb	20.06 Bb	23.47 Ba	CV_2 = 5.29
	20	16.25 Ac	24.75 Ab	23.94 Ab	27.93 Aa	29.00 Aa	

Means followed by the same uppercase letter within columns and lowercase letter within rows do not differ significantly according to Tukey's test at 5% significance. V= green, VA= green-yellow, A= yellow, AP=yellow-straw, P= straw.

Table 3. Fruit mass and diameter of *Physalis peruviana* fruits with and without calyx at different harvest points.

Parameter	Harvest point					CV (%)
	V	VA	A	AP	P	
Mass with calyx (g)	2.53 b	3.54 a	3.62 a	3.55 a	3.77 a	CV_1 = 7.59
Mass without calyx (g)	2.27 b	3.22 a	3.33 a	3.31 a	3.59 a	CV_1 = 8.64
Diameter (cm)	1.26 b	1.38 ab	1.42 a	1.50 a	1.48 a	CV_1 = 7.04

Means followed by the same letter in the row do not differ significantly according to Tukey's test at 5% significance. V= green, VA= green-yellow, A= yellow, AP= yellow-straw, P= straw.

associated with higher fruit mass and diameter values.

Fruit diameter values were consistent across elapsed time and harvest points, falling within the range reported by Fischer (2000) (1.25 cm to 2.50 cm), and being close to the mean values of 1.41 and 1.80 cm reported by Lima et al. (2009) for green and ripe fruits, respectively.

The lower fruit mass, with and without calyx, and diameter observed at harvest point V, is consistent with previous reports for *P. peruviana* (Rodrigues et al., 2012; Barroso et al., 2022; Weber et al., 2024), and can be attributed to early fruit development prior to reaching physiological maturity (Herrera, 2000; Fischer et al., 2011; Balaguera-López et al., 2017). Accordingly, fruits harvested at the least mature harvest point (V) were smaller and lighter compared to fruits collected at the fully ripe point (P) (Table 3). Notably, fruit mass and diameter decrease progressively over time after harvest (Table 4). According to Fischer et al. (2011) and Silva et al. (2013), this reduction results from water loss from fruits via transpiration and respiration, which determines fruit perishability and ultimately compromises postharvest quality.

The fresh mass loss of *P. peruviana* fruits with calyx between harvest and after 10 DAH was 10.58%, reflecting an expected reduction due to the loss of liquids through respiration and transpiration processes (Herrera, 2000; Figueroa-Avalos et al., 2023; García-Muñoz et al., 2024).

Seed quality analysis

The harvest point that yielded the highest average number of seeds per fruit was AP, reaching 275.8 seeds, and showing no significant differences compared to VA and P (Table 5).

Table 4. Fruit mass, diameter, and pH of *Physalis peruviana* fruits with calyx at different days after harvest (0, 10, and 20 DAH).

	Parameters		
Time (DAH)	Mass with calyx (g)	Diameter (cm)	pH
0	3.59 A	1.47 A	3.50 C
10	3.21 B	1.43 A	3.92 B
20	-	1.32 B	4.14 A
CV (%)	13.45	5.84	4.22

Means followed by the same letter within the columns do not differ significantly according to Tukey test at 5% significance.

Table 5. Physical attributes of freshly extracted (wet) and post-drying (dried) seeds of *Physalis peruviana* fruits at different harvest points.

		Wet seeds (freshly extracted)			Dried seeds (post-drying)		
Harvest points	Seeds per fruit	Fresh mass (g)	Water content (%)	Dry mass (g)	Fresh mass (g)	Water content (%)	Dry mass (g)
V	202.80 B	0.19 A	38.45	0.12 A	0.18 A	6.42	0.17 A
VA	235.20 AB	0.15 A	28.14	0.10 A	0.20 A	7.82	0.18 A
A	213.40 B	0.19 A	34.64	0.12 A	0.15 A	8.66	0.13 A
AP	275.80 A	0.13 A	36.55	0.10 A	0.25 A	8.75	0.23 A
P	238.80 AB	0.13 A	29.89	0.09 A	0.22 A	7.92	0.20 A
CV (%)	13.72	14.16	-	17.88	18.06	-	17.58

Means followed by the same letters within the columns do not differ significantly according to Tukey's test ($p \leq 0.05$). V= green, VA= green-yellow, A= yellow, AP= yellow-straw, P= straw.

In contrast, the other developmental stages presented lower mean values ranging from 202.8 to 238.8. These findings agree with Fischer (2000), who reported 150-300 seeds per fruit, whereas Diniz and Novembre (2019) reported 250-330 seeds per fruit, comparing four harvest points and two flowering periods over two years.

Rodrigues et al. (2021) and Ramos et al. (2021) reported that the number of seeds increases with fruit maturation and is positively associated with fruit size in *P. peruviana* and *P. angulata*, respectively. In contrast, a previous study conducted by Rodrigues et al. (2014) observed an inverse relationship, in which larger fruits contained fewer seeds. In the present study, no clear relationship between fruit size and seed number could be established, as the highest values were observed at the VA, AP, and P harvest points.

According to Diniz and Novembre (2019) and Almanza (2000), the mass of 1,000 *P. peruviana* seeds is approximately 1 g, consistent with the 0.095 g found by Rodrigues et al. (2014) for 100 seeds and close to the values obtained in the present study, between 0.100 g and 0.200 g, for both wet (freshly extracted) and dried seeds (Table 5).

No statistically significant differences were observed between the harvest points for fresh or dry mass of freshly extracted seeds. However, point V presented higher values for mass and water content. This is because the seeds have high water contents in addition to accumulated reserves before reaching physiological maturity, which decrease linearly as maturation progresses (Rodrigues et al., 2021).

The water content of freshly extracted seeds was approximately 30% at all harvest points (Table 5). Similar values were obtained by Diniz and Novembre (2019), who observed a decrease from the first to the second harvest point, followed by stabilization. In the present study, differences among harvest points were small and not subjected to statistically analysis; however, the highest value was recorded at point V, whereas the lowest values were observed at points VA and P.

After drying, water content decreased

significantly (Table 5), ranging from 6 to 9%, with the lowest values at the least mature harvest points and increasing toward the more advanced ripening points, except for P, which had a lower value. Ramos et al. (2021) also observed a decrease in the water content of wet seeds and greater stability in dried seeds. The decrease in water content has been characterized as a seed dehydration process that occurs in fleshy fruits, in which water content slowly decreases until the seeds reach their hygroscopic equilibrium point, and this process may vary with environmental relative humidity (Carvalho and Nakagawa, 2012). According to Marcos Filho (2015), from this point on, characterized as physiological maturity, the seed attains maximum physiological quality and is optimal harvest point, as it marks the readiness to break bonds and to flow photoassimilates to the mother plant.

In the germination test, with evaluations at 7 and 14 days, differences were observed between the harvest points for both freshly extracted and dried seeds (Table 6).

Seeds from harvest point V did not germinate in the first evaluation of wet seeds (7 days), differing statistically only from point A, which had the highest germination rate, although it did not differ from the remaining harvest points. At 14 days, this pattern was maintained, with V showing the lowest germination rate, with no significant differences from the other points except for A, which again recorded the highest germination rate (86%).

De Freitas et al. (2024) observed that the mean germination time for *P. peruviana* seeds is 8.26 days, extending to 10.31 days at an average temperature of 25°C. Diniz et al. (2020) identified optimal germination conditions for this species at an average temperature of 25°C, or under alternating temperatures of 20-30°C with an 8-h photoperiod, using sand as substrate, or paper and vermiculite as alternatives. These factors directly influence final germination rates.

In dried seeds, the highest germination rates at 7 days were from points AP and P, differing only from V. At 14 days, the lowest germination rate remained at point V, which did not differ from VA. From harvest point A onward, germination increased, which did not differ from AP and P. Ramos et al. (2021) observed similar germination rates for wet and dried seeds after the intermediate point of maturation, corresponding to point A in the present study. However, in our experiment, differences in germination rates were evident, with higher rates observed in wet seeds.

Physalis sp. seeds are classified as orthodox, characterized by tolerance to desiccation and the ability to be stored for extended periods at low temperatures without compromising germination potential (Souza et al., 2014). However, in addition to the harvest point, seed processing may also affect final seed quality, reducing germination capacity and vigor. Barroso et al. (2022) demonstrated that seed development in *P. peruviana* is closely associated with fruit ripening, with germination serving as one of the key parameters of physiological maturity. Similarly, Diniz and Novembre (2019) reported an increase in germination percentage with advancing fruit ripening. In contrast, Sbrussi et al. (2014) concluded that fruit maturation stage does not significantly influence seed germination and vigor.

In the seedling emergence test, lower percentages were observed at the least mature points (V and VA), followed by an increase with maturation. However, the highest emergence was recorded at point A, which did not differ

Table 6. Percentage of seed germination of freshly extracted (wet) and post-drying (dried) *Physalis peruviana* fruits at different harvest points, after 7 and 14 days in a Gerbox box. Percentage of seedling emergence and emergence speed index of dried seeds.

	Wet seeds (freshly extracted)		Dried seeds (post-drying)			
	Germination (%)					
Harvest points	7 days	14 days	7 days	14 days	Emergence (%)	ESI
V	0 B	27 B	0.5 B	17.5 B	22 B	0.61 B
VA	5.5 AB	48.5 AB	4 AB	40.5 AB	32 B	0.85 B
A	9 A	86 A	6 AB	65 A	74 A	1.91 A
AP	3.5 AB	55.5 AB	8.5 A	49 A	69.5 A	1.80 A
P	1.5 AB	52 AB	7 A	50.5 A	71.5 A	1.76 A
CV (%)	94.79	33.01	56.61	31.14	14.73	22.04

Means followed by the same letters within the columns do not differ significantly according to Tukey’s test ($p \leq 0.05$). V= green, VA= green-yellow, A= yellow, AP= yellow-straw, P= straw.

from points P and AP (Table 6). Similarly, Diniz and Novembre (2019) observed low seedling emergence at the earliest maturity point, with a subsequent increase as maturity progressed; however, values were significantly higher from the second harvest point onward, corresponding to an intermediate point between VA and A in the present study. Sbrussi et al. (2014) reported a seedling emergence of 78.5% at the least mature point, with the highest value (81%) occurring at the second point (equivalent to VA in this study), declining at the third and fourth points and increasing again at the most mature point. This pattern is consistent with the trend observed in the present experiment.

The low seedling emergence observed at point V can be attributed to the fact that seeds had not yet reached physiological maturity. Upon reaching physiological maturity, *P. peruviana* seeds undergo visible changes in color, from whitish to light beige or yellowish (Kumar and Mohil, 2022). Furthermore, Rodrigues et al. (2021) observed that higher vigor rates, including seedling emergence, are achieved from approximately 34 days after anthesis (DAA), corresponding to point A in the present study, when fruits and calyx are fully yellow. At this stage, seeds are fully developed, which favors faster and total emergence of seedlings. Rodriguez-Burgos et al. (2011) highlighted that, although fruit and seed maturation do not occur simultaneously, physiological quality increases progressively until reaching its maximum potential. According to Marcos Filho (2015), this maximum occurs after peak dry matter accumulation and a reduction in water content, which coincides with physiological maturity.

Regarding the emergence speed index (ESI), the lowest values were observed at the least mature points (V and VA), which differed significantly from the remaining harvest points. A marked increase occurred at point A, reaching the highest value and with no statistically significant differences with respect to points AP and P. Diniz and Novembre (2019) reported a similar pattern, with ESI values below 1 at the least mature points, increasing to values above 2 from the second maturity point onward, and exceeding g 3 in the first year of evaluation. In the present study, the prominence of the value at point A relative to the others supports the hypothesis that seeds reach physiological maturity around this point.

According to Almanza (2000), several diseases that limit germination and subsequent cultivation can be transmitted to *P. peruviana* plants through seeds. Among the main fungal pathogens reported are scab (*Cladosporium fulvum*), early blight (*Alternaria solani*), and wilt (*Fusarium* sp.). The occurrence of these pathogens is shown in Table 7. No significant effects of harvest points were observed for any of the evaluated pathogens.

According to the sanitary quality analysis, the fungal genera found in *P. peruviana* seeds were *Aspergillus*, *Penicillium*, *Fusarium*, *Cladosporium*, *Epicoccum*, *Nigrospora*, and *Bipolaris* (Table 7). The most frequent isolate was *Aspergillus*, present at all harvest points, with a higher incidence at point V, followed by point P. *Cladosporium* and *Fusarium* were the second most frequently detected genera, occurring at all harvest points and showing higher incidence at point V, although in smaller proportions. Among the remaining genera, only *Nigrospora* occurred at all points, although at low frequency, while the other fungi were detected sporadically at specific points. Only harvest points V and VA recorded the occurrence of all fungal genera analyzed. *Bipolaris* was detected exclusively at these points, as were *Penicillium* and *Epicoccum*, which also occurred at points A and P, respectively. The highest mean fungal incidence was observed at V (3.4%), followed by VA (2.4%). In a study conducted by Diniz (2018), the same fungal genera were found, along with *Alternaria*, which was not detected in the present experiment. The most frequent genera were *Cladosporium*, *Penicillium*, and *Epicoccum*, while *Alternaria*, *Bipolaris*, and *Aspergillus* were absent after storage. Diniz (2018) observed a

Table 7. Mean occurrence of pathogenic fungi in *Physalis peruviana* seeds after drying at different harvest points.

	Aspergillus	*Penicillium*	*Fusarium*	*Cladosporium*	*Epicoccum*	*Nigrospora*	*Bipolaris*	M
V	10	1	5	5	1	1	1	3.4
VA	5	2	3	4	1	1	1	2.4
A	4	1	2	1	0	1	0	1.3
AP	6	0	1	4	0	4	0	2.1
P	9	0	2	1	1	1	0	2
Mean	6.8	0.8	2.6	3	0.6	1.6	0.4	

V= green, VA= yellow-green, A= yellow, AP= straw-yellow, P= straw.

higher occurrence of fungi at the fully ripe point in freshly extracted seeds (90 DAA), which corresponds to harvest point P in the present experiment. After drying, the highest fungal incidence was observed at the least mature point (45 DAA), corresponding to harvest point V in the present experiment.

Considering all seed quality tests, the highest overall performance was observed at harvest points A (yellow calyx) and AP (straw-yellow calyx). However, in terms of germination and vigor parameters, such as seedling emergence and emergence speed index, the highest values were obtained at harvest point A. These results indicate that this harvest point (A) ensures that seeds have reached physiological maturity and can be considered the optimal harvest point for physalis fruits.

CONCLUSIONS

Based on the five harvest points of *Physalis peruviana* L. defined by calyx color (V: green, VA: yellow-green, A: yellow, AP: straw-yellow, and P: straw), the optimal harvest stages for commercialization and fresh consumption were identified as VA, A, and AP. Fruits harvested at the fully ripe stage (P) exhibited reductions in postharvest fruit height during storage.

For high-quality seed production, the most suitable harvest point corresponds to A (yellow calyx). The most frequently detected fungal pathogens belonged to the genera *Aspergillus*, *Cladosporium*, and *Fusarium*.

Authors collaboration

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ACKNOWLEDGMENTS

We thank the Coordination for the Improvement of Higher Education Personnel-Brazil (CAPES) - Finance Code 001, the Graduate Program in Agroecology and Rural Development (PPGADR), and the Center for Agricultural Sciences of the Federal University of São Carlos (UFSCar/CCA).

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