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PHYSICOCHEMICAL CHARACTERIZATION OF THE CAPE GOOSEBERRY (PHYSALIS PERUVIAN L.) ECOTYPE VARIETY IN THE ASSOCIATION OF AGRICULTURAL PRODUCERS AND MARKETERS OF VENTAQUEMADA (PROCOAVEN)

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ABSTRACT

The cape gooseberry (Physalis peruviana L.) is an exotic fruit of high nutritional value, recognized for its content of vitamins A and C, bioactive compounds and medicinal properties. In this study, the physicochemical and physiological behavior of the fruit was analyzed in seven stages of maturity, according to the INCOTEC 4580 classification, which ranges from state 0 (green) to 6 (overripe). The samples were collected in the village of Puente Piedra, El Arrayán farm, municipality of Ventaquemada (Boyacá), selecting 50 fruits without calyx for the analysis of color index, firmness, respiration rate, acidity, total soluble solids (TSS) and pH. The results showed that in the zero state the values of pH, firmness and respiration were higher than the other states, evidencing greater metabolic activity in early stages. In contrast, TSS increased progressively with maturation, reflecting the conversion of starches into simple sugars. The color index showed an upward variation, going from green to intense orange tones in the advanced stages. Finally, the titratable acidity was increased to stage three, and then gradually decreased until reaching values similar to the initial values in stage six. These results allow us to understand the dynamics of fruit ripening and establish criteria for its post-harvest management and agro-industrial use.

INTRODUCTION

The cape gooseberry (Physalis peruviana L.), belonging to the *Solanaceae* family, is a round fruit between 1.25 and 2.50 cm in diameter and an average weight of 4 to 10 g, which contains 150 to 300 seeds inside. Its development occurs inside the calyx or capacho, a protective structure that measures about 5 cm and protects the fruit against adverse weather conditions, diseases, insects and birds. This fruit is considered an exotic product of high agro-industrial value, standing out for its pleasant flavor, its richness in vitamins A and C, minerals such as phosphorus and iron, as well as bioactive compounds with antioxidant and medicinal properties, including antispasmodic, diuretic, analgesic and sedative effects.

The ripening process is a determining factor in post-harvest quality, as it directly influences the texture, colour, flavour and shelf life of the fruit. Harvesting gooseberries in immature or overripe stages can lead to losses due to physiological damage or accelerated deterioration. Color is one of the main visual indicators of the degree of maturity: it progressively changes from green to orange as a result of the degradation of chlorophylls and the accumulation of carotenoids, especially β-carotenes, accompanied by internal transformations in the levels of sugars and organic acids. During this process, the starch content decreases, simple sugars increase, and acidity is reduced, which influences the pH and sensory acceptability of the fruit.

The objective of this study is to analyze the physicochemical and physiological behavior of the cape gooseberry in the seven stages of maturity established by the NTC 4580 standard (1999). Variables such as color index, firmness, respiration rate, titratable acidity, total soluble solids (TSS) and pH were evaluated, in order to identify the most suitable state of ripeness for fresh consumption, industrial transformation or storage. Understanding these changes allows us to optimize harvesting and post-harvest management practices, guaranteeing fruits of higher quality, stability and commercial value in the agro-industrial chain.

Figure 1. Seven stages of maturity of the cape gooseberry in different physical presentation. Own auntoria.

METHODOLOGY

The study was carried out in the plant physiology laboratory of the Pedagogical and Technological University of Colombia, Tunja campus. As plant material, ecotype gooseberry fruits were used in 7 stages of maturity. Grown on the El Arrayan farm located in the municipality of Ventaquemada (Boyacá Colombia) with an altitude of 2,512 m above sea level, average temperature is 16 °C. Humidity of 67% and pressure of 1024 hPa. Fruits were selected under optimal phytosanitary conditions, with homogeneous size and color in each of the stages of maturity and without evidence of mechanical damage. A completely randomized experimental design was used with 7 treatments and 3 replications for a total of 10 experimental units (UE), each UE was composed of approximately 60 fruits.

The following variables were measured:

Physical variables

Color of the epidermis: by means of a Konica CR digital colorimeter, the parameters of the CIELab system "L", "a" and "b" were determined, each fruit was given three readings in the equatorial diameter. L indicates luminosity, where 0 is black and 100 is white; values of

"a" <0 indicate a trend towards green and >0 towards red; "B" has the same range but values <0 indicate a trend towards blue and >0 towards yellow.

Color index: (CI) was calculated using the formula CI=1000*a/L*b. Reported by (García et al., 2012).

Fruit firmness (N): by using a PCE-PTR200 digital penetrometer with 0.05 N approximation.

Physiological Variables

The physiological variables measured were the following:

Determination of the respiration rate (mg CO_2 $^{kg-1h-1)}$: approximately 50 g of sample were taken in 2L hermetic chambers, in the chamber an infrared CO2 sensor was located which was connected to a Labquest (data capture equipment). Every 4 seconds and for 5 minutes the CO_2 values were recorded, with these values the slope was calculated, which corresponded to the respiratory rate, the weight of the fruits and the volume of the chamber were taken into account to convert the data to mg of $^{CO_2 kg-1h-1}$

Chemical Variables

The variables measured were the following pH: it was measured by automatic titrator 916 Food Ti-Touch 120.

Total Titratable Acidity (ATT): expressed as a percentage of citric acid by titration base acid with

NaOH (0.1N) up to pH 8.2, using automatic titrator 916 Food Tiouch 120.

Total Soluble Solids (TSS): through Brix measurements with a Hanna digital refractometer from 0 to 85% with 0.1 °Brix accuracy. Maturity ratio (RM): It was determined by the SST/ATT ratio.

RESULTS AND DISCUSSIONS

pH: Graph 1 shows the pH values corresponding to the seven stages of maturity of the cape gooseberry (*Physalis peruviana L.*). It is observed that the highest values are recorded in stages one, five and six, which suggests a physiological variation associated with the metabolic processes of the fruit. This behavior can be explained by the degradation of acidic compounds during ripening, a process that leads to a progressive decrease in organic acids such as citric and malic acid responsible for the acidic character in the early stages (Fischer et al., 2014).

According to Lucera et al. (2011), the increase in pH is related to the binding of pectin fragments released from the cell wall, which modifies the colloidal structure of the juice and contributes to the increase in titratable acidity. This phenomenon is typical of climacteric fruits, which exhibit high enzymatic activity during the ripening phase, with simultaneous changes in texture, flavor and chemical composition (Fischer, 2005).

In addition, the variability observed between the stages of maturity can be attributed to factors such as agroecological conditions, crop nutrition, and postharvest management, which directly influence the accumulation of sugars and the degradation of acids (Córdoba et al., 2015). These results are consistent with similar studies carried out on Andean fruits, where the pH tends to increase gradually until an equilibrium is reached in the final stages of commercial ripeness.

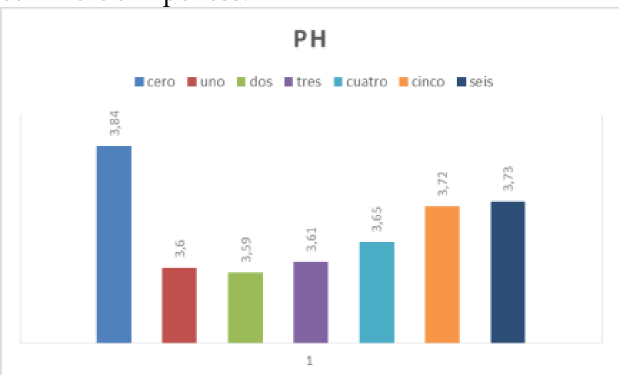


Figure 1. pH results in the 7 stages of ripeness of the cape gooseberry

Respiration rate: Graph 2 shows the behavior of the respiration rate of the cape gooseberry (*Physalis peruviana L.*) in their seven stages of maturity. The results show that the zero state has the highest respiratory rate, which is associated with the intense metabolic activity characteristic of fruits in early development. During this phase, the fruit requires high levels of energy for the processes of cell growth and synthesis of structural compounds (Fischer et al., 2014). As maturation progresses, the respiration rate tends to decrease, stabilizing in the intermediate states and reducing in the final stages, when the metabolism is oriented towards senescence.

According to Iqbal et al. (2009), respiratory rate is strongly influenced by abiotic factors, including storage temperature, which directly affects the rate of enzymatic reactions. High temperatures accelerate respiration and, therefore, the consumption of sugars and organic acids, reducing the shelf life of the fruit. On the contrary, refrigeration at temperatures between 8 and 12 °C allows a significant decrease in metabolic activity, preserving post-harvest quality for longer (Rodríguez et al., 2019).

Likewise, Novoa (2006) showed that fruits harvested in the state of maturity 5 and dried at 24 °C had the lowest respiratory intensity, which suggests a physiological balance that reduces energy expenditure and maintains tissue integrity. In this sense, proper management of temperature and relative humidity is essential to control respiration and slow the degradation of bioactive compounds.

On the other hand, Fischer (2005) and Fischer & Miranda (2022) argue that fruits that retain their calyx have lower respiration rates and ethylene production, which contributes to prolonging their shelf life in post-harvest. This is due to the protective effect of the calyx, which acts as a physical barrier against moisture loss and excessive gas exchange. These results are consistent with what was reported by Ramírez et al. (2020), who indicate that calyx integrity and storage in modified atmospheres decrease respiration and oxidative processes in gooseberry.

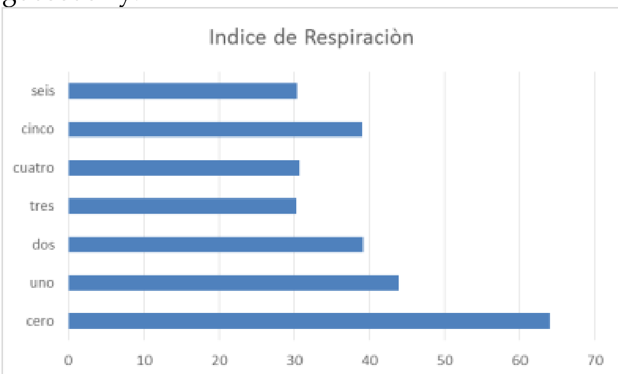
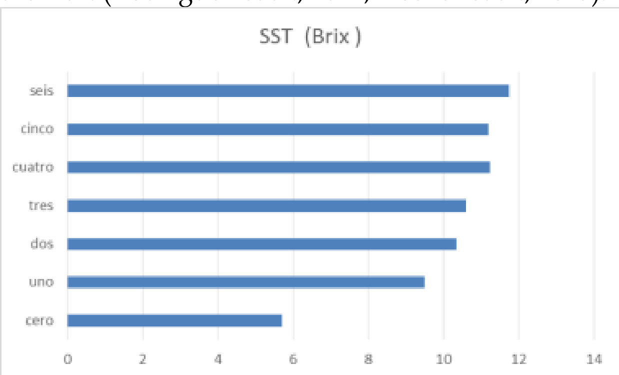


Figure 2. Results of respiration rate in the 7 stages of maturity of the cape gooseberry

Total Soluble Solids (TSS): Graph 3 shows the results of (TSS) expressed in °Brix, corresponding to the seven stages of maturity of the cape gooseberry (*Physalis peruviana L.*). It is evident that the zero state of maturity presents the lowest values, which is characteristic of fruits in early stages of development, when carbohydrates are predominantly in the form of structural starches not yet hydrolyzed. As ripening progresses, enzymatic processes mainly catalyzed by amylases and sucrases convert starches into reducing sugars (glucose, fructose, and sucrose), increasing the TSS content and, therefore, the sweetness and sensory acceptability of the fruit (Novoa, 2006; Balaguera-López et al., 2015).

The progressive increase in TSS during maturity is a key physiological indicator of the degree of fruit development and its suitability for consumption or industrial processing. Recent studies show that soluble solids content is directly related to respiratory rate and ethylene synthesis, as both processes stimulate the degradation of reserve polysaccharides (Ramírez et al., 2020). Likewise, the increase in TSS is associated with a reduction in titratable acidity, reflecting the balance between sugars and acids that defines the characteristic flavor of ripe gooseberry (Fischer & Miranda, 2022).

On the other hand, Balaguera-López et al. (2015) highlight the effect of the calyx as a natural regulator of the ripening process, since fruits with calyx have a slower release of ethylene and a lower respiration rate, which slows the increase in TSS compared to fruits without calyx. This condition protects the fruit from moisture loss and prevents accelerated ripening, prolonging its post-harvest shelf life. Recent research confirms that the calyx functions as a semipermeable barrier, reducing gas exchange and preserving the firmness and organoleptic quality of the fruit (Rodríguez et al., 2021; Fischer et al., 2023).

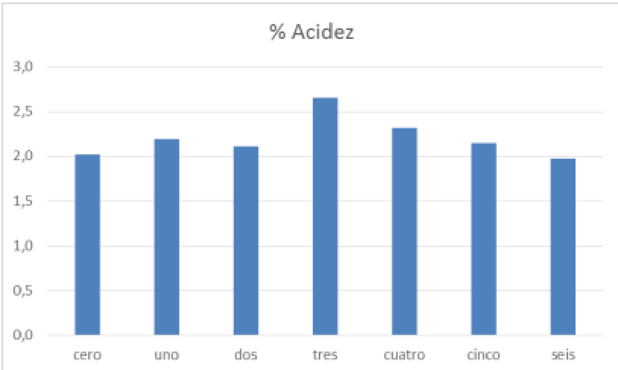


Graph 3: Results of Total Soluble Solids (TSS) in the 7 stages of maturity of the cape gooseberry.

Acidity: Graph 4 shows the percentage values of titratable acidity in the seven stages of maturity of the cape gooseberry (*Physalis peruviana L.*). It is observed that state three presents the highest acidity value, while states zero and six show similar and lower values. This behavior is related to the dynamics of organic acids (mainly citric and malic), which act as respiratory substrates during the ripening process. In the early stages of fruit development, acidity is high due to the high concentration of these compounds; however, as maturation progresses, acids are degraded or used in metabolic pathways, which causes a progressive decrease in pH and total acidity (Martínez, 1999; Fischer et al., 2014).

Fischer (2005) points out that fruits with a lower degree of ripeness tend to retain a higher proportion of organic acids, which improves their postharvest behavior by maintaining a slower respiration and a lower susceptibility to physiological damage. This phenomenon coincides with the observed results, where early stages of maturity present greater metabolic stability. According to Ramírez et al. (2020), organic acids not only influence respiration, but also the stability of the color, flavor, and firmness of the fruit, being decisive in its sensory and commercial quality.

On the other hand, recent studies such as those by Fischer and Miranda (2022) and Rodríguez et al. (2021) confirm that the decrease in acidity is closely related to the increase in total soluble solids (TSS), reflecting a change in the balance between sugars and acids, a classic indicator of the progress of ripening. Likewise, the storage temperature and the presence of the calyx have a direct impact on the conservation of acids, since a controlled environment and the natural protection of the calyx reduce the respiration rate and the loss of acidity, prolonging the shelf life of the fruit.



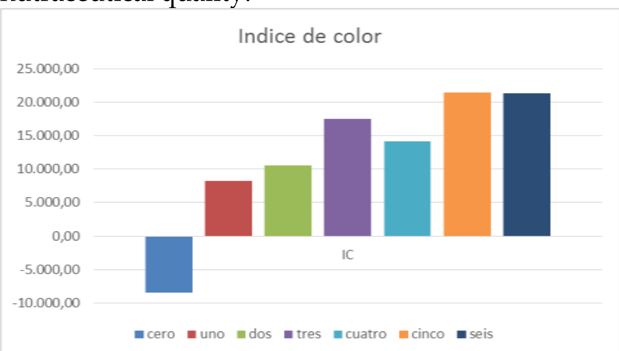
Graph 4: Results of the % Acidity in the seven stages of maturity of the cape gooseberry.

Color index: Figure 5 shows the values of the color index in the seven stages of maturity of the cape gooseberry (*Physalis peruviana L.*), where it is evident that the zero state presents negative values, indicating a predominantly green hue, typical of immature fruits. As the fruit progresses in its development, the color index increases progressively until it reaches positive values in the final stages, which reflects the transition to yellow-orange tones, associated with physiological and commercial maturity. This chromatic change is one of the most relevant visual indicators to determine the optimal harvest time (Mendoza, 2012; Pinzón et al., 2015).

The process of color change is mainly determined by the degradation of chlorophylls and the synthesis or exposure of carotenoid pigments, especially β-carotenes and xanthophylls, responsible for the characteristic color of the ripe gooseberry. According to Pinzón et al. (2015), during maturation there is a progressive disorganization of chloroplasts, which are transformed into chromoplasts, facilitating the accumulation of fat-soluble pigments. This process is influenced by physiological factors such as ethylene production, respiratory rate, and environmental culture conditions (Fischer & Miranda, 2022).

Likewise, the water content and epicuticular waxes affect the perception of the color of the fruit. In the initial stages, the waxy surface reflects light, giving it a greenish glow; however, as maturity progresses, the loss of natural waxes and the reduction of water content increase the translucency of the epidermis, which intensifies the yellow tones (Rodríguez et al., 2021). On the other hand, Fischer, Balaguera-López, and Ramírez (2023) report that calyx conservation can delay color change by limiting direct exposure to radiation and oxygen, prolonging the visual and commercial stability of the fruit during postharvest.

These results are consistent with the reports of Mendoza (2012), who points out that lots with a higher proportion of fruits in maturity grades 4 and 6 have more uniform orange tones, while in lower grades the color tends to heterogeneity, which makes commercial classification difficult. In summary, the color index reflects not only the physiological maturity of the fruit, but also the influence of post-harvest and environmental factors on its visual and nutraceutical quality.



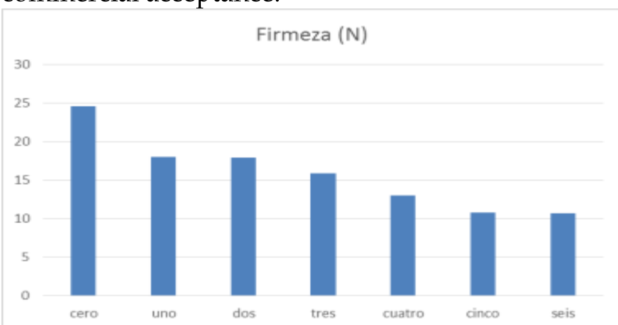
Graph 5: Color index results in the seven stages of maturity in the cape gooseberry

Firmness: Figure 6 shows the firmness values in the seven stages of maturity of the cape gooseberry (*Physalis peruviana L.*), and it is observed that the zero state exhibits a significantly higher firmness than the others. This behavior is typical of fruits in the immature state, where the cell walls maintain high structural integrity due to the abundance of insoluble pectins, hemicelluloses and cellulose that confer rigidity to the tissue (Pinzón et al., 2015). As the fruit advances in the ripening process, firmness progressively decreases, as a result of the enzymatic activity that degrades structural polysaccharides, transforming insoluble pectins into soluble ones and reducing cohesion between parenchymal cells (Ramírez et al., 2020).

According to Pinzón et al. (2015), one of the main causes of loss of firmness in climacteric fruits is the action of enzymes such as polygalacturonases, pectinametilesterases and cellulases, whose activity increases with maturity and is regulated by temperature and ethylene availability. In this sense, storing the fruit at temperatures between 8 and 12 °C makes it possible to reduce the speed of enzymatic reactions and prolong its firmness during storage (Rodríguez et al., 2021).

Likewise, Fischer and Miranda (2022) highlight that fruits with calyx have a slower loss of firmness than those without calyx, because this structure acts as a protective physical barrier that reduces water loss and gas exchange, delaying the softening processes. Recent research by Fischer, Balaguera-López, and Ramírez (2023) confirms that fruit firmness is directly related to its postharvest behavior, being a key indicator of quality and shelf life.

The progressive decrease in firmness observed in the advanced stages of maturity is therefore a reflection of the dynamic balance between processes of cell wall hydrolysis, respiration and loss of turgor, which determine the final texture of the fruit and its commercial acceptance.



Graph 6: represents the frimeza in the seven stages of maturity of the cape gooseberry

Table 1: Description of the physicochemical and physiological characteristics of the cape gooseberry in the seven stages of maturity.

STATE OF MATURITY	FEATURES
	pH: 3.84 Respiration rate: 64,674 SST: 5.7 % Acidity: 2.024 Color Index: -8.396 Firmness: 24.6
	pH: 3.6 Respiration rate: 43.957 SST: 9.5 % Acidity: 2.199 Color Index: 8.202 Firmness: 18.03
	pH: 3.59 Respiration rate: 39.182 SST: 10.35 % Acidity: 2.119 Color Index: 10.607 Firmness: 17.9
	pH: 3.61 Respiration rate: 30.330 SST: 10.6 % Acidity: 2.663 Color Index: 17.465 Firmness: 15.9
	pH: 3.65 Respiration rate: 30.688 SST: 11.25 % Acidity: 2.314 Color Index: 14.186 Firmness: 12.97
	pH: 3.72 Respiration rate: 39.138 SST: 11.75 % Acidity: 1.980 Color Index: 21,344 Firmness: 10.83
	pH: 3.73 Respiration rate: 30.408 SST: 5.7 % Acidity: 2.024 Color Index: 83.96 Firmness: 10.67

CONCLUSIONS

It is concluded that the physicochemical parameters of the cape gooseberry (*Physalis peruviana L.*) exhibit differentiated behaviors throughout the seven stages of maturity, reflecting the complexity of the physiological processes that determine their quality, shelf life and commercial destination. These variations allow precise criteria to be established for the selection of the fruit according to its final use: the initial stages (0 to 2) are more suitable for storage and prolonged transport, due to their greater firmness, acidity and lower respiration rate; while the intermediate states (3 to 5) represent a balance between sensory attributes and post-harvest stability.

The respiration rate, as a key parameter of metabolism, is consolidated as a determining indicator of physicochemical stability during the distribution chain. Its control through adequate temperature and humidity conditions is essential to maintain the nutritional and structural quality of the fruit (Fischer & Miranda, 2022). On the other hand, flavor, directly linked to the content of total soluble solids (TSS), is the main factor of consumer acceptance, with the state of maturity 5 or 6 presenting the most balanced and stable bittersweet profile, associated with high values of TSS and a moderate reduction in acidity (Balaguera-López et al., 2015; Ramírez et al., 2020).

In addition, the color index and external appearance act as decisive sensory attributes in the perception of quality. The intense orange color, characteristic of state 6, is the most attractive to the consumer and coincides with optimal ripeness for fresh consumption or industrial processing (Pinzón et al., 2015; Fischer et al., 2023). Overall, the results allow us to conclude that a comprehensive understanding of the physicochemical behavior of the fruit throughout its ripening is essential to establish harvesting, storage and marketing strategies that maximize its quality and added value.

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