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Characterization of cape gooseberry (*Physalis peruviana* L.) fruits from plants irrigated with different regimens and calcium doses

Caracterización de frutos de uchuva (*Physalis peruviana* L.) provenientes de plantas regadas con diferentes regímenes de riego y dosis de calcio

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Cape gooseberry fruit at harvest.

Photo: G. Fischer

ABSTRACT

Cape gooseberry fruits have positioned in the world market due to their excellent nutritional characteristics, because they are an ideal food that contributes to raising the defenses of the human body and helps it to face diseases such as COVID-19, they are also a natural source of antioxidants and anticancer agents. In order to avoid the physiopathy of cracking in cape gooseberry fruits, these were characterized at harvest time, coming from greenhouse plants irrigated with different applications of water levels and irrigation frequencies, as well as different calcium doses, in a design of randomized complete blocks with 12 treatments. The blocks were the irrigation frequencies (4, 9 and 14 days), while the treatments were the combination of four irrigation coefficients (0.7, 0.9, 1.1 and 1.3 of the evaporation of the tank class A) and three doses of calcium (0, 50 and 100 kg ha^{-1}). The plants were sown in 20 L pots with peat moss substrate. Fruits were harvested at the color stage 5 and 6 of the calyx, from 19 weeks after transplanting. The different water levels and irrigation frequencies did not significantly affect the firmness of the cape gooseberry fruits, but there was a strong tendency that cracked gooseberry fruits are less firm than healthy fruits. As the irrigation coefficient increased, the total soluble solids (TSS) increased while the total titratable acids (TTA) decreased. Irrigation frequency of 14 days generated fruits with higher TSS and pH values. The calcium doses did not affect the calcium concentration

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in the fruits or the TSS, TTA and pH values. Therefore, it can be concluded that incremented irrigation coefficients (up to 1.3) increase the quality of cape gooseberry fruits.

Additional key words: irrigation; firmness; soluble solids; titratable acidity; maturity index; pH.

RESUMEN

Los frutos de uchuva se han posicionado en el mercado mundial por sus excelentes características nutricionales debido a que son un alimento ideal que contribuye a elevar las defensas del cuerpo humano y lo ayuda a hacer frente a enfermedades como el COVID-19, además son fuente natural de antioxidantes y agentes anticancerígenos. Con el fin de evitar la fisiopatía del rajado en los frutos de uchuva, estos fueron caracterizados al momento de la cosecha, provenientes de plantas bajo invernadero regadas con diferentes aplicaciones de láminas y frecuencias de riego, así como distintas dosis de calcio, en un diseño de bloques completos al azar con 12 tratamientos. Los bloques fueron las frecuencias de riego (4, 9 y 14 días), mientras que los tratamientos fueron la combinación de cuatro coeficientes de riego (0,7; 0,9; 1,1 y 1,3 de la evaporación del tanque clase A) y tres dosis de calcio (0, 50 y 100 kg ha^{-1}). Las plantas fueron sembradas en materas de 20 L con sustrato de turba rubia. Los frutos fueron cosechados en estado de color 5 y 6 del cáliz, 19 semanas después del trasplante. Las diferentes láminas y frecuencias de riego no afectaron significativamente la firmeza de los frutos de uchuva, no obstante, se presentó una tendencia fuerte en cuanto a que los frutos rajados son menos firmes que los sanos. A medida que se incrementó el coeficiente de riego, los sólidos solubles totales (SST) aumentaron mientras que la acidez total titulable (ATT) disminuyó. La frecuencia de riego de 14 días generó frutos con mayores valores de SST y pH. Las dosis de calcio aplicadas no afectaron la concentración de calcio en los frutos ni los valores de SST, ATT, pH, ni los parámetros de color. Los frutos provenientes de plantas regadas cada 14 días fueron más oscuros, y presentaron menor luminosidad. Por lo tanto, se puede concluir que al aumentar los coeficientes de riego hasta 1,3, la calidad de los frutos de uchuva mejora.

Palabras clave adicionales: irrigación; firmeza; sólidos solubles; acidez titulable; índice de madurez; pH.

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INTRODUCTION

The cape gooseberry (*Physalis peruviana* L.) now occupies an important place in the global market for exotic fruits with a tropical origin because it has excellent nutritional characteristics since it is rich in proteins, vitamins, citric acid, phenols, carbohydrates and fiber (Maruenda *et al*., 2018). In addition, it is a source of minerals such as potassium, phosphorus (Mokhtar *et al*., 2018) and iron (Miranda and Fischer, 2021). These properties make the cape gooseberry fruit an ideal food that improvers the defenses of the human body and helps it to cope with diseases such as COVID-19 (Aman and Masood, 2020). Likewise, cape gooseberry fruits are a natural source of antioxidants and anticancer agents (El-Beltagi *et al*., 2019).

For more than 20 years, Colombia has remained at the forefront of global cape gooseberry production, and, in the last 10 years, the area planted with this crop has increased by 75%, reaching 1,311 ha by 2018 (Agronet, 2020). However, yields have decreased by 23% as the result of excessive costs for controlling pests and diseases and inadequate management of irrigation and fertilization, which causes fruit cracking and significant economic losses (Álvarez-Herrera *et al*., 2021).

In Colombia, the cape gooseberry enjoys good ecophysiological conditions for its commercial cultivation between 1,800 and 2,800 m a.s.l., with temperatures between 13 and 16°C and rainfall between 1,000 and 1,800 mm $year^{-1}$ (Fischer and Melgarejo, 2020; Miranda and Fischer, 2021). Global warming, among others, increases the soil temperature causing water stress and thus yield and quality reductions (Bhatt *et al*., 2019; Fischer *et al*., 2022). Unfortunately, land at higher tropical altitudes is available if the temperature increases from climate change (Fischer *et al*., 2021a).

Given the demand for excellent quality fruits, in terms of color and size, farmers are forced to apply large amounts of fertilizers and water, which probably contribute to the physiopathy of cracking (Fischer *et al*., 2021b). In this regard, Álvarez-Herrera *et al*. (2012, 2014) found that cape gooseberry fruits present less cracking in the epidermis when they receive an adequate water supply.

Similarly, Gordillo *et al*. (2004) tested different irrigation levels in cape gooseberry plants and found that an irrigation coefficient of 1.2 increased the fruit yield per plant regardless of the applied fertilization treatments. Kochhar and Gujral (2020) affirm that Ca-deficient plants present little or no fruiting. And Álvarez-Herrera *et al*. (2015), with a net irrigation coefficient of 1.3 and 100 kg ha^{-1} of Ca under greenhouse conditions, observed a decrease in production, size and percentage of cracked fruits. Likewise, Fischer (2005) stated that cracking in gooseberry fruits is attributed to Ca deficiencies because this element has a large effect on the fruit quality because it maintains the structure and integrity of the cell wall and membrane and controls the levels of enzymes, such as pectinesterase (PE), that degrade the cell wall. In addition, Ca strengthens cell-to-cell adhesion (Kathpalia and Bhatla, 2018), which is important to reducing cracking in gooseberry fruits. Marschner (2012) stated that even a small increment of the Ca concentration in fruits are effective in reducing or preventing physiological disorders during postharvest.

To avoid cracking, irrigation and fertilization treatments have been visualized formerly that could reduce this physiological disorder; however, the impact that these applications will have on fruits at harvest must be known. The objective of this study was to characterize cape gooseberry fruits at harvest from plants watered with different irrigation regimes and calcium doses and to determine how much cracking affects fruit firmness, which will provide information for proper crop management.

MATERIALS AND METHODS

Location of the experiment

This experiment was developed in a greenhouse of the Faculty of Agricultural Sciences at the Universidad Nacional de Colombia, Bogota, which is located at an altitude of 2,556 m a.s.l., 74°5'20" W and 4°38'7" N. The mean temperature inside the greenhouse was 18°C, and the RH was 60%. The laboratory analyses were carried out in the Plant Physiology laboratory of the same Faculty at the Universidad Nacional de Colombia-Bogota.

Experiment design and treatments

A randomized complete block experiment design with 12 treatments was used. The blocking criterion was the irrigation frequencies (4, 9 and 14 d). The treatments had a 4×3 factorial structure. The first factor was the irrigation level (0.7, 0.9, 1.1 and 1.3 of the evaporation of the class A evaporimeter tank), and the second factor was the calcium dose (0, 50 and 100 kg ha^{-1}). Each block corresponded to one repetition, which represented 36 experiment units (EU). Each EU consisted of two plants, which were planted in 20 L pots filled with white peat.

Experiment setup

Colombia ecotype cape gooseberry plants were transplanted 45 d after germination with a spatial arrangement of 2 m between plants and 2 m between rows. The usual cultural practices of tutoring in high V, pruning, fertilization and phytosanitary management of commercial production areas were carried out (Fischer *et al*., 2021c). Fruits were harvested at the color stage 5 and 6 of the calyx (Colombia Icontec, 1999), from 19 weeks after transplanting. The fertilization was divided into six applications, at 0, 3, 6, 8, 10 and 12 months after transplantation, the sum of which was 150, 220, 150, 60 and 40 kg ha^{-1} of N, P_2O_5, K_2O, MgO and S, respectively, while 1, 3, 2 and 0.5 kg ha^{-1} of B, Zn, Cu and Mn were applied, respectively.

An irrigation system with two drippers per plant, 4 L h^{-1}, was used. The Ca^{2+} doses were applied in the crown form around the plant, incorporating it in the substrate, distributed on a monthly basis with three doses during the first three months because of the low mobility of calcium in the soil. The irrigation level was applied according to equation (1).

$$\text{Water application} = \frac{Etp*C*A}{\eta_r} \quad (1)$$

where, *Etp* was evapotranspiration in mm measured in a class A evaporimeter tank installed inside the greenhouse; C multiplier coefficient according to the treatments; A area of the pot (254.4 cm^2); η_r efficiency of the drip irrigation system (0.9).

Response variables

At the second crop harvest (19 weeks after transplantation), which had the highest production (Álvarez-Herrera *et al*., 2021), among ten harvests, response variables were measured. The total soluble solids (TSS) were determined, for which 5 mL of gooseberry fruit juice was taken from each EU and placed in a Hanna HI 96803 digital refractometer (Hanna Instruments, Spain).

The total titratable acidity (TTA) was determined by measuring the volume of NaOH used in the titration of a solution brought to pH 8.2, 5 mL of fruit juice with 3 drops of phenophthalein added. Equation (2) was used.

$$\text{TTA}(\%) = \frac{(\text{A*B*C})*100}{D} \quad (2)$$

where, A was volume of NaOH used; B normality of NaOH (0.097 meq mL^{-1}); C equivalent mass expressed in g of citric acid (0.064 g meq^{-1}); D mass in grams of the sample used (5 g).

The maturity index (MI) was calculated by dividing the TSS by the TTA. The pH measurement was determined with a HANNA HI 8424 digital potentiometer (Hanna Instruments, Spain) in 5 mL of juice. The fruit firmness was measured in ten healthy fruits and ten cracked fruits per EU with a PCE-PTR200 digital penetrometer (PCE-Ibérica, Spain).

The calcium concentration [Ca^{2+}] in fruits was quantified following the protocols for the repair of the plant tissue sample (POE-F001), calcination and digestion with HCl (POE-F002), and atomic absorption of Ca (POE F003), prepared by the Water and Soil Laboratory of the Faculty of Agricultural Sciences of the Universidad Nacional de Colombia.

Analysis of data

An analysis of variance (Anova) was carried out for a completely randomized block design with factorial treatment structure to elucidate the existence of significant differences between irrigation frequencies (blocks) and between treatments (water level x frequency) and factors for the measured response variables. Additionally, a Tukey mean comparison test (P<0.05) was performed to classify the levels of the evaluated factors with SAS v. 9.2.

RESULTS AND DISCUSSION

Total soluble solids (TSS)

The TSS were significantly affected by the increase in the amount of water applied to the cape gooseberry plants. The highest irrigation coefficient produced fruits with 10% less TSS (Fig. 1). The values ranged between 16.8 and 18.7%, higher than the 14.8% reported by Bazalar *et al*. (2019) and similar to the report by Bazalar *et al*. (2020) of between 14.0 and 18.7% and from 12 to 15% for fruits in 3 stages of maturity (Garzón-Acosta *et al*., 2014).

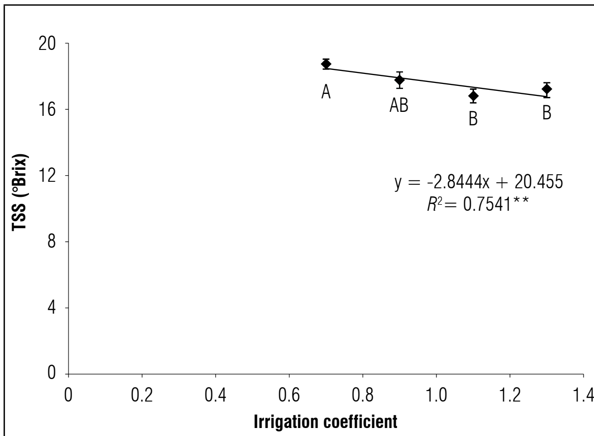

Figure 1. Effect of the irrigation coefficient on total soluble solids (°Brix) in gooseberry fruits of plants planted in peat moss and subjected to different irrigation regimes and calcium nutrition. Means with different letters indicate statistical differences according Tukey test (P<0.05). Vertical bars indicate standard error (n=9).

The irrigation frequency showed significant differences in the TSS of the cape gooseberry fruits (Fig. 2). As the irrigation frequency became longer, the TSS increased since, when going from an irrigation frequency of 4 d to 14 d, the TSS increased approximately 7% on average. This increase in TSS as a result of a decrease in the irrigation level has been reported by several authors for different fruits, such as the apple (Soliman *et al*., 2018), peach 'Rubirich' (Guizani *et al*., 2019), melon (Özbahçe *et al*., 2014), grapevine (Cataldo *et al*., 2021) and tomato (Agbemafle *et al*., 2014). Similarly, decreasing the irrigation frequency increased the TSS in pepper (Marín *et al*., 2009).

The TSS increase was probably due to the fact that a stress-induced osmotic adjustment occurred, generating a greater split of reserve carbohydrates to the simpler sugars used in respiration (Yahia *et al*., 2019). The effect results from a lower water supply, so the fruits have a lower moisture content; therefore, the concentration of dry matter increases (Ripoll *et al*., 2014) and the TSS are greater, known as a "concentration effect". Increases in free sugars in fruits occur through the hydrolysis of starch reserves caused by α-amylase, β-amylase and starch phosphorylase, enzymes whose activity increases dramatically during fruit ripening (Yahia *et al*., 2019). Under conditions of water stress, sucrose phosphate synthase increase their activity (Duan *et al*., 2021), thus increasing the sucrose concentration gradient between leaves and fruits, which results in greater transport of photoassimilates towards the fruits, and a possible increment of TSS. Also, the TSS values were high, probably because the greenhouse temperature was between 3 and 5°C on average higher than the outside temperature; therefore, the water stress reduced the absorption of water by osmosis but not with the same proportion as the amount of sugars, so their concentration was higher in the fruits (Marín *et al*., 2009).

The calcium doses did not affect the TSS concentration in the fruits. There are reports where pre-harvest applications of calcium did not affect the TSS in blueberry fruits (Lobos *et al*., 2021), apples (Fallahi and Mahdavi, 2020) or pepper (Marín *et al*., 2009); however, according to Rahman *et al*. (2016), fruits generally present a higher amount of TSS when they do not receive calcium applications, as seen in this research, where the TSS value was 15.7% without calcium applications but, when calcium was applied in doses of 100 kg ha^{-1}, the TSS value was 15.3%. Also, Khan and Ali (2018) reported that the results of preharvest Ca applications, in many cases, are erratic and even contradictory, possibly because of genotypic differences among varieties and fruit species or Ca concentrations and formulations used (Lara, 2013).

Total titratable acidity (TTA)

The irrigation level significantly ($P<0.05$) affected the TTA of the gooseberry fruits. The TTA ranged between 2.1 and 2.8% (Fig. 3). The TTA presented a linear adjustment with respect to the increase in the application of water, as the irrigation coefficient increased, the TTA decreased. The irrigation frequency did not present significant differences in the TTA.

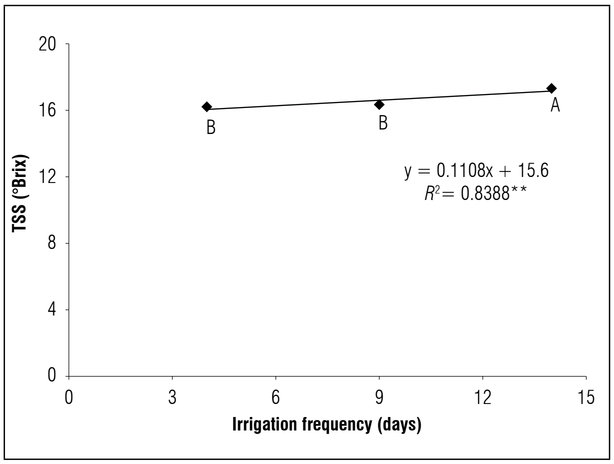

Figure 2. Effect of the irrigation frequency on total soluble solids expressed in Brix degrees in gooseberry fruits of plants planted in peat moss and subjected to different irrigation regimes and calcium nutrition. Means with different letters indicate statistical differences according Tukey test (*P*<0.05). Vertical bars indicate standard error (*n*=9).

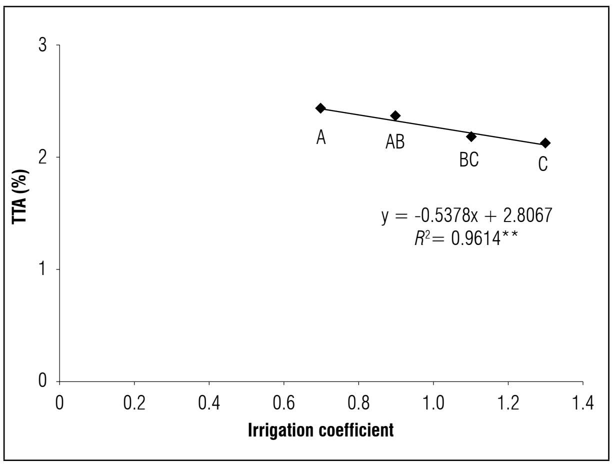

Figure 3. Effect of the irrigation coefficient on total titratable acidity in gooseberry fruits of plants planted in peat moss and subjected to different irrigation regimes and calcium nutrition. Means with different letters indicate statistical differences according Tukey test (*P*<0.05). Vertical bars indicate standard error (*n*=9).

When water was supplied to the crop every 4 d, the fruits presented an acidity of 2.13% but, when it was done every 14 d, the TTA was 2.16%. Marín *et al*. (2009) applied different irrigation frequencies to pepper and found no differences in the TTA. The calcium applications to the soil did not affect the TTA of the cape gooseberry fruits, as reported for pepper (Marín *et al*., 2009), blueberries (Lobos *et al*., 2021) and pear (Wojcik, 2012). However, a calcium deficiency can decrease the integrity of the cell membrane; thus, the respiration will increase, and the concentration of acids will be lower (Bhatla, 2018).

During ripening, a decrease in organic acids occurs in many fruits (Vallarino and Osorio, 2019). This loss is mainly due to the use of these compounds as respiratory substrates and as carbon skeletons for the synthesis of new components. With a water deficit, fruits probably present a higher respiration, which causes the conversion of acids to sugars more quickly (Bhatla, 2018) or the higher respiration affects citric and malic acids content directly because of its function in the Krebs cycle (Lambers and Oliveira, 2019). However, according to the results, the fruits from plants with a greater application of water had a greater amount of water in their tissues, which probably caused the concentration of acids to decrease as a result of the dilution effect (Fischer and Martínez, 1999). Thus, the amount of acids was similar in all treatments. In cape gooseberry fruits, citric acid constitutes 85% of the organic acids (Novoa *et al*., 2006). Medyouni *et al*. (2021) reported that, when tomato plants suffered water stress, they reduced water absorption and increased the production of acids in the fruits as a mechanism of adaptation to stress, where ascorbic acid and total carotenoids stand out. A similar result was found for the cape gooseberries in this study and in another study on the tomato (Patané *et al*., 2011).

Maturity index (MI)

The level and the frequency of the irrigation presented statistically significant differences for the maturity index (Tab. 1), which presented an average of 7.89. This MI value was within the range reported by Novoa *et al*. (2006), from 7 to 8. Batista-Silva *et al*. (2018) stated that, during ripening, the proportion of acids decreases and the concentration of sugars increases, making the MI the degree of maturity higher. The calcium doses applied to the cape gooseberry plants did not have a significant effect on the MI values of the fruits (Tab. 1), which agrees with Arah *et al*. (2015) who reported that calcium has little influence on MI but has a large influence on prolonging postharvest life. Similarly, Marín *et al*. (2009) tested different calcium doses and did not find significant differences in TTA, TSS or MI pepper; however, they stated that these values varied when the state of maturity changed.

Table 1. Effect of the irrigation coefficient, calcium dose and irrigation frequency on the total soluble solids (TSS), total titratable acidity (TTA), maturity index (MI), pH and firmness of gooseberry fruits from plants grown in the greenhouse.

Factor	Level of the factor	TSS (°Brix)	TTA (%)	MI	pH	Firmness of healthy fruits (N)	Firmness of cracked fruits (N)
Irrigation coefficient	0.7	18.73±0.30 a	2.42±0.08 a	7.76±0.19 b	3.92±0.02 a	9.30±0.42 a	7.29±0.36 a
	0.9	17.75±0.50 ab	2.35±0.05 ab	7.56±0.27 b	3.92±0.02 a	9.61±0.38 a	6.21±0.41 a
	1.1	16.80±0.42 b	2.18±0.05 bc	7.71±0.20 ab	3.94±0.03 a	9.84±0.33 a	6.70±0.35 a
	1.3	17.15±0.44 b	2.11±0.07 c	8.13±0.29 a	3.92±0.02 a	9.59±0.35 a	6.35±0.33 a
Calcium doses (kg ha^{-1})	0	17.78±0.39 a	2.27±0.06 a	7.82±0.21 a	3.92±0.02 a	10.59±0.26 a	6.89±0.25 a
	50	17.66±0.37 a	2.29±0.06 a	7.70±0.18 a	3.92±0.02 a	10.76±0.34 a	6.71±0.41 a
	100	17.40±0.48 a	2.24±0.06 a	7.76±0.24 a	3.92±0.02 a	10.69±0.36 a	6.31±0.26 a
Irrigation frequency (days)	4	17.22±0.44 b	2.13±0.07 a	8.08±0.21 b	3.87±0.01 b	9.43±0.32 a	6.83±0.25 a
	9	17.06±0.36 b	2.16±0.06 a	7.89±0.10 b	3.90±0.01 b	9.77±0.33 a	6.97±0.41 a
	14	18.54±0.30 a	2.16±0.05 a	8.58±0.18 a	3.98±0.02 a	9.55±0.31 a	6.12±0.26 a

Means with different letters in the same column and classified by factor indicate significant differences between the factor levels according to Tukey's test ($P \leq 0.05$).

Cape gooseberry fruits have an MI that increases linearly during the different ripening phases (Fischer and Martínez, 1999). This results from the fact that the TSS increase from the green maturity state (0) to the maturity state 5 (Herrera, 2000), then decline until harvest. The TTA decreases constantly throughout the ripening period (Fischer, 1995). This behavior includes decreased acid levels and increased sugars because of the increase in the translocation of sugars from the leaves and towards the fruits and the mobilization and degradation of the starch reserves within the fruits (Yahia *et al*., 2019). However, the MI may vary when the cape gooseberry plants receive different irrigation coefficients; that is, increasing the amount of water applied decreases the MI decreases, which suggests that applying a larger irrigation level (coefficient of 1.3) affects the concentration of sugars to a greater extent than acidity. The MI is similar to that of tomato fruits since, when plants are subjected to water stress, the MI increases (Beckles, 2012).

pH value

This variable showed significant statistical differences between the applied irrigation frequencies. The irrigation frequency of 14 d presented the highest pH value (Tab. 1). Neither the irrigation level nor the calcium dose significantly affected the pH behavior of the gooseberry fruits at harvest. The pH averages found for the cape gooseberry fruits were similar to those obtained by Bazalar *et al*. (2019), who reported average values of 3.92, were lower than those reported by Mubarok *et al*. (2019), from 5.0 to 5.2, and were higher than those registered by Herrera (2000), who found values that ranged between 3.5 and 3.7 for fruits at maturity stage 5 and 6, respectively.

Vallarino and Osorio (2019) reported that the acidity of fruits depends on the content of organic acids stored in the vacuole, which decrease as the fruit matures because many are transformed into sugars, a process called gluconeogenesis. During fruit filling, a large part of the accumulation activity is given by simporte, where H^+ ions play an important role since they are part of the formation of substrates, such as sucrose and glucose. Their concentration at the vacuolar level decreases, and the pH is slightly increased (Lal, 2018). As the irrigation frequency became longer (14 d), the pH of the fruits increased, so they were less acidic, as reported by Marín *et al*. (2009) in pepper, who also found no effect from calcium doses on pH. No significant effect of the irrigation coefficient and the calcium doses was registered (Tab. 1). Likewise, as there was no effect of the calcium doses in the TTA, it did not affect the pH significantly.

Firmness

The water level and the frequency of the irrigation did not present significant differences in the firmness of the cape gooseberry fruits (Tab. 1), which had an average value of 9.91 N and a standard deviation of 0.55, lower than that found by Amézquita *et al*. (2008) and Balaguera-López *et al*. (2021), 11.19 and 15 N, respectively, and that obtained by Ciro *et al*. (2007), 13.1 N for ripe fruits, 16.8 N for dark fruits and 23.2 N for green cape gooseberry fruits.

Some authors have confirmed that reducing irrigation increases fruit firmness in the pear (Bayona-Penagos, 2017), blueberry (Almutairi *et al*., 2017), apple (Faghih *et al*., 2021), and peach (Zhou *et al*., 2017; Rufat *et al*., 2010). This decrease is attributed to the fact that water stress reduces the size of fruits, and smaller fruits tend to be more compact and firmer than large fruits (Faghih *et al*., 2021). Likewise, Patané *et al*. (2011) reported that tomatoes increase firmness when smaller amounts of water are applied because the turgor pressure decreases, which results in less pressure on the cell wall, making the epidermal elasticity higher. However, Porro *et al*. (2010) found that, in vines, a decrease in the amount of water applied reduced the firmness of the fruits, as did García-Tejero *et al*. (2010), who reported that a water deficit during the growth of citrus fruits generates a breakdown of the cell wall polymers and a greater reduction of the osmotic potential of fruits and their firmness.

For the cape gooseberry, the firmness could have increased with the treatments with less water application; however, they had smaller fruits, resulting in similar values since smaller fruits generally tend to present greater firmness because of the higher cell density, which makes cells more compact and rigid, and the greater availability of calcium assigned for the composition of the cell wall, which increases fruit firmness and resistance (Lima *et al*., 2021). This probably explains why there were no significant differences between the different irrigation regimes.

The calcium doses applied to the cape gooseberry plants did not significantly influence the firmness of the fruits at harvest. However, when Ca^{2+} was applied, the fruits presented 1.6% more firmness. Despite the absence of differences in the levels of resistance to penetration, the fruits that received Ca^{2+} showed 11% less cracking (Álvarez-Herrera *et al*., 2012), which highlights the importance of calcium applications in the quality of fruits since it has the ability to provide greater resistance to the cell wall and thickens it. Likewise, calcium has a large effect on firmness because this element maintains the integrity and structure of the cell membrane and decreases the activity levels of enzymes that degrade the cell wall, such as pectinesterase (PE) because it strengthens cell-to-cell adhesion and maintains the relationship of stiffness and extensibility (Kathpalia and Bhatla, 2018).

The application of calcium did not have a marked effect on the firmness of the fruits since it had a reduced effect when combined with irrigation treatments because these conditions may have decreased as a result of the excess or deficient water, the quantity of calcium absorbed by the plant, the amount of calcium, and the water supplied to the fruit, as reported by Agbemafle *et al*. (2014) in tomatoes. In general, the Ca-doses did not affect the measured fruit quality parameters, and also Garzón-Acosta *et al*. (2014) found only 0.79% of cape gooseberry fruits cracked of plants which were grown without Ca applications.

When evaluating the firmness of the cracked fruits, the Anova did not showed significant differences for any of the studied factors (Tab. 1). However, firmness of the cracked fruits per treatment presented average values of 6.64 N, 33% lower than the firmness of the healthy fruits. This strong tendency in firmness decrease of the cracked fruits is attributed, according to Jiang *et al*. (2019), that prior to cracking, increases in the activity of enzymes such as polygalacturonase and expansins occur during maturation, which together disassemble the polysaccharide network of the cell wall allowing softening. Likewise, these authors mention that the incidence of cracking was directly and significantly correlated with the low solubility of the cell wall pectins and the cellulose content, but not with the concentration of Ca^{2+}. On the other hand, Niu *et al*. (2020) stated that the metabolic pathways of galactose and phenylpropanoid biosynthesis are involved in fruit ripening and cracking. However, some authors have found effective mechanisms to reduce cracking, by bagging fruits, spraying calcium chloride, applying 6-Benzyl amino purine in tomato (Wang *et al*., 2021) and applying of gibberellins in cape gooseberry (Amézquita *et al*., 2008).

Calcium concentration in the fruits

The Ca^{2+} in the cape gooseberry fruits did not show significant differences between the calcium treatments and maintained an average percentage of dry mass value, 0.07663 ± 0.00215. This behavior is similar to that found in sweet cherries by Winkler and Knoche (2021), who tested different applications of combinations of Ca^{2+} and surfactants and found no differences in the calcium concentration in the fruits. Likewise, Poovarodom and Boonplang (2010) stated that calcium applications to the soil decreased the presence of physiological disorders in mangosteen; however, the Ca^{2+} in the pulp was similar to that of the control, as reported by Pessoa *et al*. (2021) for pears, where Ca^{2+} applications could be more effective in the early stages of fruit development and where the accumulation of calcium in fruits depends mainly on the Ca^{2+} transported through the xylem because of the low mobility required in the phloem. Hocking *et al*. (2016) reported that an increase in calcium supplements in fertilization allows an increase in Ca^{2+} in the leaves but not necessarily in the organs with little transpiration, such as fruits, since the plants have developed mechanisms to restrict the transport of Ca^{2+} to these organs, which have a low calcium requirement and a high membrane permeability that favors rapid cell expansion.

CONCLUSIONS

The firmness of the cape gooseberry fruits was not affected by the application of different water levels and irrigation frequencies. Cracked gooseberry fruits are less firm than healthy fruits. The highest irrigation coefficient applied to cape gooseberry plants (1.3) produced fruits with 10% less TSS and caused a decrease in the TTA. The irrigation frequency of 14 days generated an increase in the TSS and pH values. The calcium doses did not affect the TSS, TTA, and pH values. Therefore, it can be concluded that incremented irrigation coefficients (up to 1.3) increase the quality of cape gooseberry fruits.

Conflict of interests: the manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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