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Physicochemical properties of seven outstanding strawberry (*Fragaria* x *ananassa* Duch.) varieties cultivated in Cundinamarca (Colombia) during maturation

Propiedades fisicoquímicas de siete variedades destacadas de fresa (*Fragaria* x *ananassa* Duch.) cultivadas en Cundinamarca (Colombia), durante su maduración

Propriedades físico-químicas de sete variedades notórias de morango (*Fragaria* x *ananassa* Duch.) cultivadas em Cundinamarca (Colombia), durante a sua maturação

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Abstract

The strawberry market in Cundinamarca (Colombia) is mainly size driven with no consideration for its maturation state and nutritional quality, wasting therefore, its organoleptic and nutritional potential. For that reason, the physicochemical differences among seven strawberry varieties (Albión, Dulce Ana, Lucía, Monterrey, Ruby June, Sabrina and Ventana) cultivated in the municipality of Sibaté (Cundinamarca) were established. Fruits collected from a productive plot with homogeneous cultivation management conditions were analyzed in six maturity states, establishing the degree of red pigmentation according to the Colombian Standard NTC 4103. Fresh weight, size, color, firmness, total soluble solids (TSS), total titratable acidity (TTA), maturity and respiration indices were evaluated. Fruits in stages 4, 2 and 3 developed their largest size and weight, where the variety Dulce Ana stands out. The highest color index values were found in the maturity stage 5 in the variety Ventana. Moreover, the highest firmness values were recorded in stages 4 and 5 in the varieties Monterrey and Ventana. The varieties Sabrina, Dulce Ana and Monterrey accumulated the highest TSS concentration and the last two showed the best maturity relations. Respiration rates increased with maturation, especially from stage 3. The results suggest that the optimum commercialization and consumption points are stages 3 and 4, namely because these stages exhibit the highest maturity index and fruit weight. Among the varieties studied, Monterrey stands out due to its firmness and maturity index.

Keywords: Chemicophysical properties, Cundinamarca (Colombia), food quality, *Fragaria ananassa*, maturity

Resumen

El mercado de la fresa en el departamento de Cundinamarca (Colombia) se rige principalmente por el tamaño del fruto, sin valorar su estado de maduración ni su calidad nutricional, desaprovechando su potencial organoléptico y nutritivo. Por esta razón, se determinaron las diferencias fisicoquímicas en frutos de siete variedades de fresa: Albión, Dulce Ana, Lucía, Monterrey, Ruby June, Sabrina y Ventana, cultivadas en el municipio de Sibaté, Cundinamarca. Se analizaron frutos recolectados en un predio productivo en condiciones homogéneas de manejo, en seis estados de madurez, determinados por su grado de pigmentación roja, de acuerdo con la Norma Técnica Colombiana NTC 4103. Se evaluaron peso fresco, tamaño, color, firmeza, sólidos solubles totales, acidez total titulable, e índices de madurez y de respiración. En los estados 4, 2 y 3, los frutos desarrollaron su mayor tamaño y peso, y se destacó la variedad Dulce Ana. Los valores más altos en el índice de color se encontraron en el estado de madurez 5, en especial en la variedad Ventana. Las mayores firmezas se registraron en los estados 4 y 5 en Monterrey y Ventana. Sabrina, Dulce Ana y Monterrey acumularon la mayor concentración de sólidos solubles totales, y las dos últimas mostraron la mejor relación de madurez. Las tasas de respiración aumentaron con la maduración, sobre todo a partir del estado 3. Los resultados sugieren que los puntos óptimos para la comercialización y el consumo son los estados 3 y 4, debido al mayor índice de madurez y peso del fruto. Entre las variedades estudiadas, Monterrey sobresale por sus mayores firmeza e índice de madurez.

Palabras clave: calidad de los alimentos, Cundinamarca (Colombia), *Fragaria ananassa*, madurez, propiedades fisicoquímicas

Resumo

O mercado de morango em Cundinamarca (Colômbia) é governado principalmente pelo tamanho do fruto, sem dar valor o estado de maduração e qualidade nutricional do mesmo. Por esta razão, foram determinadas as diferencias físico químicas em frutos de sete variedades de morango (Albión, Dulce Anna, Lucia, Monterrey, Ruby June, Sabrina e Ventana) cultivadas no município de Sibaté, segundo produtor na Cundinamarca. Foram analisados frutos coletados numa propriedade produtiva com condições homogéneas de manejo, em seis estados de maduração determinados pelo grau de pigmentação vermelha de acordo à Norma Colombiana NTC 4103. Foi avaliado o peso fresco, tamanho, cor, firmeza, sólidos solúveis totais (SST), acidez total titulável (ATT), índices de maduração e de respiração. Nos estados 4, 3 e 2 os frutos desenvolveram seu maior tamanho e peso, destacando-se a variedade Dulce Anna. Os valores mais altos no índice de cor encontraram-se no estado de maduração 5, especialmente na variedade Ventana. Os valores mais altos de firmeza, nos estados 4 e 5, observaram-se para Ventana e Sabrina. As variedades Sabrina, Dulce Anna e Monterrey acumularam a maior concentração de SST, mostrando as duas últimas a melhor relação de maduração. As taxas de respiração aumentaram com a maduração, especialmente a partir do estado 3. Os resultados indicam que os melhores momentos de comercialização e consumo são os estados 3 e 4, devido ao maior índice de peso da fruta. Entre as variedades estudadas, Monterrey se destaca por apresentar maiores valores de firmeza e maturidade.

Palavras chave: Cundinamarca (Colombia), *Fragaria ananassa*, maturidade, propriedade físico-química, qualidade do alimento

Introduction

Strawberry *Fragaria* x *ananassa* Duch. (Rosaceae) is a soft fruit of high economic value that millions of people worldwide include in their diet, thanks to its organoleptic properties and its phytochemical content, since it is a substantial source of vitamin C, phenolic compounds and antioxidants (Halvorsen et al., 2006; Hancock, 1999).

Strawberries are extremely desirable for their unique taste and flavor being one of the most popular fruits in the world. In the international market, the average consumption is 3.9 kg/year/person, including fresh and processed fruit, although in Colombia its consumption is only 0.7 kg/year (Olmue Colombia, 2010).

Consumers buy this fruit mainly for its pleasant taste, but currently, the national strawberry marketing model for fresh consumption searches fruits based solely on several size categories. These categories are arbitrary and do not consider the maturity state, which, in perishable and non-climacteric products, has a marked influence on the quality and shelf life, especially during storage. It also affects the postharvest, transport and marketing management, being especially a crucial variable in postharvest technology (Reid, 2002).

Among the many factors that can affect the product's quality and flavor, the maturity state, the variety, and the irrigation and fertilization schemes are especially important (Kay, 1991). The quality components can be sensorial and nutritional, which implies the use of both the physical as well as the chemical characteristics of the fruit to establish the optimum maturity state, due to changes in these parameters and its correlation with the perception of product quality (Kay, 2004).

In 2014, Colombia produced 43,778 t of strawberries and the department of Cundinamarca had a participation share of 52 % that registered the highest yields in the country, i.e. 40.41 t/ha. The municipalities of Chocontá, Sibaté, Guasca, Soacha and Facatativá showed the highest production representing ca. 90 % of the country's total production (Red de Información y Comunicación del Sector Agropecuario [Agronet], 2016). These high yields are possible due to continuous production throughout the year with harvest peaks every three and five months (Grijalba, Pérez-Trujillo, Ruiz, & Ferrucho, 2015; Hancock, 1999).

Harvesting fruits at the appropriate maturity stage is essential for optimum quality, especially in non-climacteric fruits such as strawberries. The growing trend towards an agriculture that each day opens even more to world trade and industrialization requires that agricultural activities must be increasingly more productive and competitive, generating quality products that meet consumer requirements.

For the Colombian strawberry agribusiness, one of the factors that limits its development is the impossibility to locate producers who meet industrial requirements in relation to fruit uniformity, maturity and health (Ruiz & Piedrahíta, 2012).

Currently, the strawberry varieties that are mostly cultivated in Cundinamarca are Monterrey and Albión. However, there is lack of sufficient quality analysis in which an optimum harvest point has been established or even recommended, in terms of compound concentration and focused on consumer acceptance.

The aforementioned is because the Colombian Technical Standard (NTC) 4103 for fresh fruit —strawberry Chandler variety— does not govern strawberry marketing, as it is an outdated regulation that requires urgent updates. Moreover, the national strawberry market does not show much specialization and lacks planning, especially for the export and industrialization sectors.

For the reasons stated so far, the objective of this study was to establish strawberry fruit quality in seven promising varieties in Colombia harvested at different maturity stages; this information will contribute to the development of practical tools to establish the optimum fruit harvest time. Furthermore, this research will stimulate the development of future studies related to the selection of varieties for industrial and export purposes.

Materials and methods

Plant material

The plant material used for this study came from the production farm El Porvenir located in the village of San Miguel, in the municipality of Sibaté, Cundinamarca. Seven strawberry varieties were selected for this study: Albión, Dulce Ana, Lucía, Monterrey, Ruby June, Sabrina and Ventana. The farm is located at 04°26'43'' N and 74°17'43.9'' W, at an altitude of 2,663 meters above sea level, with an average temperature of 13 °C and an average annual precipitation of 850 mm.

The plants were cultivated in a planting frame of 0.3 m between these, in triangle (locally known as *tres bolillos)*. Measurements were taken when plants were 42 weeks old. The agronomic management was homogeneous for all varieties according to what was established for this region.

The plants were cultivated in an open field on beds of 45 m long and 1 m wide, covered with a black, three-layered, smooth, 1.2-caliber polyethylene film. Irrigation and fertigation were carried out with a drip system. In addition, foliar fertilizers were applied to further complement the crop's nutrition.

For each variety, harvested fruits of two categories A *(*≥ 34 mm, 21.8 g on an average) and B (30 to 33 mm, 16.1 g on an average) were selected by weight and diameter according to the Colombian technical standard NTC 4103 (Instituto Colombiano de Normas Técnicas y Certificación [Icontec], 1997). These categories correspond to "second" and "third" commercial categories, i.e. fruit with characteristics that are most frequently found in the national market.

The maturity state of different fruits was established assessing the pigmented proportion of their epidermis on a scale of 0 (pale green color) to 5 (100 % of the fruit with an intense red color) (Icontec, 1997).

The fruit samples of each state by variety had an approximate weight of 0.6 kg (±25 fruits). On the same day the fruits were harvested the plant material was transported at a stable temperature of 17 °C to the Postharvest & Grain and Seed Quality Control Laboratory of the Civil and Agricultural Engineering Department of Universidad Nacional de Colombia in Bogota.

Fruit dimensions

Fruit diameter corresponds to the maximum length perpendicular to the height; it was measured in centimeters with a conventional calibrator; fresh weight was measured with an analytical balance Precisa XT-220A model (precision of 0.0001 g) [Dietikon, Switzerland], following the methodology published by Herrera (2010).

Fruit color

The color was established with a Minolta colorimeter CR-400 model [Tokyo, Japan] in the CIELab mode; five points on the equator of the fruit's surface were considered, measuring the coordinates l^*, a^* and b^* of five fruits, by state and variety. In addition, the coloration index (CI) was calculated using the equation established by Vignoni, Césari, Forte and Mirábile (2006).

$$IC^* = \frac{a^* \cdot 1.000}{l^* \cdot b^*}$$

A negative CI^* value (-40 to -20) goes from blue-violet to deep green; if this value goes from -20 to -2, the color seen goes from deep green to yellowish; on the other hand, a positive CI^* value is associated with colors ranging from a soft orange to a deep red.

Firmness

Firmness was established following the methodology published by Herrera (2010); to determine firmness the peak load value was obtained, i.e. the load supported by the fruits measured in grams using a Brookfield texture analyzer CT3-4500 model [Massachusetts, USA]. The equipment was adjusted to a reading sensitivity of 0.5 g and a fruit penetration length of 5 mm using the Magness Taylor tip with a diameter of 2 mm, at a speed of 1 mm/s (recommended in the manufacturer's manual for this type of fruit). The measurement was made in five strawberries of each variety and maturity state on the fruit`s midpoint.

Respiration

One-hundred grams of fruits of the same variety and maturity state were selected and weighed, and the respiratory intensity of three repetitions was measured following the methodology established by Herrera (2010). A respiration chamber Biochamber 2000 Vernier model [Beaverton, USA] was used for 15 minutes at 22 °C. The CO_2 concentration was measured using a CO_2-BTA Vernier sensor in a LabQuest LQ2-LE Vernier model, and the results were expressed in mg of CO_2/kg/h.

Chemical tests

The following chemical tests were carried out to fruit extracts (20 ml of strawberry mash with three repetitions each) that were prepared for each of the six maturity stages and each of the seven varieties: total soluble solids (TSS), pH, total titratable acidity (TTA), and maturity ratio. Total soluble solids were measured using the Kikuchi analog refractometer [Tokyo, Japan], with a reading range in Brix degrees between 0 and 32 °Bx.

The pH and titratable total acidity that corresponds to the citric acid were measured with the digital titrator SI Analytics, TitroLine® 6000 TM 235 model, NaOH 1N, and the potentiometer IOLine Schott Instruments [Mainz, Germany], analyzing a solution composed of distilled water and fruit extract in a 1:1 weight ratio. The formula applied for the calculation of titratable acidity followed the methodology published by Nielsen (2009), and the maturity ratio was calculated as the quotient between the TSS and the TTA values.

Data analysis

For each variable three repetitions per maturity state and variety were made, and were then processed and analyzed with the SAS® program version 9.3. A two-way analysis of variance was performed in which the maturity states and the varieties were the variation components.

Orthogonal contrasts with the Duncan test at 95 % confidentiality were carried out by comparing means and groupings generated by significant differences, and comparing all the varieties in each maturity state for each variable.

Results and discussion

In the commercial field in Colombia value is given to strawberries based on parameters as fruit diameter and weight, due to the practicality of this measurement. However, these criteria overlook the nutritional and organoleptic qualities and all other physicochemical properties as color, firmness, respiration, TSS and TTA of the fruits in different varieties and maturity states; however, according to Nunes, Brecht, Morais, and Sargent (2006) these characteristics have been studied in other varieties.

Fruit diameter and fresh weight

According to the different maturity stages the behavior of the fruit's diameter and fresh weight of the fruit showed significant differences (figure 1) in all the varieties. The largest sizes were found in the maturity states 4 (3.51 cm), 2 (3.37 cm) and 3 (3.34 cm), and the lowest were found in states 1 (3.14 cm), 5 (3.06 cm) and 0 (2.95 cm). Fresh weight showed similar results (figure 1b) in states 2, 4 and 3, with the highest weights (21.48, 21.25 and 20.68 g, respectively), compared to states 1 (17.76 g), 5 (16.71 g) and 0 (14.63 g).

When the diameter of the seven evaluated varieties was compared (figure 1a), Dulce Ana (3.48 cm) and Ruby June (3.45 cm) showed the largest size, and they also showed significant differences ($p < 0.001$) compared to the others. Then, the varieties that followed were Lucía, Monterrey and Albión with averages of 3.25, 3.0 and 3.12 cm, respectively. The varieties Ventana (3.01 cm) and Sabrina (2.90 cm) were significantly smaller than the rest of the varieties.

Regarding fresh weight (figure 1b), the results show a similar tendency as the one seen in diameter but with significant differences; moreover, the highest values were found in the variety Dulce Ana (25.22 g), compared to Ventana (with only 14.44 g) ($p = 0.0007$). Dulce Ana presented the heaviest fruits in all maturity stages, except in state 5, in which its fresh weight was significantly lower

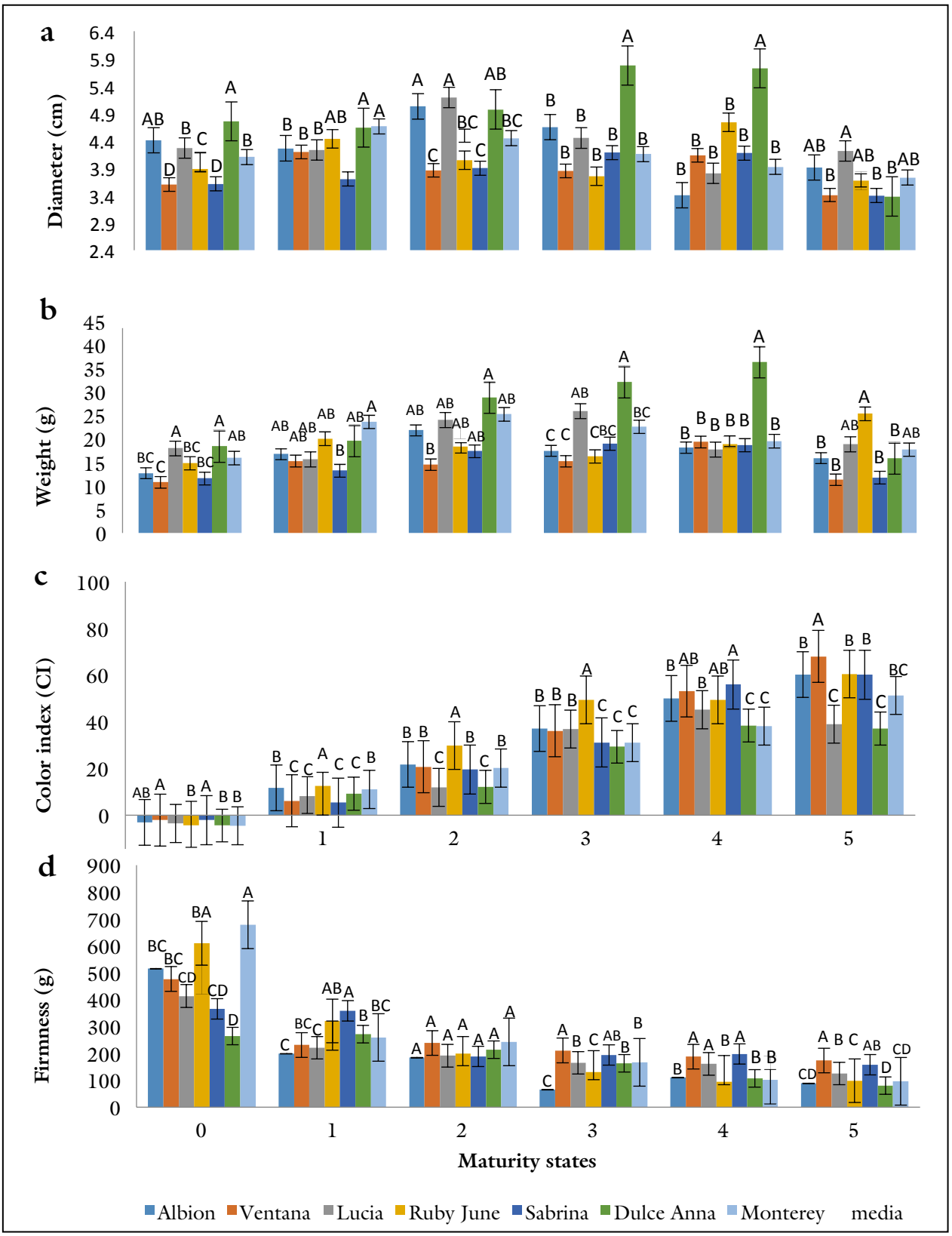

Figure 1. Variables measured in seven strawberry varieties in six maturity states: a. Diameter; b. Weight; c. Color index; d. Firmness. The letters over the bars indicate statistical differences according to the Duncan test ($p \leq 0.05$).
Source: Prepared by the authors

than the one shown by Ruby June, whereas on the contrary, Ventana consistently showed the lowest values in all maturity stages.

Fruit size and weight depend on endogenous factors such as the variety's genetics, and exogenous factors such as the climate and the crop's agronomic management (Fischer et al., 2012b). As the climate and the crop's management are the same for all varieties in this study, it is likely that the varietal factor was one of the most influential elements in the fruit's dimension differences (Fischer, Almanza-Merchán, & Ramírez, 2012).

Hancock (1999) states that the fruit's final size depends around 15 % to 20 % of cell division —which occurs mostly before anthesis— and from 80 % to 85 % of cell lengthening, for which water and nutrients supply —especially potassium— is extremely important (Fischer, Ramírez et al., 2012).

At full maturity (state 5) the reduction in size and weight was noted in parallel with the decrease in firmness (figure 1d) and the increase in respiration (figure 2), especially in the Dulce Ana variety. Rahmann, Moniruzzaman, Ahmad, Sarker and Alam (2016) found similar results in strawberry varieties when comparing states 2, 3 and fully mature.

Fruit color

During fruit development and maturation, many changes occur in its pigmentation; some may continue after harvest and are not always expected or wanted. In the case of strawberry, the development of anthocyanins is desirable, but these water-soluble compounds are unstable and degrade easily (Kader, 2002).

Color is an easily identifiable reference property in strawberry to define its maturity state and has a direct relationship with the maturity index. The color index (*CI*) depends on the fruit's epidermis coloration, which allows following the evolution of fruit maturation. According to Vignoni et al. (2006), when the maturity state is zero (0) there is a green coloration in all the varieties (figure 1c); among the varieties studied, Dulce Ana (-5.07)

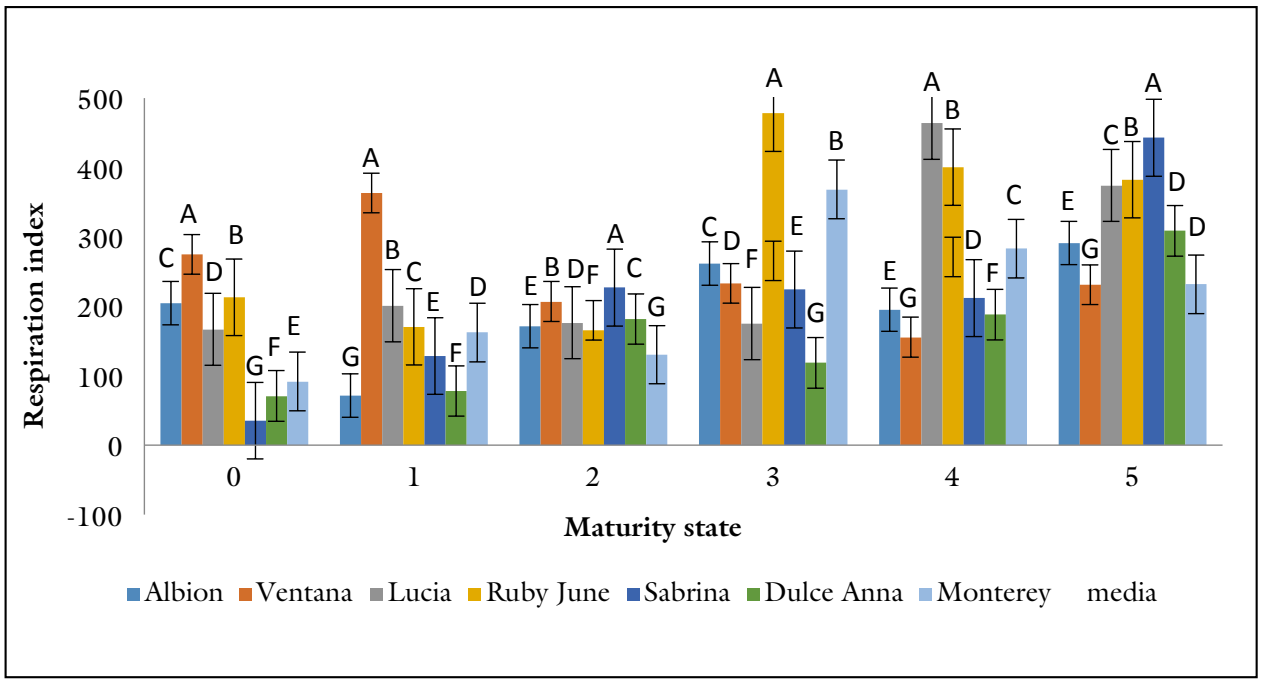

Figure 2. Respiration index of seven strawberry varieties harvested at six maturity states. Averages with different letters for each maturity state indicate a significant difference according to the Duncan test ($p \leq 0.05$).
Source: Prepared by the authors

and Monterrey (-5.58) stand out because they show notably green fruits.

If the *ci* value is between -2 and 2, this corresponds to a yellow-green color, whereas if it is between 2 and 20, it is associated with colors ranging from pale yellow to intense orange. This last range was found in the cases of the states 1 and 2 in all varieties, with the exception of Monterrey (26.26) which showed a red color in these states.

On the other hand, if the *ci* value found is between 20 and 40 it is linked with colors that ranges from intense red to deep red. This corresponds to the maturation states between 3 and 5 in all varieties; however, among these, the variety Ventana showed the fruits with the most intense red color, and therefore, it has the highest pigments and anthocyanins accumulation, i.e. 68.2 —in the maturity state 5— (Nunes et al., 2006).

This varietal difference is influenced by different cyanidin-3-glucoside concentrations, which gives the fruit a red-orange color (magenta and crimson); pelargonidin gives orange, pink and red colors (Mazza & Miniati, 1993). Therefore, the color diversity between the strawberry varieties and maturity states is given by different concentrations of these two pigments.

Firmness

The firmness or texture are properties that affect considerably the fruit's consumption and storage habits (Priya, Prabha, & Tharanathan, 1996), and are currently used as a parameter for the management improvement and postharvest product quality follow-up (Herrera, 2010).

When assessing the firmness in different maturity stages, a tendency of showing a higher resistance in a smaller state was found (figure 1d). Furthermore, significant differences were found in each of the states ($p < 0.0001$), being zero (0) the one with the highest resistance, and showing an average value of 474.0 g; the one with the lowest one had an average of 117.3 g.

Loss of firmness is associated with the degradation of the components of cell walls (cellulose and pectin), which increases with respiration and the fruit's maturity state. This occurs through the joint action of enzymes as cellulase, pectinmetilesterase and pectinase (Paliyath, Murr, Handa, & Lurie, 2008), which explains the gradual loss of material in the cell walls of the cortical tissue, due fruit maturation; this occurs both in the field as well as during storage (Koh & Melton, 2002).

Nunes (2008) explains that the characteristic fragility of ripe strawberry fruit cells obeys, in part, to the fact that they adopt an elongated structure with thin cell walls; this explains what is observed in the opposite tendencies of variables as firmness (decreasing) and respiration (increasing), as the state of fruit maturation increases.

This behavior was observed in all varieties as the maturation process requires energy investment and carbon compounds of the fruits for the synthesis of pigments and proteins, a process that occurs from respiration (Seymour, Taylor, & Tucker, 1993).

Ménager, Jost and Aubert (2004) found that the firmness in strawberries decreases rapidly from their white coloration (state 0) until they show half of their coloration (state 3); in this point, the variable stabilizes until its complete maturity point. Likewise, it is reported that firmness in state 3 is at least 20 % higher than at the point of total maturity (Forney, Kalt, McDonald, & Jordan, 1998; Ménager et al., 2004, Nunes et al., 2006).

The data obtained show significant differences ($p = 0.019$) among the varieties in all their maturity stages, but the value shown by Dulce Ana (183.0 g) was clearly lower, compared to those found in Monterrey (257.5 g), Ventana (253.0 g), Sabrina (243.7 g), Ruby June (242.3 g), Albion (213.6 g) and Lucia (212.7 g).

The highest differences within varieties are expressed in the early maturity stages maintaining the trend shown by Monterrey —as the firmest— and Dulce Ana —as the least firm—; however, Ventana showed the highest values during the last three maturity stages: 210.6 g, 187.8 g and 173.6 g, respectively.

In the Albión variety's patent, Shaw and Larson (2006) reported a firmness of 0.93 pounds in 3

mm² at maturity stage 5, that is 281.2 g, a value significantly higher than those found in the current trial for all varieties. Further, Haig (2013) describes that Lucia has a superior firmness when compared to that of Dulce Ana in results obtained for states 0, 3, 4 and 5.

Shaw and Larson (2009) report equal firmness values in Albion and Monterrey, which agrees with what this study found for states 1 to 5, in which these two varieties did not show significant differences. On the other hand, in studies carried out by Pierron (2012) and Larson and Shaw (2003), when they compared the Sabrina and Ventana varieties with the Camarosa variety, Ventana showed a superior firmness, agreeing with the results obtained in this study.

On the other hand, Xie et al. (2016) irradiated production plants with UV-C (280-190 nm) in Canada and found that fruits of the Albion variety had higher firmness; this is an interesting result, considering that at the altitude of Sibaté (2,663 m.a.s.l.) there are also high levels of ultraviolet radiation that promotes firmness in strawberries.

Total soluble solids

Total soluble solids (TSS) showed significant differences in all maturity stages and in all varieties ($p = 0.0004$ and $p = 0.002$), respectively (figure 2). Fruits in a state of maturity zero (0) showed a lower value than in the other states, followed by state 1, that although it showed a significantly higher average, it also showed a wide variance.

According to Ménager et al. (2004), Nunes et al. (2006) and Salamat, Ghassemzadeh, Heris and Hajilou (2013), the strawberries' soluble solids tend to increase during fruit maturation when still on the plant. This agrees with the results obtained in all maturity stages, in which, in general, as shown by the trend line seen in figure 3, the highest TSS values were obtained in states 3, 4 and 5.

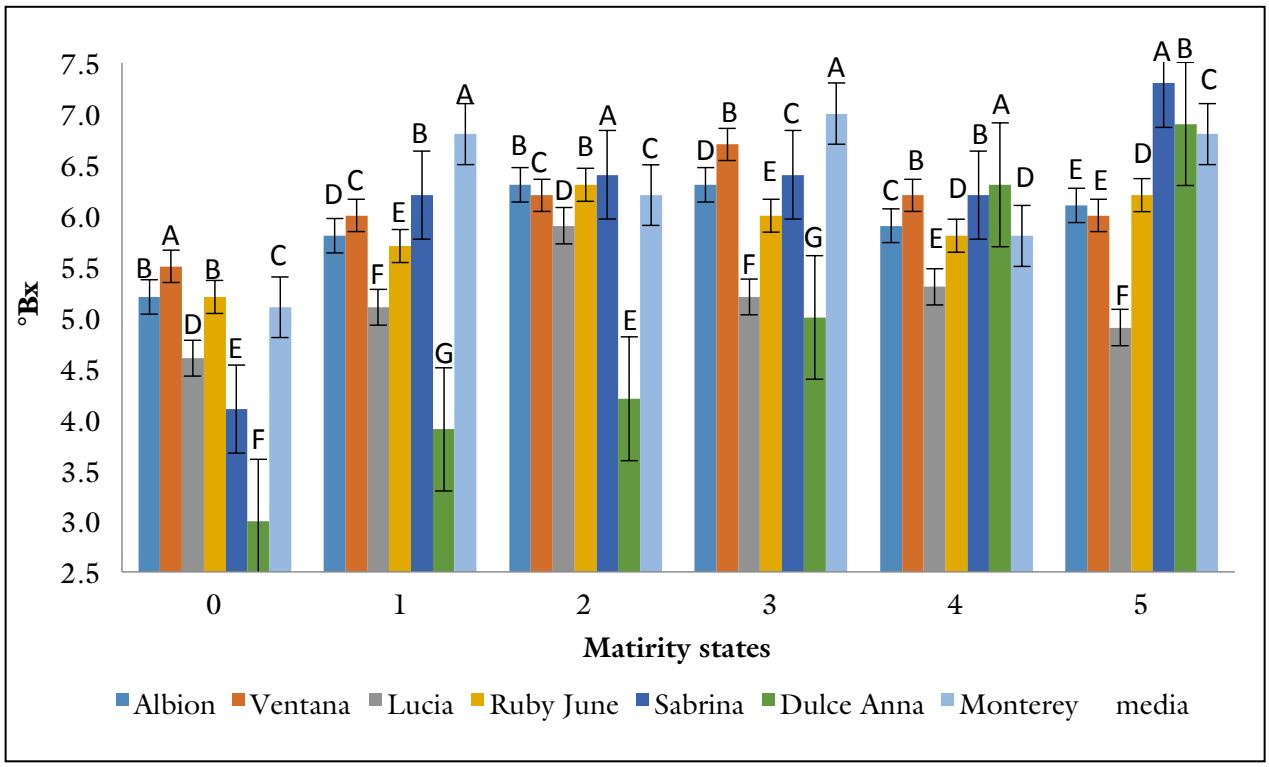

Figure 3. Total Soluble Solids (SST) for seven strawberry varieties harvested in six maturity states. Averages with different letters for maturity states indicate a significant difference according to the Duncan test ($p \leq 0.05$).
Source: Prepared by the authors

Ogiwara, Habutsu, Hakoda and Shimura (1998) have reported diversity in the TSS content among varieties, mainly due to different sugar concentrations that accumulate in the fruit from the beginning of maturation, but not in its previous stages of development. This could explain the significant differences found in the TSS content at maturity state zero (0) compared to the other states.

The TSS of the varieties showed significant differences ($p = 0{,}002$) (figure 3), and the highest values correspond to Monterrey, Sabrina, Ventana and Albion. Sabrina obtained the highest accumulation of TSS during the fruit's complete maturity (5), and Dulce Ana showed the lowest concentration due to its low initial TSS content (in the maturity states 0, 1, 2 and 3); however, it was the variety that showed the highest accumulation rate during the entire fruit development.

Nunes, Morais, Brecht and Sargent (2002) found significantly higher TSS content in strawberry fruits in the maturity state 5 compared to the one found in state 3. The result of this study agrees with the ones published by Pineli et al. (2011) who found in strawberries in the maturity state 5 TSS levels of 7.9 and 6.3 °Bx, and values of 7.5 and 7.1 °Bx for fruits in state 4 for the varieties Oso Grande and Camino Real, respectively. This also agrees with the results obtained by Goulas and Manganaris (2011) and Kader (1991).

Shaw and Larson (2006) found in the Albion variety a TSS concentration of 11.2 °Bx, Bagdasarian (2012) obtained a value of 12.1 °Bx for Dulce Ana, and Pierron (2012) a value of 6.9 °Bx in Sabrina. Generally, the authors agree with what was published by Wang (2007), i.e. the differences among different varieties in relation to TSS content might be due to genetic factors that play an important role in fruit composition of berry type fruits.

Total titratable acidity (tta)

The TTA values obtained in different maturity stages only showed significant differences in state zero (0) (figure 4); moreover, these also showed an inverse relationship between the fruit's increase in maturity and the percentage of acid in the same.

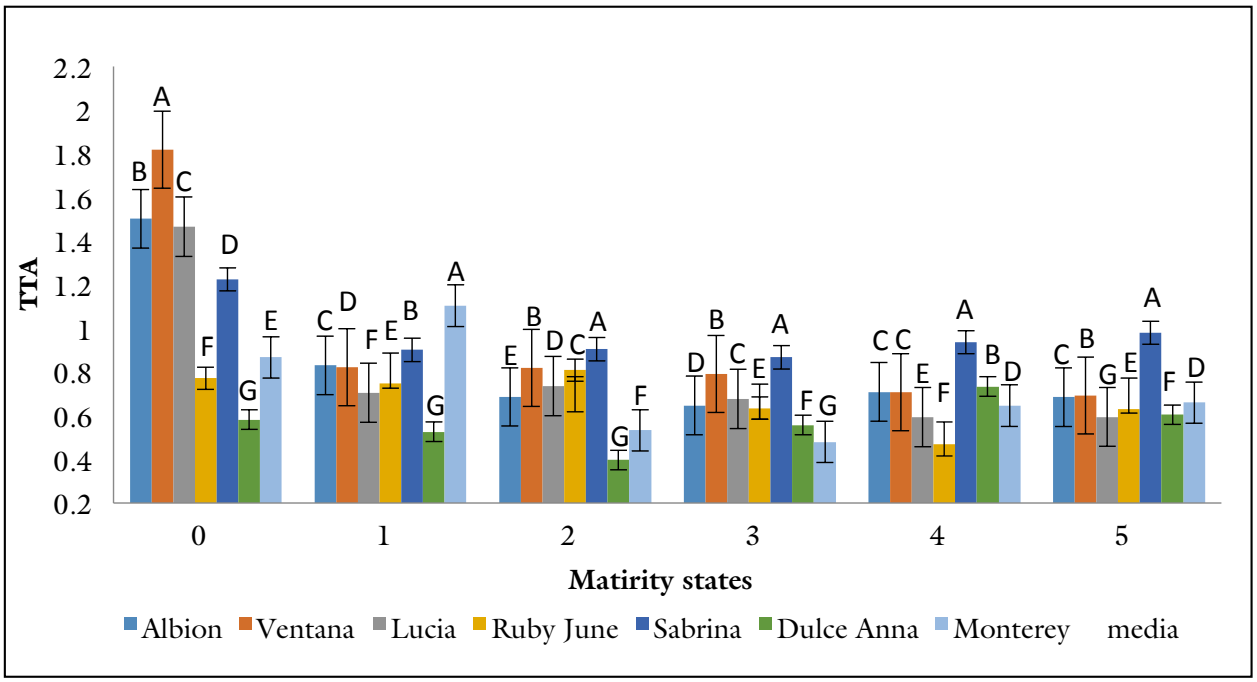

Figure 3. Total titratable acidity (TTA) of seven strawberry varieties harvested in six maturity stages. Averages with different letters for each stage of maturity indicate a significant difference, according to the Duncan test ($p \leq 0.05$).
Source: Prepared by the authors

According to Paliyath et al. (2008) the main molecules present in fruits during their filling phase and before starting maturation, are organic acids.

In the case of strawberry, the main organic acid found is citric acid, which shows a maximum concentration in the fruit's greenest states. This concentration decreases due to TSS gain as it is converted into sugars (Wills, McGlasson, Graham, & Joyce, 2007).

In previous studies carried out by Vicente, Martínez, Civello and Chaves (2002) with the strawberry variety Selva, they observed a decrease in TTA according to reports published for other fruits as apples, peaches, grapes and tomatoes. These changes are the result of the use of organic acids as a substrate for the respiration process (Wills et al., 2007).

The Sabrina and Ventana varieties accumulated the highest TTA contents with significant disparities compared to the others. Sabrina showed higher acidity values from state 2 to 5, while Dulce Ana had the lowest content and significant differences below what other varieties showed (figure 4).

It should be noted, that although most of the varieties showed a decreasing behavior in acidity percentage with an increase in maturation, Dulce Ana did not show this tendency. Skupién (2003) agrees with this statement, as the acidity is a characteristic that depends on the variety, on climatic conditions and on agronomic factors. Kallio, Hakala, Pelkkikangas and Lapveteläinen (2000) reported that the organic acids content in the strawberry normally does not exceed 3%, and the fruit's total acidity is based on the citric acid and citrates contents.

The results of this study are in accordance with the ones reported by Forney et al. (1998), Moing et al. (2001), Nunes et al. (2006) and Sturm, Koron and Stampar (2003), who found that acidity increases slightly in green fruits, and then decreases rapidly in later maturity stages.

Furthermore, the TTA differences recorded in this work between the varieties agree with the results given by Kafkas, Koşar, Paydaş, Kafkas and Başer (2007) and Morvai, Molnár-Perl and Knausz (1991) who recorded significant variations in the titratable acidity of different germplasm material. They assume that these inequalities between varieties might be caused by different citric acid concentrations of each one, and this in turn may be due to differences in the synthesis or in the vacuolar storage capacity during fruit maturation.

Maturity ratio

The pleasant taste of the strawberry is related to the proportion of sugars and organic acids (Perkins-Veazie, 1995; Shaw, 1988), which determines the optimum harvest time as it is considered a quality index (Cordenunsi, Oliveira do Nascimento, Genovese, & Lajolo, 2002).

During maturation, the simple sugars that contribute to sweetness increase, the organic acids and phenols that cause acidity and astringency decrease, and the aromatic volatiles that characterize the flavor and aroma of the strawberry increases (Salunkhe, Bolin, & Reddy, 1991).

The maturity relation in the fruits studied showed significant differences between different maturity states (figure 5). The highest values were reached in states 3, 5 and 4, compared to state zero (0) which obtained the lowest numbers.

When comparing the results obtained per varieties, the Monterrey and Ruby June showed the highest maturity ratio. However, in the state of maximum maturity, the fruits of Dulce Ana reached the highest relation. Furthermore, there were significant differences in Sabrina, which consistently recorded lower values during the various maturity stages.

Respiration index

Kader (2002) classifies the strawberry as a fruit with high respiration, and relates it to the deterioration rate of the harvested fruit. This fruit is classified as non-climacteric since it lacks a high respiration peak during its maturation. However, Wills et al. (2007) considers that this concept is arbitrary, taking into account that in general, the respiration in this species is high.

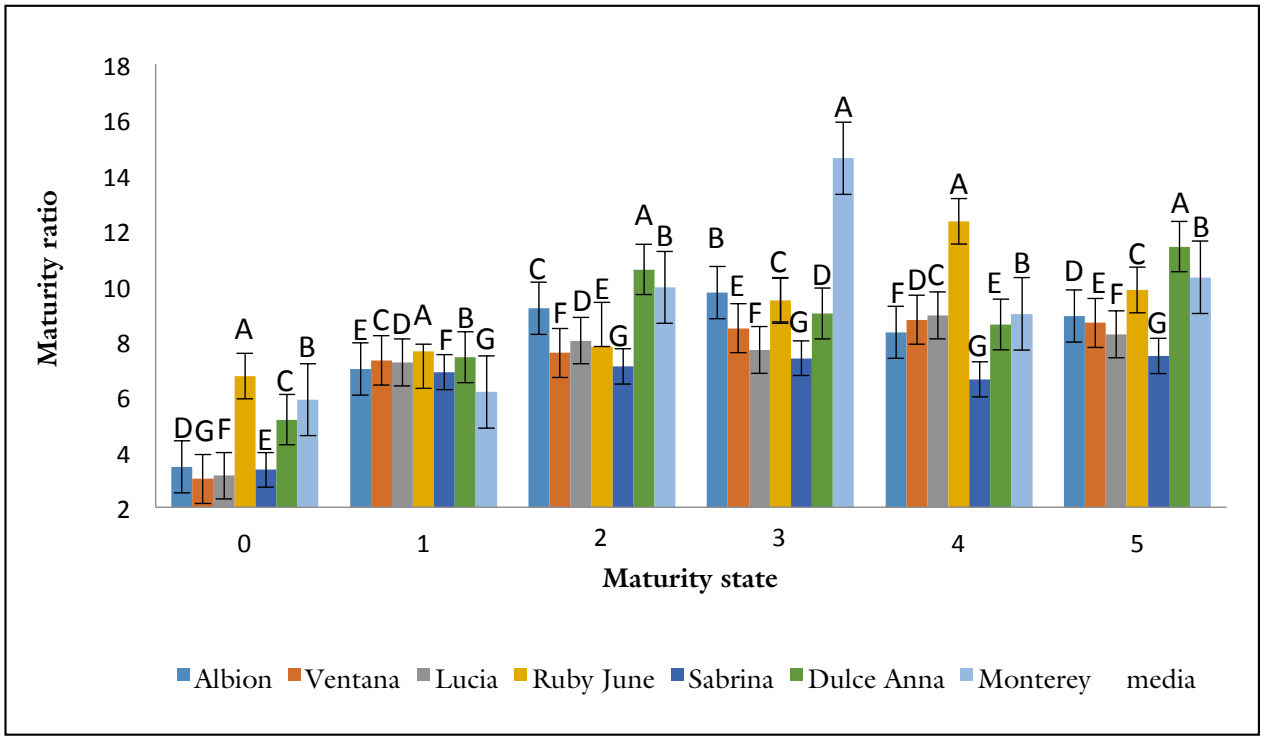

Figure 5. Maturity ratio of seven strawberry varieties harvested at six maturity stages. Averages with different letters for each maturity state indicates a significant difference according to the Duncan test ($p \leq 0.05$).
Source: Prepared by the authors

Significant differences were found between all maturity stages with a tendency to increase the respiration rate as maturation progresses (figure 2). The greatest similarity between the averages for this variable was found in states 3 and 4. With an increase in maturation, the respiration index showed an inverse tendency to the one observed for the firmness variable.

Among the varieties examined important disparities were found: the highest values for the respiration index were recorded in Ruby June (284.9 mg CO_2 kg/h) and Lucia (276.9 mg CO_2 kg/h) during the maturity stages 3 and 4. On the contrary, Dulce Ana (157.5 mg CO_2 kg/h) and Ventana (155.4 mg CO_2 kg/h) showed the lowest respiration indexes (figure 5). Furthermore, the highest respiration peaks for the variety Ventana were found in the first stages of maturity, i.e. 0 and 1.

The results found for the respiration variable in this trial (150 to 450 mg CO_2 kg/h between states 4 and 5) were higher than the range reported by Kader (1999), who recorded strawberry respiration rates between 100 and 200 mg CO_2 kg/h. These values only agree with those obtained in the most advanced maturity stages in the Monterrey and Ventana varieties found in this study. However, the respiratory rates evaluated correspond to values that are within the high respiration ranges reported by Kader (2002) and Herrera (2010).

Conclusions

Significant differences in chemical and physical variables evaluated in seven selected varieties from the municipality of Sibaté were found. The largest dimension and weight values found in fruits were obtained in the maturity states 4 and 3, and especially in the Dulce Ana variety.

The identification of these maturity states and a variety with current marketing potential are of great interest to producers, as the market criteria considers these as the main characteristics in order to consider a product as "first category".

The best physicochemical characteristics were recorded for the maturity stages 4 and 5 in all varieties assessed, showing their highest organoleptic and nutritional potential. The most desirable values in terms of color (color index) were found in the maturity state 5, especially in the variety Ventana, followed by Albion, Ruby June and Sabrina.

However, this quality, which is usually used as a harvest criterion, does not correspond to the point in which the fruits exhibit their highest weights; therefore, given that marketing is based on this last factor, the color variable is not the most appropriate feature for choosing a suitable harvest point for strawberry.

The highest firmness values in all maturity states were observed in the Ventana and Sabrina varieties. This characteristic gives the fruits of these varieties a greater mechanical resistance and a high potential to maintain acceptable characteristics during transport, postharvest processes and an increased shelf life. A variety that stands out is Ventana that also has the lowest respiration rate among the varieties, gaining an extra point for being adequate for export markets or for markets that require prolonged transport.

Sabrina, Dulce Ana and Monterrey maintained the highest total soluble solids concentration, and the last two showed the best maturity ratios (TSS/TTA); therefore, these have a better taste and potential to be used for fresh consumption and in the food industry.

It is necessary to carry out further measurements and similar studies adapted to several strawberry production areas in Colombia as these show particular agroecological conditions that enhance specific attributes in each variety, both in the field as well as during postharvest.

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Disclaimers

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