

Article

Planting Density Interferes with Strawberry Production Efficiency in Southern Brazil

Juliana Martins de Lima ¹, Paola Daiane Welter ¹ , Marllon Fernando Soares dos Santos ¹ , Wanda Kavcic ¹, Bruna Miranda Costa ¹, Antonio Felipe Fagherazzi ^{1,*}, Francine Regianini Nerbass ¹, Aike Anneliese Kretzschmar ¹, Leo Rufato ¹ and Gianluca Baruzzi ² 

- ¹ Centro de Ciências Agroveterinárias da Universidade do Estado de Santa Catarina (CAV-UDESC), Av. Luiz de Camões, 2090, Bairro Conta Dinheiro, Lages 88520-000, Santa Catarina, Brazil; juumartinsslima@gmail.com (J.M.d.L.); pdaianew@hotmail.com (P.D.W.); marllon.soares@outlook.com (M.F.S.d.S.); wandakavcic@outlook.com (W.K.); brunacosta433@yahoo.com.br (B.M.C.); fr.nerbas@udesc.br (F.R.N.); aike.kretzschmar@udesc.br (A.A.K.); leo.rufato@udesc.br (L.R.)
- ² Council for Agricultural Research and Economics-Centre for Olive, Fruit and Citrus Crops (CREA-OFA), Via La Canapona, 1bis, 47121 Forlì (FC), Italy; gianluca.baruzzi@crea.gov.it
- * Correspondence: antonio.fagherazzi@udesc.br



Citation: Martins de Lima, J.; Welter, P.D.; Soares dos Santos, M.F.; Kavcic, W.; Miranda Costa, B.; Fagherazzi, A.F.; Regianini Nerbass, F.; Anneliese Kretzschmar, A.; Rufato, L.; Baruzzi, G. Planting Density Interferes with Strawberry Production Efficiency in Southern Brazil. *Agronomy* **2021**, *11*, 408. <https://doi.org/10.3390/agronomy11030408>

Academic Editor: Alain Deloire

Received: 22 December 2020

Accepted: 16 February 2021

Published: 24 February 2021

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Abstract: In the search for more efficient production systems, many changes have occurred in the strawberry production sector. Planting density is one of the management techniques that most interferes with the quality of fruits and production aspects. This study aimed to evaluate the effect of different planting densities on the photosynthetic characteristics, fruit quality, and production of the strawberry cultivar Pircinque. The study was conducted in the 2018/2019 and 2019/2020 harvests in Lages, Santa Catarina, Brazil. The treatments consisted of plant spacing of 5, 10, 15, 20, 25, and 30 cm. The experimental design was in randomized blocks, with four blocks and plots of 20 plants. Plant spacing interfered with fruit quality, photosynthetic efficiency, production, productivity, and economic return. Due to the fruits of Pircinque having a higher quality than other cultivars, the planting spacing between 5 and 15 cm allows meeting the fruit's main production and quality requirements. However, it is up to the producer to adapt the management if opting for higher planting densities, which allow for a greater economic viability of the business.

Keywords: *Fragaria X ananassa*; planting spacing; photosynthetic efficiency; productive viability; fruit quality

1. Introduction

The strawberry (*Fragaria X ananassa* Duchesne) is produced and appreciated throughout the world. It is a culture of great economic importance, standing out among producers and consumers as the main species among small fruit groups. [1]. That is mainly due to the high-quality characteristics of the fruits and their nutritional properties, highly appreciated by consumers, especially for the presence of polyphenols, ellagic acid, anthocyanins, and vitamin C [2,3]. Worldwide, 8.3 million tons were produced in 372.3 thousand cultivated hectares in 2018. As the world's largest strawberry producers, China (111 thousand hectares), Poland (47.9 thousand hectares), Russia (29.8 thousand hectares), the United States (19.9 thousand hectares), Turkey (16.1 thousand hectares), Germany (13.9 thousand hectares), and Mexico (13.6 thousand hectares) are worth mentioning [4].

Even though it is not among the leading strawberry producers globally, Brazil stands out as the largest producer in South America, with about 4.5 thousand hectares cultivated and 165 thousand tons produced in 2019 [5,6]. The leading Brazilian strawberry producers are the states of Minas Gerais, Paraná, the Rio Grande do Sul, São Paulo, Brasília, Espírito Santo, Bahia, and Santa Catarina. Together, Minas Gerais, Paraná, and the Rio

Grande do Sul represent approximately 75% of the cultivated area and national production. Due to the marketing of fruit's high added value and it being considered a microclimatic culture, strawberry cultivation has an outstanding characteristic of social and economic involvement, becoming a principal activity of small rural properties [6–11].

Many authors refer to numerous factors that may directly influence strawberry cultivation and their soil and climatic conditions and management responses [12,13]. However, among these factors, we can highlight that the correct choice of a cultivar can determine the success in cultivation, due to the interaction between environment, temperature, and photoperiod [14]; the phyllochron and thermal sum also influence the production phase and the seasonal production cycle [15,16]. The plants must have high vigor and physiological and phytosanitary quality, capable of promoting a high survival rate and vegetative growth after planting [17–19]. Different cultivation systems can also interfere with planting density, productivity, and cultivar indication [20].

It is also relevant to validate that in Brazil, about 70% of strawberry crops are carried out with the cultivars Albion, Camarosa, and San Andreas [8] and that in the states of Santa Catarina and the Rio Grande do Sul, about 80% of new strawberry crops are carried out in soilless cultivation systems, semi-hydroponic [6,8]. Thus, we observe that there are still deficiencies in the semi-hydroponic system due to adequate indications in the management techniques for strawberry cultivation and in the use of cultivars recently introduced in Brazil to enable new production alternatives. However, this system has been increasingly used as an alternative for cultivation in a protected environment, fruits have higher quality, and the harvest period can be extended for up to two months. [21,22].

The interaction between cultivar and soilless cultivation system is an essential factor to be studied, combined with different planting densities. It is necessary to optimize structure usage to obtain a greater yield per area [20]. The soilless cultivation system for strawberry cultivation is widely studied, as it has become alternative cultivation in protected environments. It is a cultivation technique growing strongly in Brazil and represents more than half of strawberry crops in Santa Catarina and the Rio Grande do Sul [8,23]. Biochar, an alternative for this cultivation, is natural charcoal obtained by controlled pyrolysis of organic materials (e.g., agricultural and forest residuals) [24].

Planting density may interfere with plant growth, biomass distribution between plant organs, fruit production and size, the qualitative characteristics of fruits, and the total yield [20]. It should also be noted that aspects related to leaf appearance [25], floral induction, flower formation, and the growth and development of the fruits [26] can be changed. In turn, these factors also interact with each other, requiring attention throughout the productive season, as they end up interfering in the capture of sunlight and directly influencing the photosynthesis of the leaves [25]. A larger population of plants puts pressure on each other, diluting the distribution of photoassimilates, these carbohydrates in a smaller amount reduce the size of the fruits. Therefore, greater productivity can be projected with smaller fruits, on the contrary it is also true [27].

The critical balance between the green area's vigor in the vegetative phase and the production of fruits during the crop's productive cycle may determine its success [26,28,29]. Few reports in the literature relate the balance between the green area with fruit load and planting density, being the spacing into isolated study [12,13]. The influence of planting density is described in the literature [30] to be correlated with the fruits' size; in a given space there is an upper limit of the plant, due to the physiological competition between them, a factor such as productivity is directly linked to the intensity and duration of the photosynthetic activity period (net carbon assimilation) of the plants. Therefore, knowledge of the leaf area is necessary to assist in the adequate spatial distribution of a plant population, being directly linked to the yield and genetic potential of productivity of a crop. In general, the greater the spacing, the larger fruits are expected to be harvested. That is done with the purpose of obtaining greater sun exposure, as the spacing increases, less competition for nutrients, and lower incidence of diseases [31]. However, the excess of space affects the gain per area, and there is a microclimate conducive to fungal diseases.

Given the above and bearing in mind that the cultivar of strawberry Pircinque has grown to be a new option for Brazilian producers, mainly due to the high quality of the fruit (sweetness, taste, size, crispness, and firmness), and its increased vigor and resistance of plants to pathogens [32,33]. Thus, this study tests the following hypothesis: the planting density influences the cultivar mentioned above.

Thus, this study aims to evaluate the interference of different planting densities in the photosynthetic, productive, and quality aspects of the fruits of the strawberry cultivar Pircinque in cultivation carried out in the mountain region of the state of Santa Catarina, Brazil. Thus, is expected to find an ideal spacing to obtain better productivity and fruit quality.

2. Materials and Methods

2.1. Plant Material and Experimental Design

The research was conducted at the Center for Agroveterinary Sciences of the University of Santa Catarina (CAV-UDESC), based in Lages, mountain region of Santa Catarina, Brazil. The evaluations were carried out during two consecutive agricultural harvests (May 2018 to January 2019 and May 2019 to January 2020). The experimental field was located at the coordinates 27°47' south latitude and 50°18' west longitude, at an altitude of 923 meters above sea level. The climate of the region is classified as humid subtropical mesothermal, Cfb, with an average annual temperature around 15.6 °C, and average yearly precipitation of 1400 mm, with rainfall well distributed throughout the year [34]. Table 1 describes the average values of the environmental variables in the 2018/2019 and 2019/2020 production cycles. The climatic data regarding the average temperature (°C), relative humidity (%), and precipitation (mm) were monitored through the meteorological station of the National Institute of Meteorology [35].

Table 1. Mean values of environmental variables measured in the 2018/2019 and 2019/2020 production cycles.

	Mean Temperature (Tmed; °C)	Maximum Temperature (Tmax; °C)	Minimum Temperature (Tmin; °C)	Relative Humidity (RH; %)	Rainfall (mm)
2018/2019					
May	13.9	14.4	13.4	86.0	66.8
June	11.6	12.1	11.1	86.0	124.8
July	12.7	13.2	12.1	83.6	80.0
August	11.0	11.5	10.5	83.8	101.4
September	15.0	15.5	14.5	84.5	191.6
October	15.6	16.1	15.2	85.5	150.8
November	17.8	18.4	17.3	80.8	161.4
December	20.0	20.8	19.3	74.7	210.4
January	22.0	22.6	21.4	80.5	137.6
Average	15.5	16.1	15.0	82.8	135.9
2019/2020					
May	15.4	15.8	15.0	89.8	241.6
June	14.0	14.6	13.5	85.7	13.6
July	11.5	12.0	11.0	82.9	96.2
August	12.0	12.6	11.5	80.6	37.2
September	15.2	15.7	14.7	80.5	51.4
October	17.7	18.2	17.1	80.2	214.0
November	18.0	18.5	17.5	79.4	170.4
December	19.7	20.4	19.1	73.4	53.2
January	20.6	21.2	20.0	74.8	35.2
Average	16.0	16.6	15.5	80.8	101.4

The conventional cultivation was carried out in a soilless cultivation system [23], with a structure of troughs filled with a commercial substrate (40% carbonized rice chaff

+ 40% decomposed pine bark + 20% sphagnum peat; and pH 6.0), and fixed greenhouse, covered with transparent polyethylene film with 100 microns thickness.

Plants type “plug plants” of the Pircinque cultivar (Short Day) were transplanted in a single row, and the treatments in six different spacing (Figure 1) between plants (5, 10, 15, 20, 25, and 30 cm); thus, a planting density equivalent to 240, 120, 80, 60, 48, and 40 thousand plants per hectare, respectively, in the ascending order from the smallest to the largest spacing of the planting between plants. The strawberry plants were produced by a commercial nursery located in Farroupilha (29°12′ S, 51°19′ W, and 720 meters of altitude), State of Rio Grande do Sul, Brazil. The type of “plug plant” was obtained from unrooted runners (tips) grown in trays containing peat, for 4 weeks until the transplants for the greenhouse [36]. The experimental design was in randomized blocks, with four blocks, the experimental unit consisting of 20 plants. The cultivation trough was 15 cm wide by 20 cm deep, supported one meter high to the ground.



Figure 1. Strawberry plants from the cultivar Pircinque, in different spacing in your cultivation structure (25 × 20 cm) in the first cycle (2018/2019).

Irrigation and fertigation were carried out by a localized system, using an irrigation tape, with drippers spaced 10 cm apart. The nutrient solution incorporated in the irrigation water was adjusted so that the nutrient solution’s electrical conductivity was approximately 1.1 dS m^{−1} and pH around 6.0 [37]. The nutrient solution’s pH and electrical conductivity were monitored and adjusted according to the necessity to maintain the proposed levels. Fertigation was performed according to the culture phase, and it was performed twice a day in the vegetative stage. The frequency was increased by up to five times a day during the reproductive phase when temperatures are higher in the summer. The planting of the

plants was carried out in the first half of May of each year. The harvests were carried out between September to January in both years, with an interval of 3 to 5 days, when the fruits' epidermis reached an 80% uniform red color.

2.2. Analyzed Variables

2.2.1. Productive Parameters

At the end of each harvest, the fruits were counted and weighed with a semi-analytical precision scale (0.01 g), model M3102, BEL scientific equipment, certified by the National Institute of Metrology, Quality, and Technology [3–5]. The results were summed, and from these, was estimated the number of fruits per plant (UN Plant^{-1}), obtained by dividing the total number of fruits harvested by the total number of plants (20) that composed each of the experimental units. The total production per plant (g plant^{-1}) was obtained from the division of the total weight of the harvested fruits by the number of plants contained in each repeat. The fresh fruit mass (g fruit^{-1}) was estimated by the ratio obtained between the commercial production variables (g plant^{-1}) and the number of commercial fruits in each experimental unit. The percentage of commercial fruit production in relation to the total output per plot was obtained by dividing commercial production by the total output of each repeat, multiplying by 100. Commercial fruits were considered those with no damage (rot or deformity) and a fresh mass greater than or equal to 10 g [38]. Based on the fruits' average monthly marketing price, we estimated the gross and net yields that each planting density could allow a strawberry producer in the state of Santa Catarina.

2.2.2. Qualitative Parameters

For the fruit quality analyzes [39], we considered uniform samples of 10 fruits each experimental unit with a total 40 fruits analyzed, in a total of four times per cycle.

The luminosity (L), Chroma (C), and hue angle ($^{\circ}\text{hue}$) parameters were quantified for the coloration of the fruit epidermis using a Konica Minolta CHROMA METER CR-400 (Made in Marunouchi, Tokyo, Japan) colorimeter. For each fruit, two readings were performed on opposite sides in the equatorial region. L^* values may range from 0 (darker) to 100 (lighter). For Chroma or color purity, the lower the value obtained, the higher the degree of color impurity, that is, the lower the pigments' saturation. Higher values increase the saturation generating purer colors. The hue angle ($^{\circ}\text{hue}$) defines the hue of the epidermis and can vary from 0 to 360, in which smaller values correspond to the shades closer to intense red and larger values to the shades closer to orange-red [40].

The pulp firmness variable, expressed in Newton, was measured with a Texture Analyzer TA.T.plusC—made in Hamilton, MA - United States of America (texturometer), with a tip of 2 mm, two penetrations of 10 mm in each fruit, on opposite faces in the equatorial region. The total soluble solids' concentration was quantified from a digital refractometer (Atago PR-101A, with automatic temperature correction—made in Honcho, Tokyo - Japan). The concentration of sugars in the fruits was obtained, measured in $^{\circ}\text{Brix}$. Titratable acidity was expressed by the citric acid content for 100 g of fresh fruit mass and was determined by an automatic TITRONIC[®] 300—made in Mainz, Germany. The sample was formulated from a dilution of 5 ml of juice in 45 ml of distilled water and then titrated with 0.1 N NaOH solution until PH 8.1 [41]. Finally, the total soluble solids/titratable acidity ratio was calculated by dividing the sugar and acidity levels obtained.

2.2.3. Photosintetic Parameters

The photosynthetic parameters were determined using the IRGA-Infrared Gas Analyzer, model Li-6400 XT from Licor (Made in Lincoln, Nebraska - United States of America [42]. Forty readings per treatment in the same plant for each block were performed on the mature leaves most exposed to the sun, with no senescence sign for having higher photosynthetic rate. In both years, the readings were performed in the second half of October (full bloom period), in periods with higher photosynthetic rates (from 11h to 13h). The chamber's internal flow was fixed at $400 \mu\text{mol s}^{-1}$ and the internal photosynthetically

active radiation (PAR) at $1500 \mu\text{mol s}^{-1}\text{m}^{-2}$, as recommended by the manufacturer for C3 plants [38]. Through the evaluations were obtained the data of liquid assimilation of CO_2 or photosynthetic yield (A , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), the intercellular concentration of CO_2 (C_i , $\mu\text{mol mol}^{-1} \text{ air}$), stomatal conductance (G_s , $\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) and transpiration rate (E , $\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). Through the relation between the CO_2 assimilation and transpiration rate (A/E), the water-use efficiency (WUE , $\text{mmol H}_2\text{O}^{-1}$) was calculated, while the carboxylation efficiency (A/C_i) was due to the CO_2 assimilation and intercellular CO_2 concentration ratio in the leaf [43,44].

2.3. Statistical Analysis

The data of each harvest, evaluated separately, were submitted to the variance analysis (ANOVA $p \leq 0.05$) through the F test. The data that showed significance, were plotted in Boxplot. To better visualize the relation between the different spacing and the variables analyzed, a principal components analysis (PCA) and Pearson correlation was also performed [45]. All statistical analyses were performed with the help of statistical software R [46].

3. Results and Discussion

3.1. Productive Parameters

For the number of fruits per plant, the increase in spacing between plants and lower planting density resulted in increments for this variable adjusted in linear models in both harvests (Figure 2A). The highest average number of fruits harvested per plant in both years of cultivation were in the largest spacing (30 cm), with average values of 40.0 and 53.5 fruits per plant, respectively (Figure 2A), whit fruits per plant, higher than other studies [47]. Other authors re-ported variations from 21.3 to 44.9 fruits in soil and substrate cultivations [48]. These variations in the number of fruits per plant are mainly due to factors such as cultivar, the date of planting [40,49], cultural practices [40,50,51], and by temperature fluctuations, water regime, and the incidence of diseases during the growing seasons [14,52].

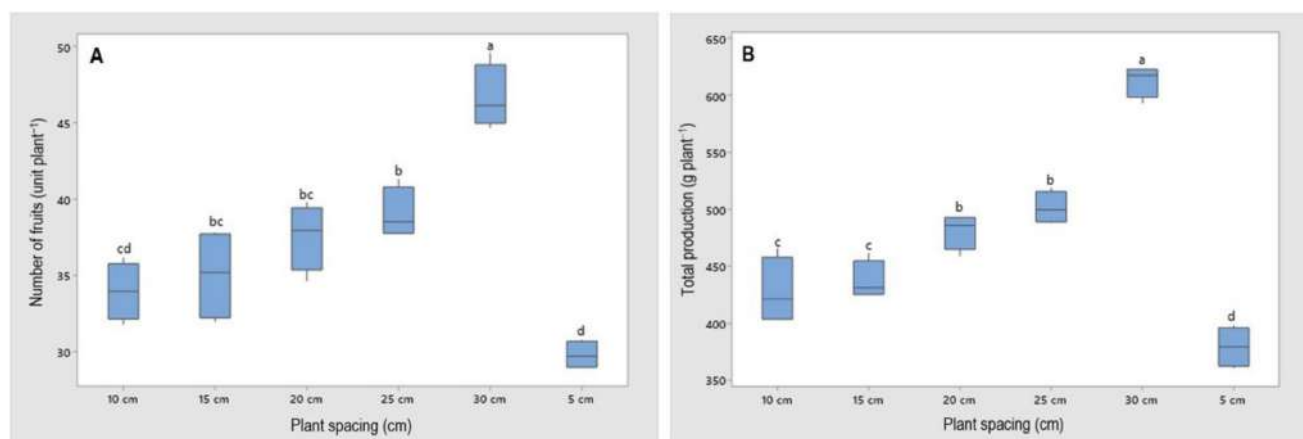


Figure 2. The response of the number of fruits per plant (A) and the total production (B) of strawberry plants cv. 'Pircinque', in the different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

Other authors reported the increase in the number of fruits verified in the present study due to increased spacing between plants and in several cultures, such as larger fruit vegetables [53,54]. Usually, the increase in planting density and the reduction of spacing between plants lead to a reduction in the proportional partition of dry and fresh matter for the fruits and, consequently, the reduction in the number of fruits harvested and the individual production of the plants, as verified in the present study (Figure 2A,B). They also point out that the decrease in spacing between plants reduces leaf expansion and provides

higher shading, which causes a reduction in solar radiation interception and consequently affects the production of photoassimilate by the plant [55].

The highest averages for total production per plant were obtained with the largest spacing between plants (30 cm) (Figure 2B). The average productions in the two evaluated crops were below the potential of the cultivar Pircinque, 1 kg per plant, considered appropriate to provide good profitability to the producer [33], and also when compared to another study that obtained the average production of 848.9 g plant⁻¹, testing four cultivars in suspended cultivation [50].

In both agricultural harvests, there was a decrease in productivity due to the increase in spacing between plants (Figure 3A). The highest productivity values were in the smallest spacing (5 cm), no matter the harvest, and consequently, in the highest planting density (240 thousand ha⁻¹ plants).

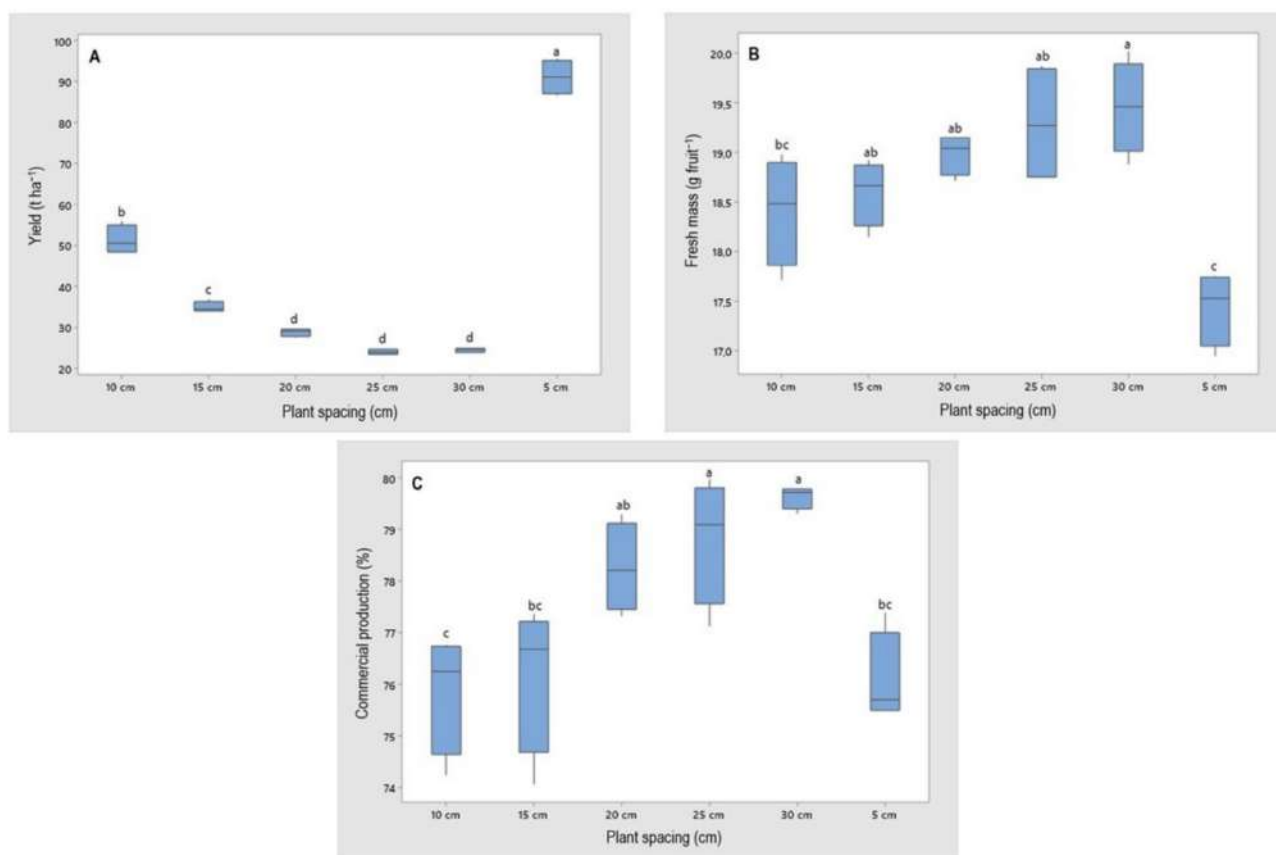


Figure 3. Yield (A), fresh fruit mass (B), and percentage of commercial production (C) of strawberry fruit cv. ‘Pircinque’ depending on the different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

The increase in the number of fruits harvested per unit area obtained in the smaller plant spacing and higher planting densities was decisive to achieve high values of this yield component. The highest yields in the present study were obtained with a plant spacing of 5 to 15 cm (Figure 3A), with values above average when compared to other studies [46]. However, when analyzing the spacing of 10 cm between plants, there are also high yields, with values above 50 ton ha⁻¹ and increases of 38.8% and 45.1%, when compared to the Brazilian average of 36.1 t ha⁻¹ [8].

The use of smaller spacing and higher planting density optimized the use of semi-hydroponic structures and the cultivation area, allowing higher yields (Figure 3A) and better use per unit area. High yields are essential to ensure the economic return and enable cultivation, especially in crops typically exploited in small areas, such as strawberries.

A study conducted with the cultivar Camarosa also indicated that the higher density of plants considered (200 thousand ha⁻¹ plants) led to higher productivity [56].

In both agricultural harvests, there was an increase in the average fresh mass of commercial fruits (Figure 3B). These results corroborate with other studies, stating that the smaller spacing between plants increased the total dry mass and fruits and higher productivity, resulting from more fruit harvested per unit of the cultivated area [20]. There were oscillations of fresh mass among the treatments in both harvests. That may be due to factors that interfere with cultivation, such as photoperiod and temperature, which affect the productive stage's hormonal regulation [57], and oscillations in temperature patterns and water regime, which always occur from one year to another [58].

There was a small oscillation between the different treatments for the percentage of production classified as commercial (Figure 3C). The maximum percentage of commercial production was obtained with the spacing of 30.0 cm and the minimum point in the spacing of 12.2 cm. [13] applied the effect of strawberry planting density under fruit yield and observed in the high planting density the largest number of fruits, however, for the small size fruits, convergent results were found by [59].

Spacing between plants also interfered with the percentage of fruits classified as small (Figure 4A). For both harvests, the portion of small fruits was lower with the decrease in planting density. These results indicate that the spacing above 5 cm and 10.0 cm for the respective years would be relevant to promote the decrease in the small fruits' production. Studies report that with the increase in planting density, there may be a decrease in the crown's fresh mass [56]. In turn, it decreases the concentration of carbohydrates and consequently also causes interference in fresh fruit mass. This may occur due to the competition for carbohydrates and assimilates.

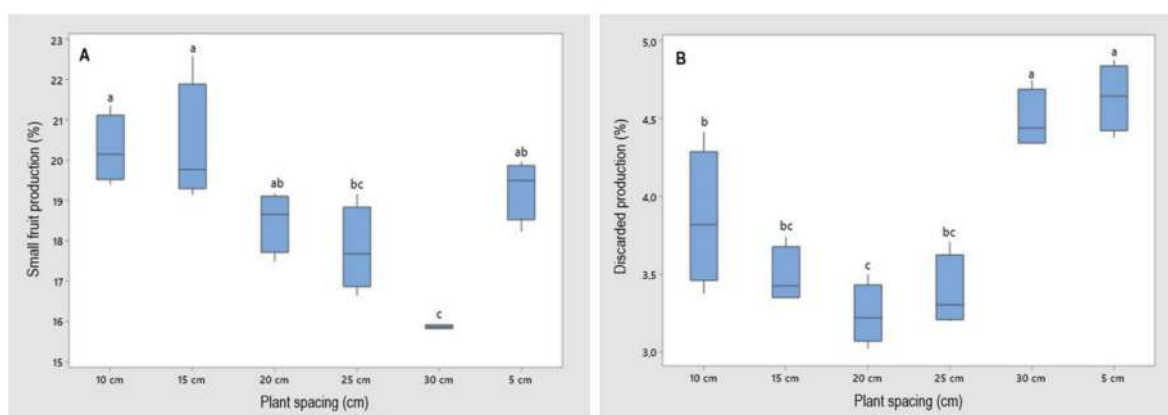


Figure 4. The percentage of small fruit (A) and fruit classified as discard (B) of strawberry cv. 'Pircinque' depending on the different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

The increase in spacing in strawberry planting increased the yield per plant by about 40% and promoted the increase in fruit size [21]. Other studies also indicate positive correlations between the number of fruits per plant to the percentage of small fruits. The higher the number of fruits, the higher the percentage of fruits classified as small [60], a fact also observed in this study. Other studies also report an increase in commercial fruit production and a decrease in small fruits' percentage as the spacing between plants increases [59,61].

Another critical piece of information is related to the percentage of discarded fruits (Figure 4B) due to fungi or pests' attack, making the commercialization of fruits impossible. And for this factor, the lowest index of discarded fruits was verified at 20.0 cm spacing between plants. The smaller spacing between plants probably resulted in a more deficient aeration of plants, increasing the vegetation's moisture indexes. Excess moisture, in turn, collaborates with the increased occurrence of pathological diseases. The smaller spacing

and the incidence of rot diseases relation are positively correlated, more severe in smaller spacing between plants [62].

Concerning gross income (US\$ ha⁻¹), estimated by the production trading, and considering the average price over the last five years from the Companhia de Entrepósitos e Armazéns Gerais de São Paulo (the largest center of the food supply in Latin America) [63], there was a tendency toward a decrease in income due to the increase of the spacing (up to 25 cm) in both growing seasons since the spacing of 5 cm was the one that allowed the highest yield per hectare (US\$ 161.00000 and 143.00000), associated to higher productivity. The 5 cm spacing obtained a better estimate of financial gain at the end of the two harvests (Figure 5A), respectively 339% and 199% higher than the larger spacing (30 cm).

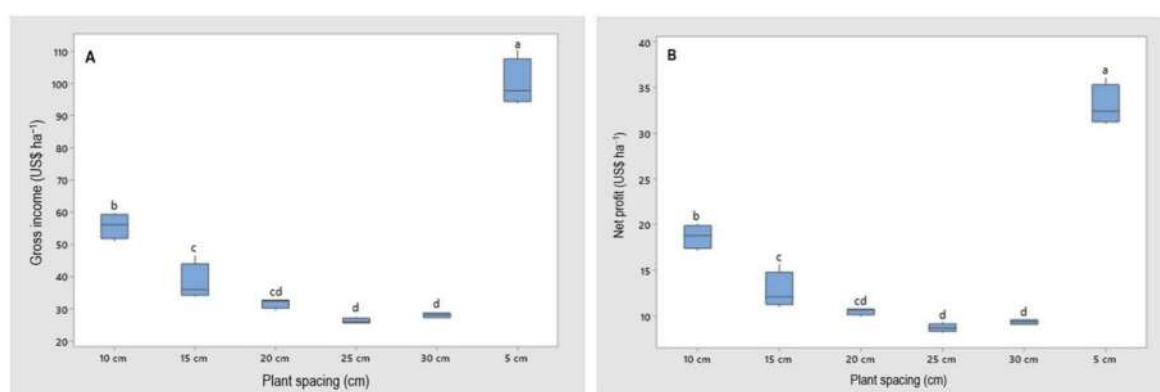


Figure 5. The response of gross income (A) and net profit (B) of strawberry production cv. ‘Pirquinque’ depending on the different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

For both years, the minimum values were obtained with the estimated spacing of 20.0 cm between plants, equivalent to a density of 50.2 thousand ha⁻¹ plants. That indicates that the yield’s viability would be related to spacing lower than 20.0 cm between plants, resulting in planting densities higher than 50.2 mil ha⁻¹ plants. Studies with planting density for the cultivation of Camino Real strawberry in the soilless cultivation system indicate a density of 125 thousand plants ha⁻¹ as the point of balance between production, fruit quality, and the number of plants required [20].

For the net profit variable (Figure 5B), the estimated production costs for the state of Santa Catarina (US\$ 1 kg⁻¹ strawberry) [64] were discounted, and the costs of the plants of type “plug plants” (US\$ 0.14 per plant-Pasa nursery), according to planting density for each planting spacing. Thus, it was observed in the two harvests that the spacing of 5 cm was the one that allowed higher net profit (US\$ 56,000 and US\$ 47,000), respectively 278% and 123% higher in relation to the lower planting density for both harvests evaluated. It is recommended planting spacing of less than 20.0 cm between plants to obtain greater net profits, which directs to a density of 51.7 thousand ha⁻¹ plants.

For the survival of any economic activity, it must be profitable to cover the value invested and the labor employed in the production, obtaining the return on investment [65]. Therefore, it should be considered that lower planting densities allow higher productivity and net profit per area. However, the producer must also consider the increased demand for labor because very dense plants require more time in some activities, such as harvesting and other required cultivation practices [66]. Therefore, studies that observe the values of income and net profit under specific conditions provide elements that measure the probability of return for investments, thus enabling the correct decision making on the choice of the feasible and appropriate spacing for each cultivation condition.

3.2. Qualitative Parameters

Regarding fruit sweetness parameters, represented by the content of total soluble solids (Figure 6A), the largest tested spacing (30 cm) produced fruits with higher sugar content (9.0 °Brix). It exceeded the averages obtained in the 2018/2019 harvest. Strawberry fruits that have an acceptable flavor must have a minimum of 7% soluble solids and a maximum of 0.8% titratable acidity [67].

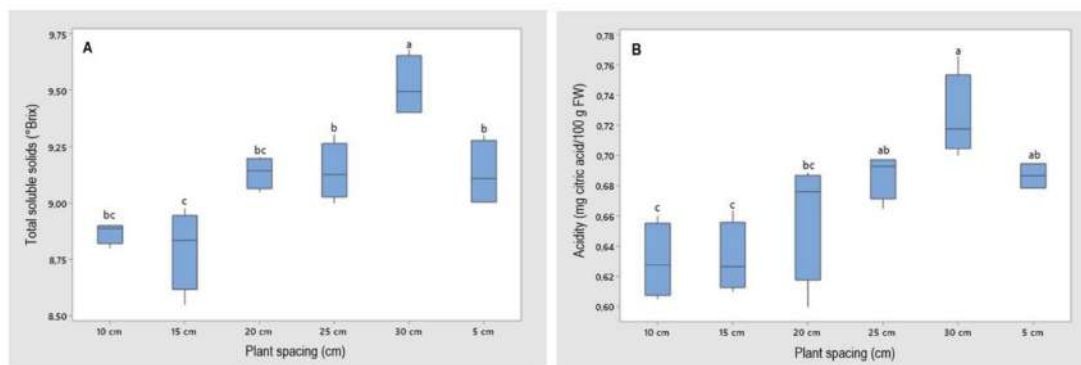


Figure 6. The response of total soluble solids value (A) and acidity (B) of strawberry plants cv. 'Pircinque' in different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

With the increase of the spacing between plants, there is a higher interception of sunlight, increasing the biomass production, and, consequently, the photosynthetic rate, due to the higher number of leaves, directly affecting the fruits' quality [20]. Besides, this higher sun exposure conditioned by the higher distance between plants raises net photosynthesis levels by plants, which results in a higher accumulation of sugars, responsible in its vast majority for fruits' sweetness [68].

As for the titratable acidity (Figure 6B), a slight decrease was observed harvest due to increased spacing. However, there was an increase in the averages, with maximum acidity value ($0.78 \text{ g } 100\text{g citric acid}^{-1}$), obtained in the largest spacing used (30 cm). Titratable acidity values greater than 0.8% of citric acid imply fruits with a low ratio, thus reducing their acceptability by the consumer [69]. The sweetness of strawberry fruits is determined by the soluble sugar contents, mainly glucose, sucrose, and fructose; concerning titratable acidity, its principal constituent is citric acid [70,71].

According to [72], as fruit ripening progresses, the content of soluble sugars in fruits tends to increase, and acids' concentration tends to reduce. This process accelerates in conditions of higher sun exposure, provided by the lower plant density. That explains the positive correlation 0.95, obtained in this research between these two variables, since a balance of both is necessary to get good-tasting fruits [73]. Positive correlations between these two parameters have already been verified by other authors [74,75], which proves these compounds' importance in the final flavor composition of strawberry fruits.

Regarding the total soluble solids/titratable acidity ratio, increases were observed in different intensities (Figure 7A). The maximum soluble solids and titratable acidity ratio (15.4) were obtained at a spacing of 15.0 cm. The fruits' flavor is mainly determined by the total soluble solids/titratable acidity ratio, so the higher the value obtained for this ratio, the greater the possibility of acceptance of fruits by consumers [76], since it contains one of the main ways of quantifying the fruits' flavor [77]. Thus, due to the higher sugar levels and lower acidity concentrations, the fruits were sweeter, configuring fruits with better flavor. Fruits with a higher soluble solids/titratable acidity ratio are the best accepted for consumption in natura, since high acidity is an undesirable factor for sensory acceptance [78]. According to [79], the parameter of the soluble solids/titratable acidity ratio that is considered adequate for fresh strawberry fruits to be accepted on the market, minimum 8.75.

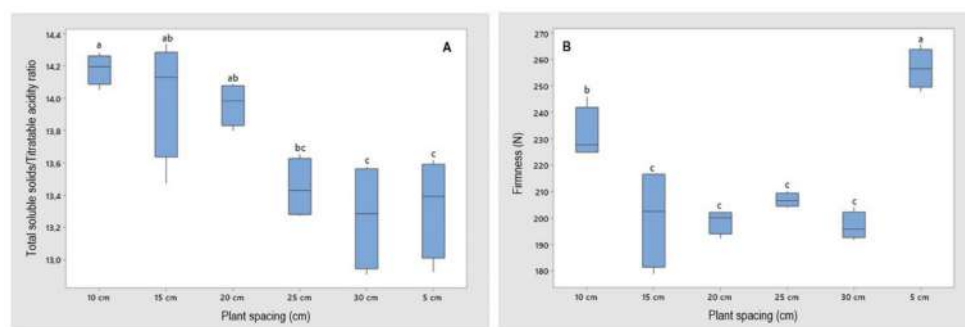


Figure 7. The response of total soluble solids value and titratable acidity ratio (A) and pulp firmness (B) of the fruits of strawberry plants cv. ‘Pircinque’, in different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

For fruit pulp firmness, a significant effect was observed, provided by the different planting spacing. In both crop harvests, generated mini-mum point when used approximately 25.0 cm of spacing between plants. We can also notice high firmness values in the smallest spacing tested, spatially 5.0, 10.0, and 15.0 cm, due to the higher production of small fruits in these spacing (Figure 7B). Pulp firmness is one of the most important characteristics for determining fruit quality; the firmer they are, the longer the postharvest and rot durability and more resistant the fruits are to transport [80]. According to [81], highly perishable fruits, such as strawberries, when they can be stored for a long period of time, make it possible to sell this product in more distant regions.

Small fruits have lower cell content, making the cells more compact and rigid, with a less internal dilution of calcium, which allows higher calcium availability for the cell wall composition, increasing its resistance and consequently the firmness of the fruit pulp [58,82]. However, the pulp firmness correlated positively with the percentage of commercial production. That explains the importance of this parameter in the fruits’ quality, which has already been verified in other studies [83]. It highlights the importance of this parameter for obtaining commercial fruits since the pulp firmness is directly related to the strength and durability of fruits, especially during harvest and post-harvest [84].

The lower pulp firmness in fruits is related to the enzyme polygalacturonase’s action, stimulated by ethylene production in the maturation process, responsible for degrading the calcium pectates constituent of the cell wall [85]. In the present study, the decrease in the firmness of the fruits in the larger spacing may be related to the larger fruit size since larger fruits tend to have more expanded cells due to the higher accumulation of water. It ends up diluting the calcium concentrations in the cells, decreasing the firmness of the pulp [58,82]. Besides, with the higher spacing of plants, the exposure of the fruits to sunlight is higher. It increases the ripening speed, accelerating the degradation of calcium pectates in the cell wall due to ethylene’s high production [85].

For evaluating the epidermis saturation or Chroma (Figure 8A), the saturation index’s highest response was verified at spacing 20.0. Smaller spacing than these indicates the production of fruits with less pure coloring. For the epidermis color tone (Figure 8B), the spacing of 20.0 and 25.0 cm resulted in fruits with a higher indication of epidermis directed to the red color. We can conclude that spacing between 15.0 and 20.0 promotes redder fruits’ production by these harvests results.

The larger hue angle, along with the luminosity, can result in brighter fruits. Color brightness is a characteristic that makes fruit more attractive and a favorite to consumers, according to [86]. For color brightness (Figure 8C), there was a tendency of larger spacing to favor fruit production with a higher solar incidence in both harvests. The lowest results for Chroma, hue angle and luminosity were found in the 5 cm spacing. A similar description was also found by other studies [69], probably due to the lower incidence of light inside the plants. The most preferred fruits by consumers are those of an intense red color,

which is one of the first factors that determines the purchase intention by the consumer [85]. According to [87], this coloration is the result of the presence of anthocyanins, being the pelargonidime 3-glucoside (responsible for the dark red color) and cyanidin 3-glucoside.

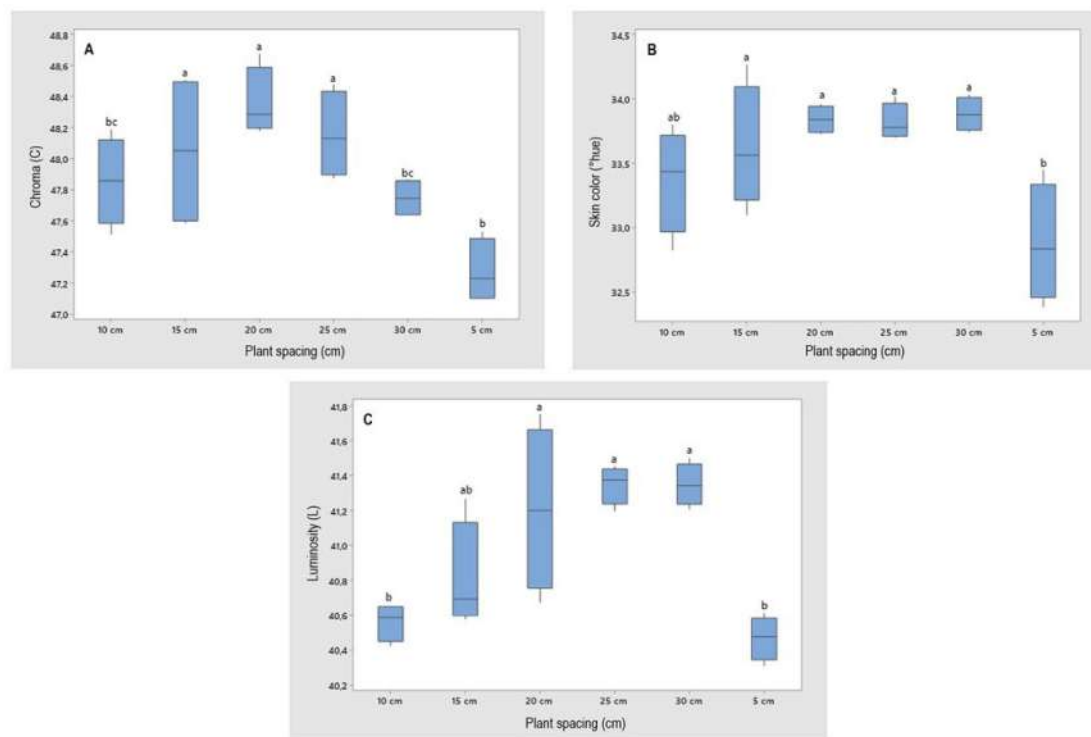


Figure 8. The response to Chroma (A), skin color (°hue) (B), and luminosity (C) parameters of strawberry plants cv. 'Pirquinque', in different spacing between with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

3.3. Gas Exchange

Strawberry plants use approximately 95% of the absorbed water for temperature regulation. They have specialized mechanisms such as the closure of the stomata, which can result in the low absorption of carbon dioxide (CO_2) [69], leading to a reduction in the flow of water out of the leaf than in the flow of CO_2 that reaches the chloroplasts, thus affecting net photosynthesis (Figure 9A) [88–90].

The variable internal carbonic concentration (Ci) (Figure 9B) and stomatal conductance (gs) (Figure 9C) demonstrated similar behavior in both years of cultivation concerning the different spacing. This similarity is because several environmental factors control the stomatal opening. Luminosity, temperature, and carbon dioxide concentration are the most important ones [72]. In this case, the smaller spacing allowed higher average values for both years of Ci ($308.9 \mu\text{mol mol}^{-1} \text{air}$) and gs ($0.45 \text{ mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), reaching a maximum point at spacing 15.19 cm for the 2018/2019 harvest (Figure 9B,C). Spacing higher than 15.19 cm between plants reduced Ci . It is expected that under conditions of CO_2 limitation, Ribulose oxygenation reactions (RuBP) are initiated, thus affecting the efficiency of the Calvin cycle and consequently reducing the values [77]. The Ci becomes a good indication regarding the physiologic mechanism that plants use to control the temperature being proportional to transpiration [91–93]. According to [94], the closure of stomata is the result of a decrease in the water potential in the leaf and its stomatal conductance, caused by water deficit, consequently, there is a reduction in the CO_2 flow to the leaves, this fact has negative impacts on productivity and affects the accumulation of photoassimilates.

The assimilation of carbon dioxide from the external environment can promote a loss of water and that this decrease can restrict the entry of CO_2 [95]. The water-use efficiency (WUE) indicates that the observed values relate to the amount of carbon that the plant

fixes [95], and thus it is verified decline in the rates of WUE, to the planting spacing increment (Figure 10A). These are reflections of the increases observed in photosynthesis. Research indicates that microclimate conditions can influence gas exchange, so the decreases recorded in the WUE may be linked to the increases in intercepted solar radiation, that is, in the different spacing microclimate [82].

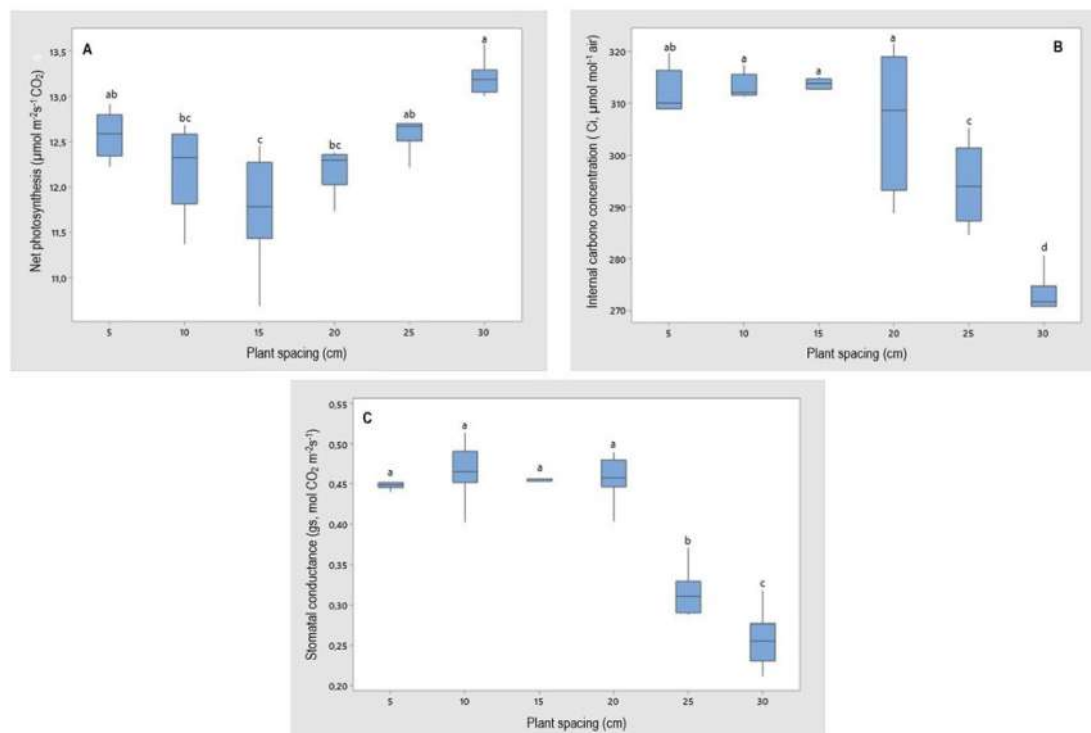


Figure 9. The response to net photosynthesis (A), internal carbon concentration (B), and stomatal conductance (C) of strawberry plants cv. 'Pircinque', in different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

When there are high C_i and g_s values, it can be stated that the carboxylation efficiency (CE) suffers an increase (Figure 10B) due to the increased availability of ATP and NADPH and by-products for rubisco [82]. Thus, denser spacing (>20 cm) directly interferes with the availability of CO_2 in the leaf mesophyll, amount of light, temperature, and enzymatic activity so that there is photosynthesis. If the C_i is low, all flow is interrupted due to the absence of essential compounds in the leaf mesophyll cells. To maintain the minimum photosynthesis activities, the plant uses CO_2 from respiration, limiting the whole process [82].

3.4. Multivariate Analysis

When we observe the multivariate analyses, the spacing 30 and 5 cm form different groups, distancing itself from other treatments (Figure 11). They can be represented by variables such as total soluble solids and titratable acidity for the spacing of 30 cm and pulp firmness, percentage of commercial fruits, and pH for the spacing 5 cm between plants. On the other hand, the 10 and 15 cm spacing form a group represented by small fruits' production and a higher relation between total soluble solids and titratable acidity (Figure 12). The spacing of 20 and 25 cm contributed to forming a fourth group, represented by epidermis coloration variables and productive variables, such as fruit numbers per plant, production per plant, and fresh fruit mass. The variables obtained through gas exchange analysis (IRGA) did not influence the PCA, demonstrating a low contribution to the variation indexes.

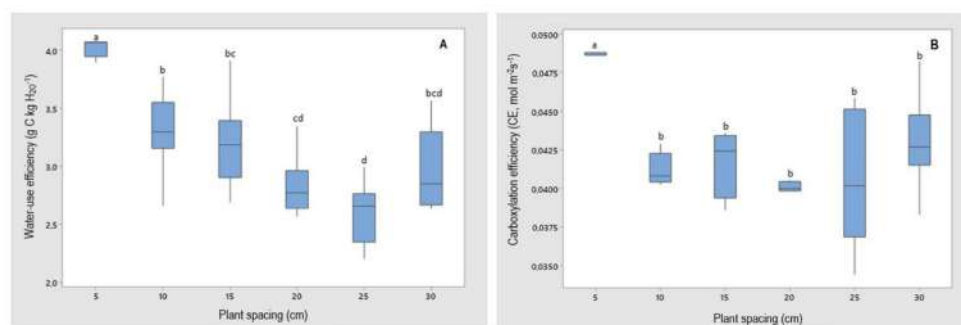


Figure 10. The response to water-use efficiency (WUE) (A), carboxylation efficiency (B) of strawberry plants cv. ‘Pircinque’, in different spacing between plants with average of the 2018/2019 and 2019/2020 harvests. For each spacing, the different letters indicate significant differences ($p \leq 0.05$).

The last group represents the fruits with the most attractive coloring and the largest size, which may be associated with greater spacing between plants. Fruits resulting from this group are intended for consumption in natura, since the concentration of the main anthocyanins decreases when the strawberry is processed, that is, destined for industry, consequently loss of color [96]. According to [97], the highest values of epidermis coloring are associated with better conservation and acceptance status for consumption, in addition, these fruits have a higher concentration of anthocyanins and vitamin C, to determine these parameters [97], used a subjective scale of coloring of strawberry epidermis in post-harvest, which demonstrates that the maximum content of the substances are found in freshly harvested fruits.

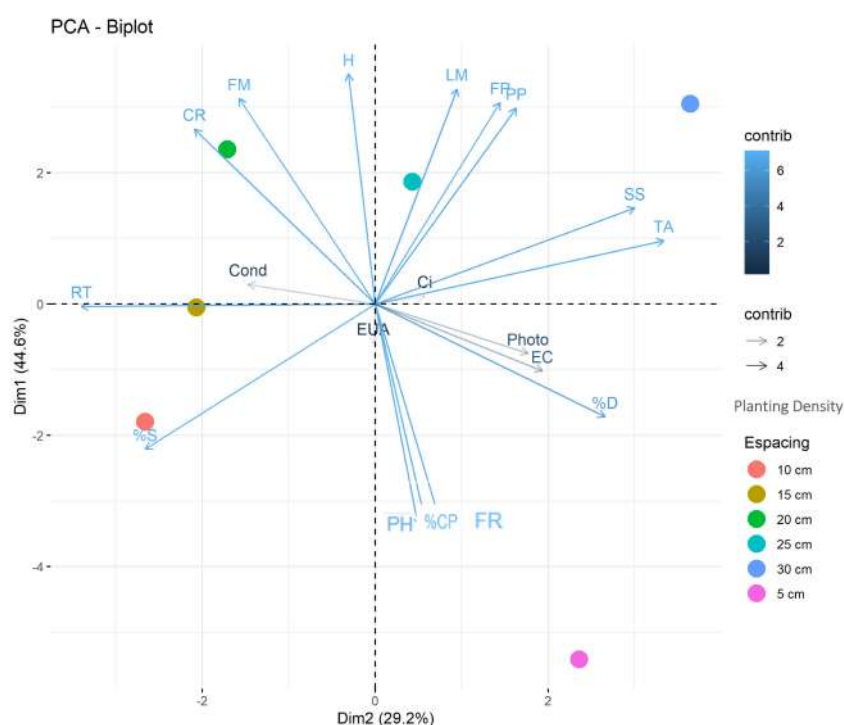


Figure 11. Analysis of the main components among the variables obtained in the spacing experiment for the cultivar “Pircinque” evaluated in Lages-SC, Brazil in the 2018/2019 and 2019/2020 harvests. Caption: FP = fruits per plant. PP = production per plant. PH = productivity per hectare. FM = fresh mass. %CP = commercial percentage. %S= small fruits percentage. %D=discard percentage. LM = epidermis luminosity. CR = epidermis Chroma. H = epidermis hue angle. FR = firmness. SS = total soluble solids. TA = titratable acidity. RT = soluble solids/titratable acidity ratio. Cond = stomatal conductance. Ci = intercellular concentration. EU = water-use efficiency. EC = carboxylation efficiency.

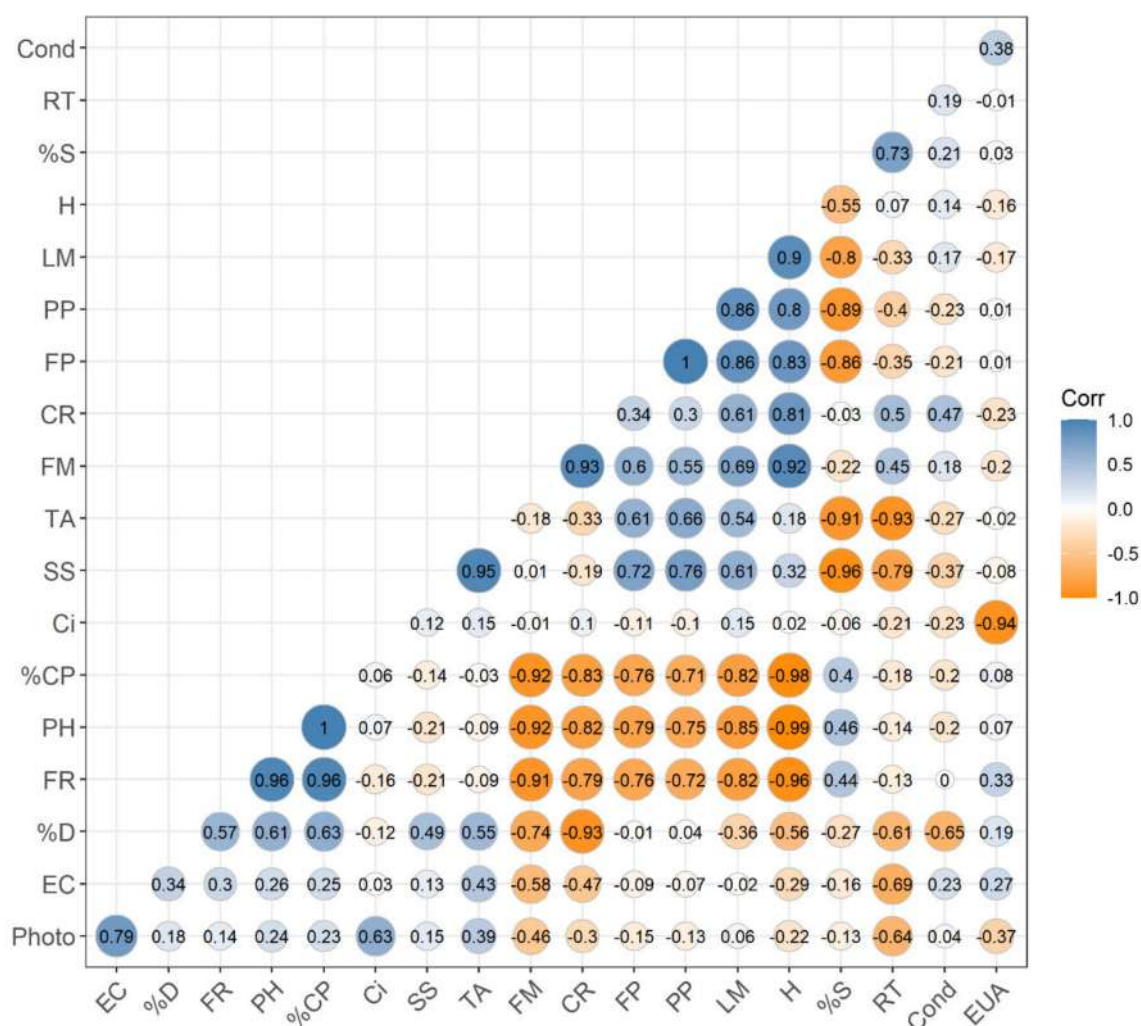


Figure 12. Correlation matrix for the six different spacing (5, 10, 15, 20, 25, and 30 cm) in the production and quality of strawberry fruits cv. 'Pircinque'. Positive correlations are displayed in blue and negative correlations in orange color. Color intensity and the size of the circle are proportional to the correlation coefficients. Caption: FP = fruits per plant. PP = production per plant. PH = productivity per hectare. FM = fresh mass. %CP = commercial percentage. %S= small fruits percentage. %D=discard percentage. LM = epidermis luminosity. CR = epidermis Chroma. H = epidermis hue angle. FR = firmness. SS = total soluble solids. TA = titratable acidity. RT = soluble solids/titratable acidity ratio. Cond = stomatal conductance. Ci = intercellular concentration. EU = water-use efficiency. EC = carboxylation efficiency.

The chamber's internal flow was fixed at $400 \mu\text{mol s}^{-1}$ and the internal photosynthetically active radiation (PAR) at $1500 \mu\text{mol s}^{-1}\text{m}^{-2}$, as recommended by the manufacturer for C_3 plants [38]. Through the evaluations were obtained the data of liquid assimilation of CO_2 or photosynthetic yield (A , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), the intercellular concentration of CO_2 (Ci , $\mu\text{mol mol}^{-1} \text{ ar}$), stomatal conductance (G_s , $\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), and transpiration rate (E , $\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$). Through the relation between the CO_2 assimilation and transpiration rate (A/E), the water-use efficiency (WUE , $\text{mmol H}_2\text{O}^{-1}$) was calculated, while the carboxylation efficiency (A/Ci) was due to the CO_2 assimilation and intercellular CO_2 concentration ratio in the leaf [40].

When using four dimensions, it is possible to explain 97% of the variation obtained in the experiment (Figure 13). Being the first axis (X) with greater representativeness (44.6%), the variables evaluated with more significant influence were: hue angle, epidermis luminosity, pulp firmness, production per plant, Chroma, and total soluble solids, ordered in increasing order by weight in the component. On the other hand, the Y-axis

(29.2%) is composed of the variables: titratable acidity, percentage of discarded fruits, stomatal conductance, photosynthesis, pulp firmness, and production per plant.

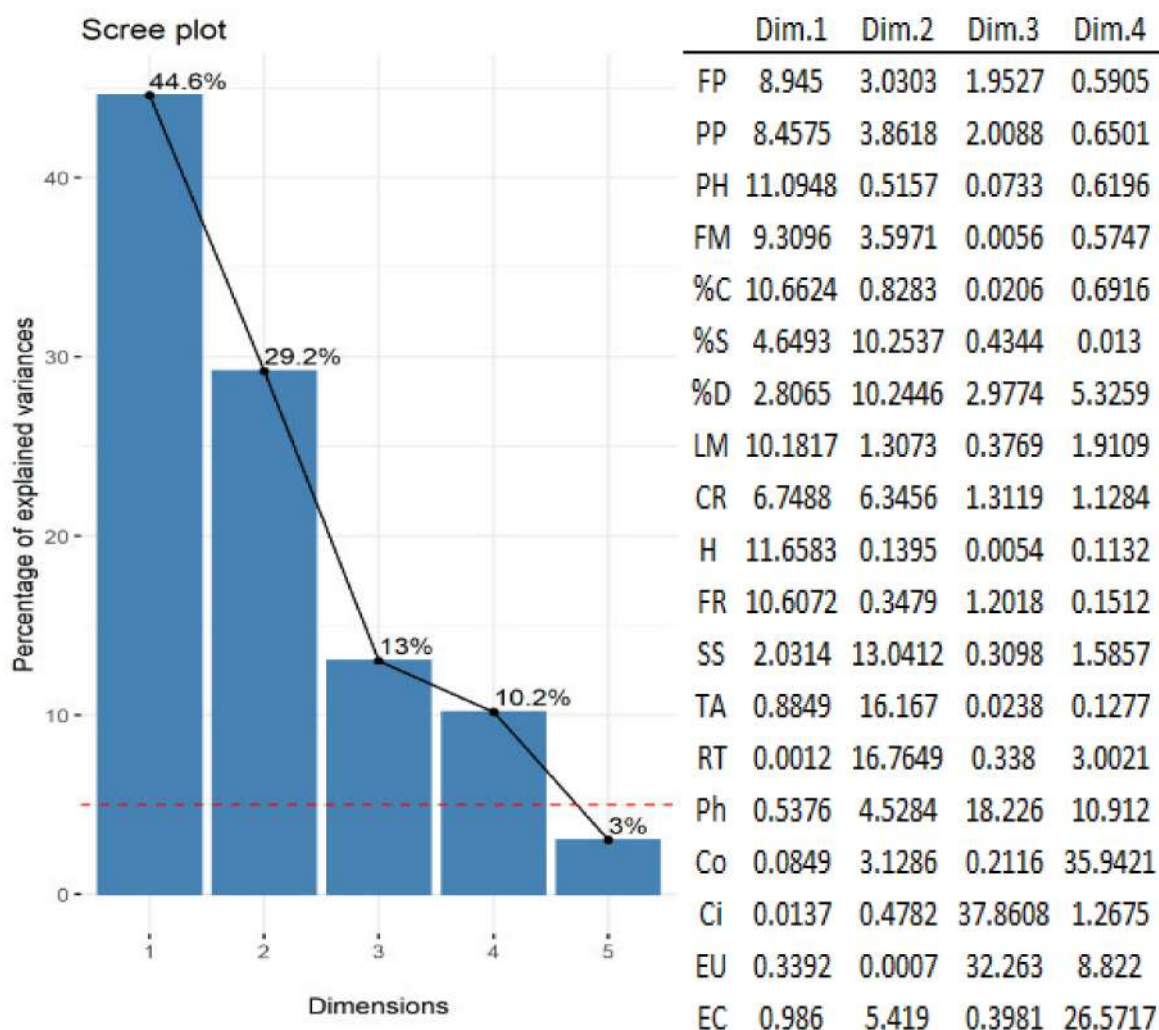


Figure 13. Decomposition of the main component analysis for the six different spacing (5, 10, 15, 20, 25, and 30 cm) in the production and quality of strawberry fruits cv. ‘Pircinque’. Caption: FP = fruits per plant. PP = production per plant. PH = productivity per hectare. FM = fresh mass. %CP = commercial percentage. %S= small fruits percentage. %D=discard percentage. LM = epidermis luminosity. CR = epidermis Chroma. H = epidermis hue angle. FR = firmness. SS = total soluble solids. TA = titratable acidity. RT = soluble solids/titratable acidity ratio. Cond = stomatal conductance. Ci = intercellular concentration. EU = water-use efficiency. EC = carboxylation efficiency.

4. Conclusions

Based on the study conducted, it is concluded:

The gas exchange analysis showed a low contribution in the spaces of 5 to 20 cm. However, spacing > 20 cm, interferes with the availability of CO₂, which is less efficient. Nevertheless, they resulted in greater production of commercial fruits, less production of small fruits, and greater intensity of color and luminosity.

Planting spacing of 5 to 15 cm between plants is recommended for growing the strawberry cultivar Pircinque, allowing higher total soluble solids/titratable acidity ratio and lower acidity.

The use of higher plant density allows for greater productivity per area and net profit. In addition, among the quality parameters, there is greater firmness, but due to densification, there is a greater production of discarded fruits.

For higher densities (<10 cm), the producer may adapt management that allows for increasing the quality of the fruits produced, which may result in the use of more labor and technologies, avoid excessive fertilising, and cleaning of the plants, to avoid microclimates suitable for diseases.

In conditions of lacking adequate workforce and technologies, the producer can opt for larger planting spacing (10 to 15 cm), aiming to balance production and fruit quality.

Author Contributions: Conceptualization, J.M.d.L., P.D.W. and A.F.F.; methodology, J.M.d.L., P.D.W., M.F.S.d.S. and W.K.; validation, formal analysis J.M.d.L., P.D.W., A.F.F. and M.F.S.d.S.; investigation, data curation, J.M.d.L., P.D.W., M.F.S.d.S., A.F.F., B.M.C. and W.K.; writing—original draft preparation J.M.d.L., P.D.W., M.F.S.d.S., B.M.C. and F.R.N.; writing—review and editing, visualization, A.F.F., F.R.N., A.A.K. and L.R.; supervision, project administration, funding acquisition, A.A.K., L.R. and G.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidade do Estado de Santa Catarina (UDESC).

Data Availability Statement: Data sharing not applicable. No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors thank all the infrastructure and logic support that was provided by the Center for Agroveterinary Sciences of the University of the State of Santa Catarina (CAV-UDESC), by the research promotion and support agencies, especially FAPESC and CNPq, for the grant of scholarships, and the assistance of research activities. They also thank the fruit growing research team of CAV-UDESC and the Council for Agricultural Research and Economics—Centre for Olive, Fruit and Citrus Crops (CREA-OFA) for supporting scientific cooperation with UDESC. They also thank the Pasa nursery for providing the plants used in the research.

Conflicts of Interest: The authors declare no conflict of interest.

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Article

Initial Crown Diameter Influences on the Fruit Yield and Quality of Strawberry Pircinque

Antonio Felipe Fagherazzi ^{1,*}, Daniel Suek Zanin ¹, Marllon Fernando Soares dos Santos ¹ , Juliana Martins de Lima ¹, Paola Daiane Welter ¹ , Adrik Francis Richter ¹, Francine Regianini Nerbass ¹, Aike Anneliese Kretzschmar ¹, Leo Rufato ¹ and Gianluca Baruzzi ² 

- ¹ Centro de Ciências Agroveterinárias da Universidade do Estado de Santa Catarina (CAV-UDESC), Av. Luiz de Camões, 2090, Bairro Conta Dinheiro, Lages 88520-000, Brazil; dsuekzanin@gmail.com (D.S.Z.); marllon.soares@outlook.com (M.F.S.d.S.); juumartinsslima@gmail.com (J.M.d.L.); pdaianew@hotmail.com (P.D.W.); adrikrichter@yahoo.com.br (A.F.R.); fr.nerbass@udesc.br (F.R.N.); aike.kretzschmar@udesc.br (A.A.K.); leo.rufato@udesc.br (L.R.)
- ² Council for Agricultural Research and Economics-Centre for Olive, Fruit and Citrus Crops (CREA-OFA), Via La Canapona 1 bis, 47121 Forlì, Italy; gianluca.baruzzi@crea.gov.it
- * Correspondence: antonio.fagherazzi@udesc.br; Tel.: +55-(49)-9-9947-5051

Abstract: In strawberry production, the combination of a high productive performance and fruits with desirable physicochemical characteristics requires the use of plants with a good quality and high initial vigor. This study aimed to evaluate the effect of plants with different crown diameters on the productive performance and fruit quality of strawberry plants of the cultivar ‘Pircinque’ (Short Day). The study was conducted in two evaluation cycles (2016/2017 and 2017/2018). The experimental design was divided into randomized blocks, with four repetitions, and plots consisting of 20 plants. This study evaluated the crown diameters of plants of 5, 7, 9, 11, 13, 15, 17, and 19 mm. The productivity and number of fruit values increased significantly by 57% with larger caliber plants, which also provided precocity of productivity. The use of more vigorous plants also favored the production of fruits with higher soluble solids/titratable acidity ratios (+28%) and with epidermis coloration closer to intense red (−4.3%). For the cultivar ‘Pircinque’, plant crown diameters between 15 and 17 mm are the most favorable because they condition the best productive performances in combination with precocity and a good fruit quality.

Keywords: *Fragaria* × *ananassa*; bare-root fresh plants; productive influence; precocity of production



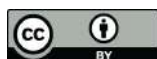
Citation: Fagherazzi, A.F.; Suek Zanin, D.; Soares dos Santos, M.F.; Martins de Lima, J.; Welter, P.D.; Francis Richter, A.; Regianini Nerbass, F.; Anneliese Kretzschmar, A.; Rufato, L.; Baruzzi, G. Initial Crown Diameter Influences on the Fruit Yield and Quality of Strawberry Pircinque. *Agronomy* **2021**, *11*, 184. <https://doi.org/10.3390/agronomy11010184>

Received: 19 December 2020

Accepted: 14 January 2021

Published: 19 January 2021

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1. Introduction

Due to its fruit’s qualitative and attractive characteristics, mainly the aroma, flavor, coloration, and firmness, and also due to the high presence of functional compounds, especially polyphenols, anthocyanins, vitamin C, and ellagic acid, strawberry (*Fragaria* × *ananassa* Duchesne) is a fruit highly appreciated by consumers [1,2]. In this context, within small fruits, the strawberry plant is the main species cultivated worldwide. In 2018, approximately 8.3 million tons were produced in a cultivated area of 372.3 thousand hectares. China, Poland, Russia, the United States, Turkey, Mexico, and Germany are the leading producers in the world [3]. Despite not being considered an important strawberry producer, Brazil is the leading producer of this fruit in South America [4]. In 2019, approximately 4500 hectares of strawberries were cultivated in Brazil, generating 165 thousand tons and an average productivity of 36.6 tons per hectare [5].

Strawberry production in Brazil has great importance both socially and economically. In the last few years, technologies that promote fruits with a better quality and export potential for foreign markets have been incorporated. In addition to the high economic return and the various ways in which the transformation is permitted regarding the fruit, the strawberry can be found growing across almost all of the Brazilian territory, mainly in

the states of Minas Gerais, Paraná, the Rio Grande do Sul, São Paulo, Brasília, Espírito Santo, Bahia, and Santa Catarina [5–8].

More than 300 million strawberry plants are needed annually to meet producers' demand. Of this demand, approximately 70% of the plants are produced in Brazil (bare-root fresh plants), and approximately 30% are imported (frigo plants) from Argentina, Chile, and Spain [5,7]. However, most of the strawberry plants produced in Brazil lack sanitary and physiological quality, and the nurseries in this sector require more significant technological innovation and a more professional approach. In this sense, the supply of different plants, especially plants with a high vigor and physiological and sanitary quality, is an improvement required to meet strawberry producers' demand.

In Brazil, the plant is perceived as one of the principal investments in implementing a strawberry crop. However, it is a critical factor for the success of cultivation since it is directly related to the fruits' qualitative characteristics. Above all, it is related to the agronomic aspects, especially the size and quantity of fruits harvested. Therefore, plants are considered the starting point for both crop and producer success [9,10]. The prerequisites are high indices of vigor and physiological and phytosanitary quality, and the capability to promote a high survival rate and vegetative growth after planting [11–13].

The strawberry plants' vigor can be affected by several factors and the initial diameter of the crown is one of the essential variables for the development of the plant, and is directly related to the accumulation and levels of carbohydrates. They alter the productive characteristics, precocity, and seasonality of production [11,13]. Several studies indicate that crown diameters above 5.1 mm are not able to increase the successful healing rate of plants after planting [11], and crown diameters above 8.8 mm allow positive effects for initial and total fruit production [14]. Other studies also indicate positive correlations between the plant crown diameter and total fruit production [15–17] and suggest that vigorous plants are associated with early production [18,19]. It is also emphasized that strawberry cultivars can behave differently in adverse conditions. It is essential to determine a minimum and maximum crown diameter standard for different cultivars, with the aim of directing producers and nurseries towards success in their activities.

Given the above, for the development and growth of the strawberry production chain in Brazil, it is essential that studies remedy deficiencies concerning quality standards of bare-root fresh plants produced in the country, as well as determine the crown diameter ranges, so that higher productive and qualitative indices of fruits can be achieved.

Therefore, the purpose of this study was to evaluate the effect of different crown diameters of strawberry plants on the production and quality variables of the fruits of the cultivar Pircinque, cultivated in the mountain region of the state of Santa Catarina, Brazil.

2. Materials and Methods

2.1. Plant Material and Experimental Design

The experiment was conducted during agricultural harvest periods (April 2016 to January 2017 and April 2017 to January 2018) at the Center of Agroveterinary Sciences of the State University of Santa Catarina (CAV-UDESC), located in the city of Lages, mountain region of the state of Santa Catarina, Brazil. The experimental area is located at the coordinates of 27°47' south latitude and 50°18' west longitude, and an altitude of 923 m above sea level. According to Köppen classification, the city of Lages has a humid subtropical mesothermal climate (Cfb) with moderate summers and winters with a high incidence of frost, having an average annual temperature of 15.6 °C and an average annual rainfall of 1400 mm, well-distributed throughout the year [20]. The local soil is classified as Haplumbrept [21].

Strawberry plants of the type “bare-root fresh plants” (Figure 1) and the cultivar Pircinque (Short Day) were classified at five months of age, according to the crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm), and thus constituted the eight treatments evaluated. The plants were produced by a commercial nursery located in the city of São Francisco de Paula (29°06' S, 50°50' W, and 900 m altitude), State of Rio Grande do Sul,

Brazil. The experimental design involved randomized blocks, with four repetitions, and an experimental unit consisting of 20 useful plants (80 plants per treatment). Conventional cultivation was carried out in the soil, in a micro tunnel system. Soil correction and basic fertilization were based on the recommendations for strawberry culture in the Manual of Fertilization and Liming for the state of Santa Catarina [22], and included adjusting the soil pH to 6.0, using dolomitic limestone.



Figure 1. Strawberry plants of the type “bare-root fresh plants” from the cultivar Pircinque, classified according to different crown diameters.

After the stage of fertilizer incorporation into the soil, the beds were prepared with the aid of a rotating Enchantress hoe and building beds that were 0.90 m wide and 0.25 m high. Subsequently, three localized irrigation lines with drippers spaced 0.15 m apart were installed at each plot. The beds were covered with black polyethylene film with a 30 micron thickness and a micro tunnel covering system, using a transparent polyethylene film with a 100 micron thickness [23]. The cultivation technique used in the research is still the most used productive model among Brazilian strawberry producers [7]. The plant spacing was 30 cm between rows and plants, resulting in a density of 60 thousand plants per hectare.

The planting of plants was conducted in the second half of April of each cycle. Daily activities were carried out to open and close the low tunnels, in order to control the plants' temperature, humidity, and foliar wetting. Fertilization via irrigation (fertigation) was carried out three times a week, providing the following products: Calcium nitrate [$\text{Ca}(\text{NO}_3)_2$] (9.92 g to 100 plants); magnesium sulfate (MgSO_4) (4.55 g to 100 plants); potassium sulfate (K_2SO_4) (31.25 g to 100 plants); monoammonium phosphate (MAP) (38.74 g to 100 plants); and P-51 (fertilizer, a liquid containing approximately 51% of the soil) (up 7.3 mL to 100 plants). The harvests were carried out from September to January of each year and carried out every 3 to 5 days. The fruits were harvested during the day's cooler hours, and when 80% of the fruit epidermis was a uniform red color. Climatic data relating to the temperature ($^{\circ}\text{C}$), relative humidity (%), and precipitation (mm) were monitored through the meteorological station of the National Institute of Meteorology (Table 1) [24].

Table 1. Mean values of environmental variables measured in the 2016/2017 and 2017/2018 production cycles.

	Mean Temperature (Tmed; °C)	Maximum Temperature (Tmax; °C)	Minimum Temperature (Tmin; °C)	Relative Humidity (RH; %)	Rainfall (mm)
2016/2017					
April	18.7	19.2	18.2	84.1	132.4
May	12.3	12.7	11.9	86.6	123.8
June	9.0	9.5	8.4	82.1	25.0
July	11.4	12.0	10.9	82.3	121.2
August	12.5	13.0	11.9	82.0	136.0
September	13.3	13.8	12.7	77.5	110.4
October	15.2	15.7	14.7	83.2	207.8
November	17.3	17.9	16.7	77.0	70.4
December	19.2	19.8	18.6	80.6	154.8
January	20.8	21.5	20.3	80.3	114.8
Average	15.0	15.5	14.4	81.6	119.7
2017/2018					
April	15.8	16.4	15.3	83.6	86.4
May	14.5	15.0	14.2	91.0	108.2
June	12.2	12.7	11.8	88.5	90.5
July	11.9	12.5	11.4	81.0	83.4
August	12.7	13.3	12.3	83.9	106.2
September	17.9	18.5	17.3	77.5	26.2
October	16.4	17.0	15.8	78.5	78.6
November	17.1	17.7	16.5	74.2	67.4
December	19.8	20.5	19.3	78.0	150.6
January	19.7	20.3	19.1	82.6	187.2
Average	15.8	16.3	15.2	82.1	98.5

2.2. Analyzed Variables

2.2.1. Productive Parameters

All the fruits of each plot and treatment were harvested. It was possible to estimate the variable number of fruits per plant (unit Plant^{−1}) by dividing the total number of fruits harvested by the number of plants present in each experimental unit. The total production (g plant^{−1}) was obtained by dividing the total weight of the fruits harvested by the number of plants contained in the plot [25]. The fresh mass per fruit (g fruit^{−1}) was obtained by dividing the commercial production, in grams per plant, by the number of commercial fruits in each experimental unit. The percentage of commercial production (%) was estimated by dividing, in each parcel, commercial production by total production, and then multiplying the results by 100. For commercial production, they were considered fruits without any anomalies (considered symptoms of rot and deformity) and fruits with a fresh mass equal to or greater than 10 g [25]. All weighing measurements were carried out with a precision digital scale (0.01 g), certified by the National Institute of Metrology, Quality, and Technology (INMETRO) [26].

2.2.2. Qualitative Parameters

For the variable of fruit quality, we grouped uniform samples of 10 fruits per plot. Fruit quality analyses were performed four times during the production cycles. The coloration parameters of the fruit epidermis were obtained through a digital countertop colorimeter by Konica Minolta CHROMA METER CR-400 (Made in Japan). For each fruit, two readings were performed on opposite sides of the equatorial region: By colorimetric analysis, the variable of lightness (L), which is provided by a scale of 0 to 100, ranging from low to high of the darker to lighter colors; the chroma (C), which indicates the epidermis' purity or saturation of color, which can range from 0 to 60, ranging in an ascending order of the colors, from less saturated to more saturated; and the hue angle (°hue), which sets the tone of the skin, ranging from 0 to 360, in which the lowest values correspond to tones closest to deep red, and higher values indicate tones closer to red-orange.

The pulp firmness was obtained with a digital countertop penetrometer (Texture Analyser TA.XT.plusC—made in United States of America), with 6.0 mm diameter tips. For each fruit, two readings were performed on opposite sides of the equatorial region. The results were expressed as the Newton force needed to break through the fruit epidermis. The titratable acidity was obtained with an automatic titrator (TITRONIC® 300—made in Germany). For each experimental unit, a sample of 5 mL of fruit juice was diluted in 45 mL of distilled water, followed by titration with 0.1 M NaOH solution, until pH 8.1 was obtained. The results were expressed as a percentage of citric acid per 100 g of fresh fruit mass. The soluble solids content was determined using a digital countertop refractometer (Atago PR-101A, with automatic temperature correction—made in Japan). For this purpose, samples of 20 mL of fruit juice from each plot were used. The results were expressed in degrees Brix (°Brix). The soluble solids/titratable acidity ratio was calculated by dividing the soluble solids content results by the titratable acidity of each plot.

2.3. Statistical Analysis

The resulting data were submitted to an analysis of variance (ANOVA) by the F test, and in the cases of significance, quadratic polynomial regression analysis was performed. To better understand the relationship between the variables analyzed concerning the different crown diameters of the evaluated plants, the averages were submitted to the principal component analysis (PCA) multivariate procedure [27]. The study also analyzed the productive seasonality by dividing the total production (g plant^{-1}) by the harvest months in each treatment. In this procedure, all of the different plant crown diameters and harvest months were compared, in a factorial scheme, using analysis of variance and the Scott–Knott test for grouping means, with a 5% error probability. All statistical analyses were performed using R software [28].

3. Results and Discussion

For the two years of evaluation (2016/2017 and 2017/2018), significant polynomial regression adjustments were verified for all evaluated variables.

A significant effect was observed for the different plant crown diameters in both harvests regarding the productive yield parameters. In terms of the number of fruits per plant, the plants' increase in the crown diameter resulted in increments for this variable, which were adjusted in quadratic models in both crop cycles (Figure 2A). In the 2016/2017 harvest, the largest number of fruits per plant (more than 40 fruits) was obtained with the largest crown diameter (19 mm). Therefore, it is impossible to estimate the curve's maximum point. In the 2017/2018 agricultural cycle, a maximum point of approximately 60 plant^{-1} fruits was obtained for the crown diameter of 15.8 mm. In both production cycles, the total production per plant increased quadratically with the plants' crown diameter (Figure 2B). The highest averages for total production were obtained with the largest evaluated crown diameter of 19 mm, being 650 g plant^{-1} for the 2016/2017 harvest and 815 g plant^{-1} for the 2017/2018 harvest. It was possible to find a minimum point indicating that significant results require crown diameters greater than 14.0 and 12.2 mm for the respective harvests.

The increase in the number of fruits and the highest product performance in this study (Figure 2A), with the increase in plant crown diameters, has already been obtained by other authors, who have verified an increase in the number of fruits in strawberry plants using plants with crown diameters between 15 and 17 mm [29]. One of the principal explanations is that larger diameter plants, besides having a higher energy reserve in the form of starch, have a high number of buds capable of differentiating into flowers and fruits [14], resulting in increases in the number of fruits per plant and total production. These authors also verified higher productive yields in two evaluation cycles for plants with a larger crown diameter ($>10 \text{ mm}$) than plants with a smaller crown diameter, corresponding to an 18% and 27% increment, for the first and second harvests, respectively. They also verified a 17% increase in total production in plants with a diameter between 10 and 17 mm, compared to

plants with a diameter of less than 10 mm [12]. With larger plants, there is an increase in the plant's biomass, which favors its photosynthetic machinery [30].

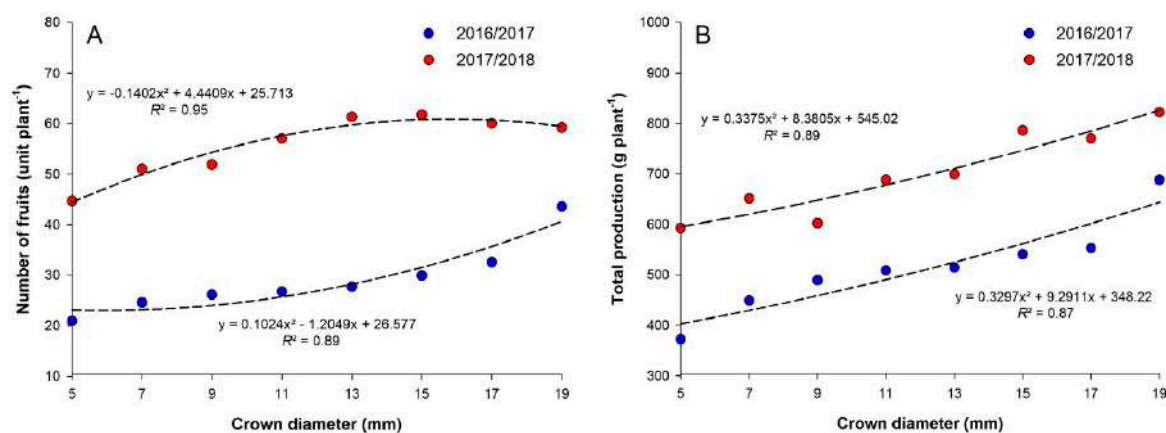


Figure 2. The number of fruits per plant (A) and the total production (B) of strawberry plants cv. ‘Pircinque’, according to different plant crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm) in the 2016/2017 and 2017/2018 production cycles.

The higher accumulation of biomass in plants is related to a higher density of foliage, which raises the productive capacity to a limited extent. When the optimal leaf area index is reached, the plant's ability to intercept light energy is favored, thus increasing organic compound production through photosynthesis, resulting in increased production [31]. Moreover, larger strawberry plants also result in plants with a more vigorous root system, allowing a higher absorption of water and nutrients by plants [32], which also benefits their production yield.

The crowns have the function of regulating the metabolic activities of strawberry plants [33]. They are also the plant's main energy storage organ, accumulating reserve substances inside, notably starch [34]. Therefore, the use of vigorous plants is an advantage, mainly during the initial fruiting period, since part of the initial production is dependent on the accumulation of reserves in the crown during plant development [12,14]. The crowns' number and diameter also serve as parameters for estimating strawberry plant production [35].

In the 2016/2017 cycle, there was an increase in the average mass of commercial fruits, with positive quadratic behavior and a maximum point of 21.43 g fruit⁻¹, obtained for the plant crown diameter of 11.8 mm (Figure 3A). In the 2017/2018 harvest, there was a small decrease in the fresh mass of commercial fruits using more vigorous plants, estimated at a minimum point of 17.75 g fruit⁻¹, for the diameter of 15.9 mm. The sharpest decrease in fresh fruit mass in the 2016/2017 cycle, after the maximum point, may be related to the increase in the number of fruits, leading to an increase in competition among fruits by assimilates, resulting in a reduction in the average mass [36].

The percentage of commercial production exhibited a small amount of variation between the different treatments. However, there was a significant difference between them (Figure 3A). In both harvests, positive quadratic curves were obtained for this variable. However, in the 2016/2017 harvest, the commercial fruit production amount was higher than in the 2017/2018 harvest. This is possibly due to the higher number of fruits per plant obtained in the 2017/2018 cycle, which resulted in a higher production of fruits below the commercial standard of 10 g per fruit, due to the need to distribute the assimilates to a larger number of fruits. The maximum percentage of commercial production was obtained with the diameters of 12.06 mm for 2016/2017 and 12.16 mm for 2017/2018, with values of 91.8% and 79.7%, respectively.

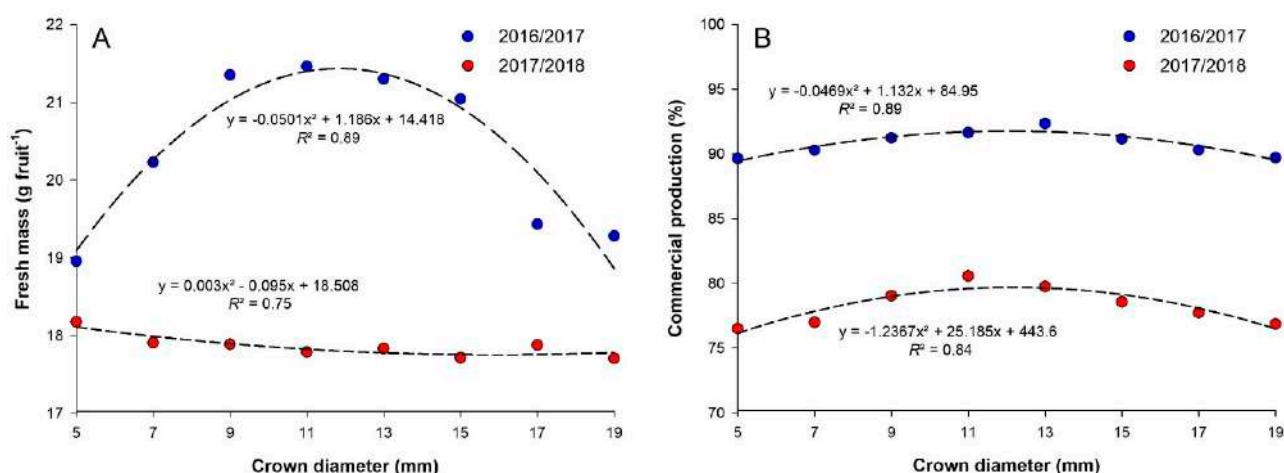


Figure 3. The response of fresh fruit mass (A) and the percentage of production classified as commercial (B) of strawberry plants cv. ‘Pircinque’, depending on different plant crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm) in the production cycles 2016/2017 and 2017/2018.

Other studies also reported productivity increases followed by a decrease in the average mass of fruits with the use of more vigorous strawberry plants, with an increase in the number of fruits and yield, but without an increase in the average weight of fruits with the use of bare-root plants with a diameter above 10 mm [14].

In the 2016/2017 harvest, the percentage of commercial fruits increased with more vigorous plants, up to a crown diameter of 12.5 mm, with an estimated 92% of commercial production (Figure 3B). In the 2017/2018 cycle, the maximum value for this variable was estimated to be 79% for the plant diameter of 12 mm. The commercial production percentage suffered small reductions from the crown diameter of 15 mm and higher due to increased fruit production, with less than 10 g in both harvests. The use of more vigorous strawberry plants usually results in plants with less stress, making them less susceptible to attacks by pathogens [30]. The crown diameter is one of the main parameters of the plant quality [12], and plants with a high physiological quality lead to high commercial fruit yields [32].

Regarding the fruit quality parameters, decreases in the titratable acidity were observed using plants with a larger crown diameter for the two harvests that were part of this study. The curves were aligned to quadratic models (Figure 4A). In the 2016/2017 harvest, the minimum value was obtained for the diameter of 14 mm, with an estimated value of 0.54% citric acid. In the 2017/2018 agricultural cycle, the use of more vigorous plants also resulted in a decrease in the titratable acidity, but one that was less pronounced, with a minimum value for the 13.8 mm diameter (0.58% citric acid). The titratable acidity, together with the sugar content, makes up the taste of the fruits. However, when the acidity is high, the sugar content must be as well, so that there is no compromise in consumer fruit taste and acceptance [37]. Therefore, for the market acceptance regarding the taste, a balance in the soluble solids/titratable acidity ratio is necessary. In the 2016/2017 harvest, there was a reduction in acidity values when the crown diameters increased and a simultaneous increase in soluble solids (Figure 4B), increasing the soluble solids/titratable acidity ratio (Figure 5A). Therefore, in this harvest, the fruits were tastier due to increased sugar levels, resulting in sweeter fruits.

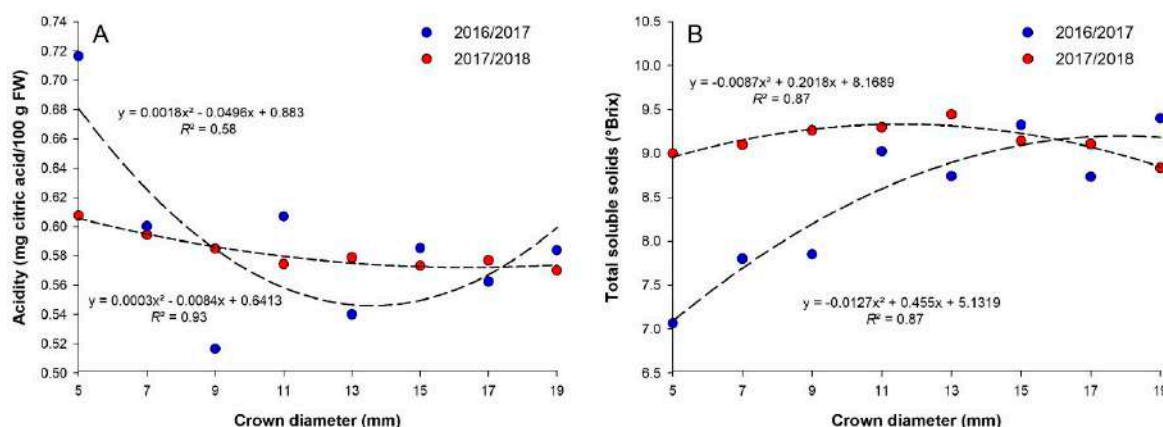


Figure 4. The titratable acidity (A) and total soluble solids content (B) in the fruits of strawberry plants cv. 'Pircinque', depending on different crown diameters of the plants (5, 7, 9, 11, 13, 15, 17, and 19 mm) during the 2016/2017 and 2017/2018 production cycles.

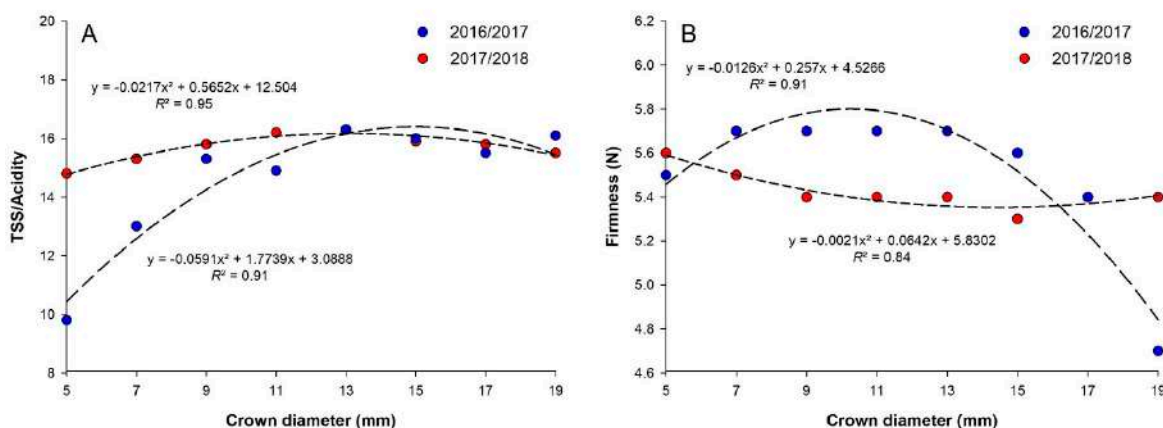


Figure 5. The response of the ratio between the content of soluble solids (TSS) by titratable acidity (A) and pulp firmness (B) of the fruits of strawberry plants cv. 'Pircinque', depending on different crown diameters of the plants (5, 7, 9, 11, 13, 15, 17, and 19 mm) during the 2016/2017 and 2017/2018 production cycles.

For the soluble solids content, quadratic increases were observed when using larger plants, but with different intensities, for the two analyzed harvests (Figure 4B). In the 2016/2017 production cycle, the maximum estimate for the sugar concentration (9.2° Brix) was obtained with the diameter of 17.9 mm. In the 2017/2018 harvest, the maximum content of soluble solids (9.3° Brix) was obtained with the plant diameter of 11.6 mm. The soluble sugar content in fruits is due to several polysaccharides from the photosynthesis process, mainly glucose, fructose, and sucrose. During fruit ripening, the production and concentrations of these compounds increase, and the reserve starch is converted into simple carbohydrates, which are soluble in water [38]. This is a possible explanation for why more vigorous plants resulted in sweeter fruits in the present study, highlighting the importance of having plants with an excellent physiological quality and high crown caliber, as well as those that are richer in terms of the carbohydrate reserve [13].

As for the soluble solids/titratable acidity ratio, there were also significant effects due to the different plant sizes, with positive quadratic behavior in both crops (Figure 5A). In the 2016/2017 cycle, the maximum value for this variable (16.4) was found for the plant crown diameter of 15 mm (Figure 5A). In the 2017/2018 harvest, the maximum value (16.5) was obtained for the plant diameter of 11.6 mm. In this cycle, the soluble solids/titratable acidity ratio averages were lower than in the 2016/2017 cycle. This was the case because,

in the 2017/2018 harvest, both the reduction in the titratable acidity and the increase in the sugar content in fruits, resulting from the use of more vigorous plants, occurred at lower intensities when compared to the 2016/2017 cycle (Figure 4A,B). Therefore, there were lower estimates of the soluble solids/titratable acidity ratio (Figure 5A).

The soluble solids/titratable acidity ratio is one of the most important fruit quality parameters. It allows us to verify the existing balance between the concentration of sugars and acidity, making this parameter more representative than isolated estimates of the titratable acidity and soluble solids content [39].

For the fruit pulp's firmness, there was also a significant effect provided by the use of plants with different crown diameters, and quadratic regression curves were obtained for both crop cycles (Figure 5B). In the 2016/2017 harvest, there was an increase in pulp firmness values, up to the estimated average of 5.86 N, corresponding to the crown diameter of 10.5 mm. However, for crown diameters above 13 mm, a sharp decrease in the averages was obtained for this variable, reaching 4.74 N for the largest crown diameter evaluated (19 mm). In the 2017/2018 cycle, the regression curve obtained resulted in a minimum value of 5.35 N for the plant crown diameter of 15 mm. In this harvest, the oscillation in fruit pulp's firmness averages provided by the different crown diameters of the plants was much lower than in the previous cycle.

In strawberry production, the fruits' pulp firmness is one of the most relevant characteristics to take into account. Fruits with firmer pulp are usually better accepted by consumers, more resistant to transport, have a longer shelf life after harvest [40], and are more resistant to rot caused by pathogens [36]. This requires combining the fruits' taste attributes (balance between sweetness and acidity) with appropriate pulp firmness values to ensure marketing and maintenance of the fruits' quality for the longest possible period post-harvest.

Three variables, considered separately, were employed to evaluate the epidermis coloration. Both production cycles (2016/2017–2017/2018) showed similar behavior. For the variable luminosity of epidermis (Figure 6A), a greater luminosity was observed in the fruit of plants with a crown diameter of 5 and 7 mm, (>40.0). Plants with a crown diameter of 13 mm generated lower luminosity values, being between 38.6 and 39.2. The luminosity ranges from 0 to 100, from darker colors (smaller values) to lighter colors (larger values).

For the variable chroma or epidermis' color saturation (Figure 6B), higher averages were observed in fruits from plants with a crown diameter between 5 and 9 mm, with averages higher than 49.0; that is, epidermis with a purer or saturated color. Lower chroma averages were found in the fruits from plants with crown diameters between 15 and 19 mm (averages between 48.0 and 48.5). As for the *hue* angle (Figure 6C), which determines the epidermis' color tone, the highest values were found in fruits produced from plants with a diameter of 5 mm, with an average of 36.4 in the first production cycle (2016/2017), and 36.0 in the second (2017/2018). In fruits from plants with a diameter of 13 mm, the lowest hue angle values were observed (33.8 in the first production cycle and 33.6 in the second cycle).

Considering the three variables of coloration together, it is possible to observe that in the fruits that had the lightest epidermis, with the highest luminosity averages, the saturation was also higher, that is, a more vivid color, and also a shade closer to light red or orange. The external epidermis color of strawberry fruits is one factor that most influences the consumers' purchase intention and fruits with more intense, bright red coloration and free of defects tend to be more desirable in the in natura consumer market [37].

Pigments belonging to the anthocyanin group are responsible for the red color in strawberry fruits [41]. The main anthocyanins in strawberry fruits are pelargonidin 3-glucoside and cyanidin 3-rutinoside, with the former being present at a higher concentration [42].

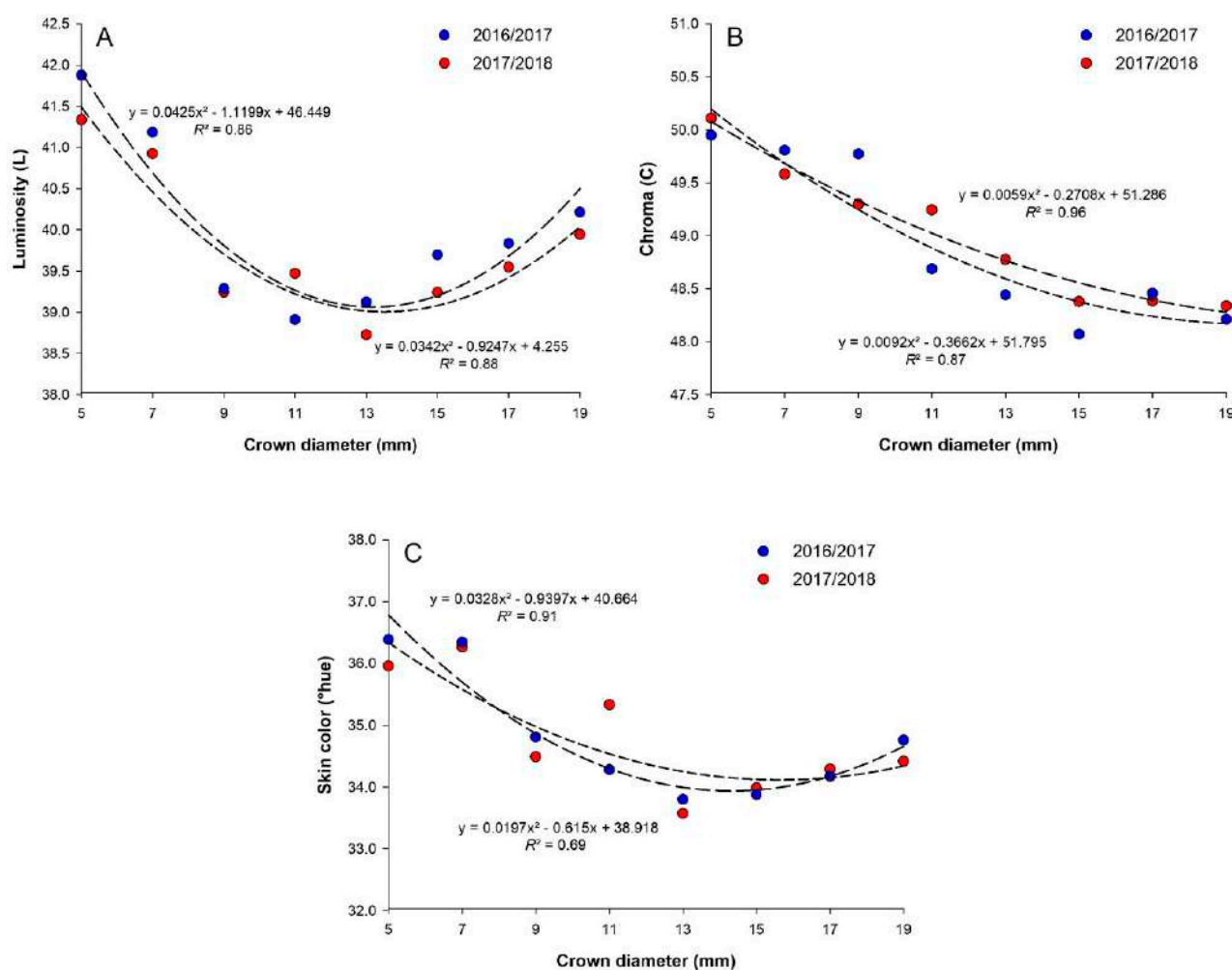


Figure 6. The response of the parameters related to the fruit's epidermis coloration, represented by the values of luminosity (A), chroma (B), and the skin color (°hue) (C) in strawberry plants cv. 'Pirquin', depending on different plant crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm) in the 2016/2017 and 2017/2018 production cycles.

In the principal component analysis (Figure 7), the first two components represented 92.2% of the variation obtained (63.8% for Axis 1 and 28.4% for Axis 2), allowing the treatments' graphical dispersion and variables to be analyzed in a two-dimensional graph (Figure 7). The main component 1 was related to the variable soluble solids/titratable acidity ratio, soluble solids content, number of fruits per plant, hue angle of the fruit epidermis, chroma, luminosity, total production, and titratable acidity (Figures 7 and 8). Plant crown diameters of 17 and 19 mm were the most strongly correlated with the total production and number of fruits per plant (Figure 7). The 15 mm treatment, in turn, was closely related to the soluble solids content and the soluble solids/titratable acidity ratio. On the other hand, the smaller crown diameters evaluated (5 and 7 mm) were related to higher titratable acidity, luminosity, chroma, and hue angle values.

On the other hand, the variables commercial fruits' average mass, percentage of commercial production, and pulp firmness were responsible for most of the variation present in the main component 2 (Figures 7 and 8). Plant crown diameters of 9, 11, and 13 mm were the treatments most closely related to these variables (Figure 7).

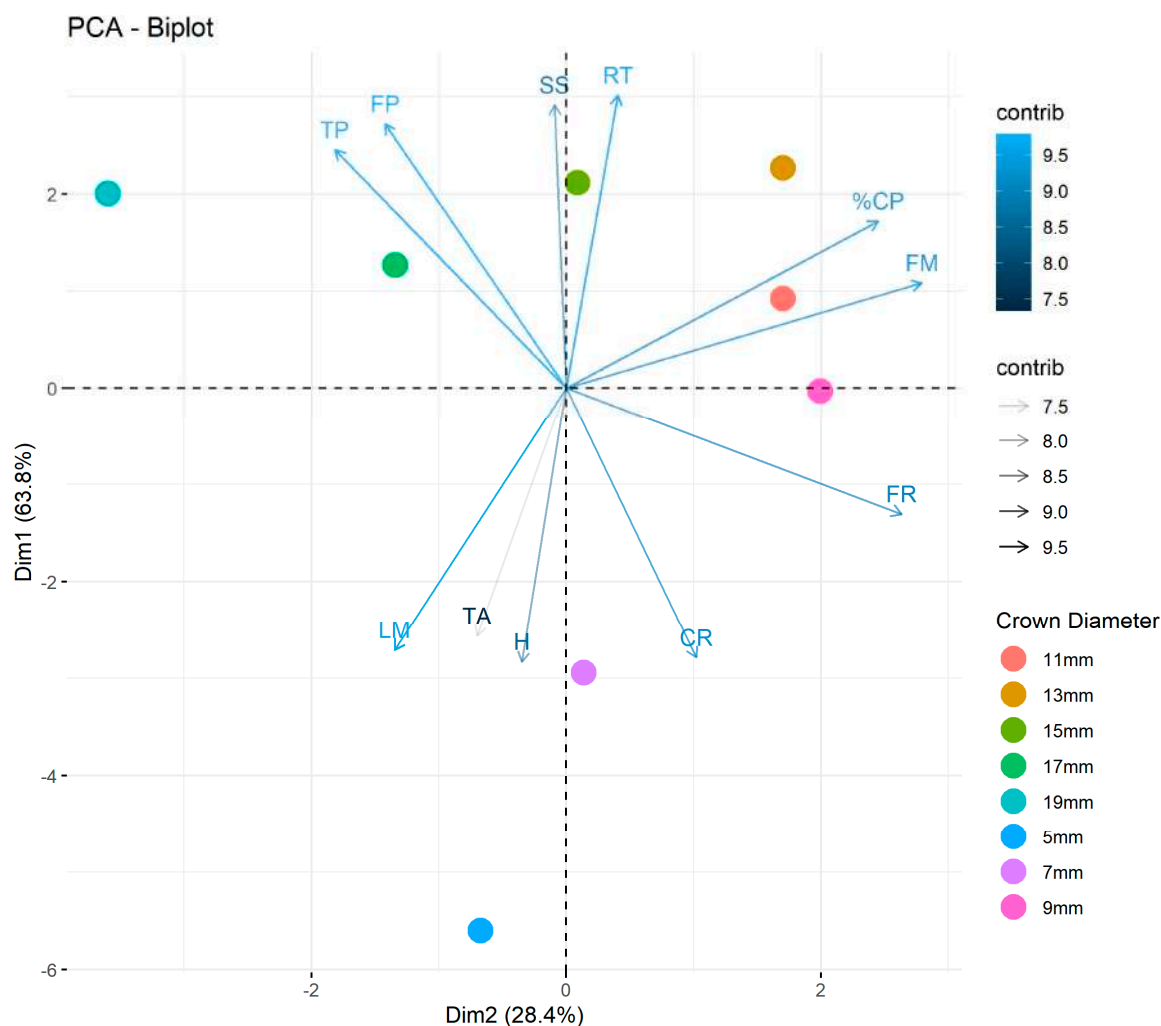


Figure 7. Principal component analysis of the variables in the study concerning the effect of bare-root plants with different crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm) on the production and fruit quality parameters of strawberry plants cv. Pircinque. Caption: FP = fruits per plant; TP = total production; FM = fresh mass; % CP = commercial percentage; SS = content of soluble solids; FR = firmness; TA = titratable acidity; RT = soluble solids/titratable acidity ratio; LM = epidermis luminosity; CR = epidermis chroma; and H = epidermis hue angle.

In a general approach to the analysis of the main components, it is possible to affirm that the plant crown diameters from 15 to 17 mm were closely related to the most important agronomic characteristics for the strawberry crop (productivity, soluble solids/acidicity ratio, and pulp firmness). The plants with the largest evaluated crown diameter (19 mm) were related to the highest yields in the two evaluation cycles and high ratios between the soluble solids content and titratable acidity. However, a sharp drop in the pulp firmness values occurred in the 2016/2017 harvest, when plants with a 19 mm crown diameter were used (Figure 5B), which suggests that new studies need to be carried out to investigate the feasibility of using plants with this caliber, for the cultivar ‘Pircinque’.

As a multivariate analysis modality, the analysis of main components is a handy tool in agricultural research in terms of identifying the most recommended treatments, taking into account the largest number of possible variables [43]. Therefore, this type of analysis often supports more precise conclusions being drawn from a research project’s result than the exclusive use of univariate analyzes, which often leave doubts in terms of the most effective treatments measurement [44]. This can be especially important in the case of a crop such as strawberry, in which the yield and fruit quality parameters are equally relevant [36,40].

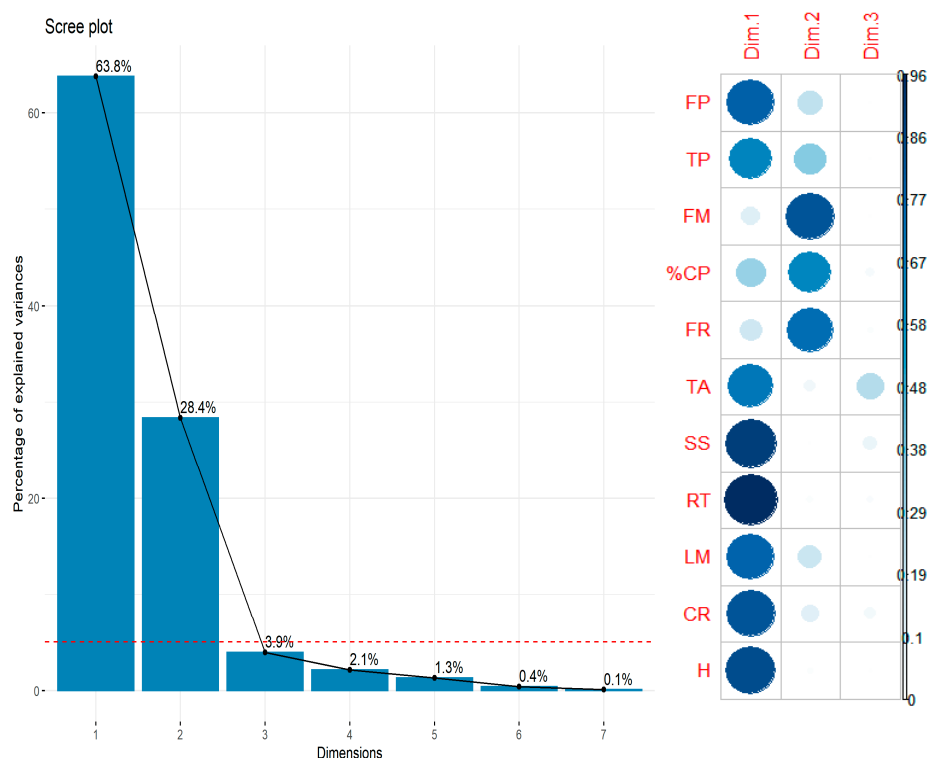


Figure 8. Decomposed principal component analysis for the variables in the study concerning the effect of bare-root plants with different crown diameters (5, 7, 9, 11, 13, 15, 17, and 19 mm) on the production and fruit quality parameters of strawberry plants cv. Pircinque. Caption: FP = fruits per plant; TP = total production; FM = fresh mass; % CP = commercial percentage; SS = content of soluble solids; FR = firmness; TA = titratable acidity; RT = soluble solids/titratable acidity ratio; LM = epidermis luminosity; CR = epidermis chroma; and H = epidermis hue angle.

The use of plants of different calibers provided different results for the seasonality of the strawberry plants cv. 'Pircinque' total production, for both harvests studied. There was an interaction between plant crown diameters and harvest months (Tables 1 and 2). In the 2016/2017 cycle, the largest productions occurred in November for most of the treatments evaluated (Table 2). Exceptions were the plant crown diameter of 7 mm, with the largest yields in November and December, with no significant difference between these months, and the diameter of 19 mm, with the highest averages in October, November, and December. In the 2017/2018 cycle, the highest total productions were obtained in October for most of the treatments evaluated (Table 3). The exception was the crown diameter of 5 mm, with the highest production in November.

Taking into account the influence of plant crown diameters within each harvest month, it was found that, in the two harvests studied, the use of more vigorous plants resulted in a higher precocity in the productive phase; that is, significantly higher yields compared to smaller diameter plants at the beginning of each harvest (Tables 2 and 3). In the 2016/2017 cycle, for example, for the first month of harvest (September), the yields with crown diameters of 17 and 19 mm were significantly higher than those of the other plant sizes. In October 2016, the largest diameter plants (19 mm) provided the most significant results, differing from other treatments. On the other hand, in November of that year, there was no significant influence of the plant sizes on the production averages, while in December, the crown diameter of 19 mm resulted in the largest productions. In January, corresponding to the final phase of the productive period, the different plant sizes provided similar productivity results.

Table 2. Productive seasonality of strawberry plants cv. ‘Pircinque’, from plants with different crown diameters, in the agricultural cycle of 2016/2017.

Treatment	SET	OCT	NOV	DEC	JAN	Average
5 mm	7.0 ^{dD *}	53.8 ^{cD}	132.7 ^{aB}	92.6 ^{bC}	85.9 ^{bA}	74.4
7 mm	6.8 ^{cD}	87.8 ^{bC}	158.6 ^{aB}	129.1 ^{aB}	66.3 ^{bA}	89.7
9 mm	16.6 ^{eC}	93.4 ^{cC}	178.0 ^{aA}	135.0 ^{bB}	66.3 ^{dA}	97.9
11 mm	24.7 ^{dC}	105.3 ^{bC}	195.8 ^{aA}	111.9 ^{bC}	70.2 ^{cA}	101.6
13 mm	32.0 ^{cB}	139.6 ^{bB}	184.1 ^{aA}	109.2 ^{bC}	49.3 ^{cA}	102.8
15 mm	41.9 ^{cB}	128.9 ^{bB}	182.9 ^{aA}	133.0 ^{bB}	53.5 ^{cA}	108.0
17 mm	49.3 ^{cA}	136.0 ^{bB}	185.2 ^{aA}	125.9 ^{bB}	56.4 ^{cA}	110.6
19 mm	62.5 ^{bA}	203.5 ^{aA}	187.6 ^{aA}	171.5 ^{aA}	62.7 ^{bA}	137.6
Average	30.1	118.5	175.6	126.0	63.8	
CV			11.21			

* Averages followed by the same lowercase letters in the rows, and uppercase letters in the columns, belong to the same group, as determined by the Scott–Knott test, with a 5% error probability.

Table 3. Productive seasonality of strawberry plants cv. ‘Pircinque’, from plants with different crown diameters, in the agricultural cycle of 2016/2017.

Treatment	SET	OCT	NOV	DEC	JAN	Average
5 mm	23.7 ^{dB *}	144.6 ^{bC}	199.2 ^{aA}	145.5 ^{bA}	79.3 ^{cA}	118.5
7 mm	36.9 ^{dB}	222.1 ^{aA}	175.5 ^{bA}	148.6 ^{bA}	68.1 ^{cA}	130.2
9 mm	58.6 ^{cA}	202.1 ^{aB}	125.0 ^{bA}	152.3 ^{bA}	63.8 ^{cA}	120.3
11 mm	59.1 ^{cA}	242.7 ^{aA}	172.4 ^{bA}	156.9 ^{bA}	56.6 ^{cA}	137.5
13 mm	65.4 ^{cA}	241.8 ^{aA}	172.6 ^{bA}	152.9 ^{bA}	66.3 ^{cA}	139.8
15 mm	78.0 ^{cA}	271.0 ^{aA}	187.4 ^{bA}	182.6 ^{bA}	67.1 ^{cA}	157.2
17 mm	64.0 ^{cA}	288.0 ^{aA}	163.5 ^{bA}	183.9 ^{bA}	70.4 ^{cA}	154.0
19 mm	86.4 ^{cA}	298.0 ^{aA}	177.7 ^{bA}	188.4 ^{bA}	71.9 ^{cA}	164.5
Average	59.0	238.8	171.7	163.9	67.9	
CV			12.06			

* Averages followed by the same lowercase letters in the rows, and uppercase letters in the columns, belong to the same group, as determined by the Scott–Knott test, with a 5% error probability.

In the 2017/2018 harvest, for the first month of the harvest (September), the use of plants with a crown diameter of 9 mm or higher provided higher production averages than smaller plants (5 and 7 mm). In the second month of that harvest (October), plants with any crown diameter from 7 mm resulted in higher yields than plants with a crown diameter of 5 mm. On the other hand, in November, December, and January, the caliber had no significant influence on the total production.

When analyzing both harvests together regarding the productive seasonality, one of the most important results was that larger caliber plants favored higher yields in the first two months of each harvest, namely, a higher productive precocity. The early production of fruits in the strawberry plants is directly correlated with the plant quality at planting [32]. Among the factors related to the quality of the plants that most influence the strawberry plant production and precocity, the crown diameter, the mass of the aerial part, and the quality and volume of the root system stand out [45]. In plants with a smaller crown diameter, the peak production is observed later when compared with plants with a larger diameter.

4. Conclusions

Plants with large crown diameters provide superior results regarding the productive performance of strawberry plants cv. ‘Pircinque’, and improve the quality of the harvested fruits, compared with less vigorous plants.

The use of plants with crown diameters of 15 and 17 mm leads to higher yields and precocity values, and a high physical-chemical quality of the fruits.

The use of strawberry plants with a diameter of less than 9 mm promotes a decrease in the production capacity and a delay in the start of production.

For strawberry plants of the type “bare-root fresh plants” of cultivar ‘Pircinque’, it is recommended that plants with a crown diameter greater than 9 mm are used.

Author Contributions: Conceptualization, A.F.F.; methodology, A.F.F., D.S.Z., M.F.S.d.S., and L.R.; validation and formal analysis A.F.F., D.S.Z., and M.F.S.d.S.; investigation and data curation, A.F.F., D.S.Z., P.D.W., M.F.S.d.S., J.M.d.L., and A.F.R.; writing—original draft preparation, M.F.S.d.S., J.M.d.L., and P.D.W.; writing—review and editing, visualization, A.F.F., D.S.Z., F.R.N., A.A.K., and L.R.; supervision, project administration, and funding acquisition, A.A.K., L.R., and G.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Universidade do Estado de Santa Catarina (UDESC).

Data Availability Statement: Data sharing not applicable. No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors are grateful for the infrastructure and logistical support provided by the Center for Agroveterinary Sciences of the University of the State of Santa Catarina (CAV-UDESC); by the research development agencies, especially FAPESC and CNPq; for the grant of scholarships; and for the assistance with research activities. They also thank the Fruit Crop research team of CAV-UDESC and the Council for Agricultural Research and Economics—Centre for Olive, Fruit and Citrus Crops (CREA-OFA) for supporting scientific cooperation with UDESC. Finally, they thank the Pasa nursery for providing the plants used in this research.

Conflicts of Interest: The authors declare no conflict of interest.

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Quality of strawberries of Italian origin grown in the mountainous region of Rio Grande do Sul

Paola Daiane Welter^{1*}, Juliana Martins de Lima², Marllon Fernando Soares dos Santos², Daiana Petry Rufato², Leo Rufato², Aike Anneliese Kretschmar²

¹ Universidade Federal de Santa Maria, Santa Maria, RS, Brasil. E-mail: paoladwelter@gmail.com

² Universidade do Estado de Santa Catarina, Lages, SC, Brasil. E-mail: juumartinsslima@gmail.com; marllon.soares@outlook.com; daianapetry@gmail.com; leoruffato@yahoo.com.br; aike.kretschmar@udesc.br

ABSTRACT: Studies that evaluate the quality of the strawberry fruit, depending on the different genetic materials and places of cultivation, are still scarce in Brazil. The objective of this work was to evaluate the quality of fruits of advanced genotypes of strawberry with Italian genetics, in the municipality of Farroupilha, belonging to the Serrana region of Rio Grande do Sul. The experimental design was in randomized blocks, with four replications and 10 plants per plot, in two production cycles, containing 21 treatments in the 2018/2019 cycle and 23 treatments in the 2019/2020 cycle. The variables were quantified: fresh mass of commercial fruits (g fruit⁻¹); luminosity and chroma of the epidermis; hue angle; pulp firmness (g); titratable acidity content (g 100g⁻¹ of citric acid); soluble solids content (°Brix) and soluble solids/titratable acidity ratio (SS/AT). Among the genotypes evaluated, the genotypes FRF PIR 075.08, ITA 10.128.09, and FRF FC 104.01, have superior fruit quality, showing greater potential to become recommended cultivars for cultivation in the Serrana region of Rio Grande do Sul, together with the cultivar Pircinque.

Key words: climate; *Fragaria x ananassa* Duch.; in natura market; genotypes

Qualidade de morangos de origem italiana cultivados na região serrana do Rio Grande do Sul

RESUMO: Estudos que avaliem a qualidade do fruto do morangueiro, em função dos diferentes materiais genéticos e lugares de cultivo, ainda são escassos no Brasil. Objetivou-se com este trabalho avaliar a qualidade de frutos de genótipos avançados de morangueiro com base genética italiana, no município de Farroupilha, pertencente a região Serrana do Rio Grande do Sul. O delineamento experimental foi em blocos casualizados, com quatro repetições e 10 plantas por parcela, em dois ciclos produtivos, contendo 28 tratamentos no ciclo 2018/2019 e 39 tratamentos no ciclo 2019/2020. Foram quantificadas as variáveis: massa fresca de frutos comerciais (g fruto⁻¹); luminosidade e croma da epiderme; ângulo hue; firmeza de polpa (g); teor de acidez titulável (g 100g⁻¹ de ácido cítrico); teor de sólidos solúveis (°Brix) e relação sólidos solúveis/ acidez titulável (SS/AT). Dentre os genótipos avaliados, os genótipos FRF PIR 075.08, ITA 10.128.09 e FRF FC 104.01, apresentam qualidade superior de fruto, demonstrando maior potencial para se tornarem cultivares recomendadas para o cultivo na região Serrana do Rio Grande do Sul, juntamente com a já cultivar Pircinque.

Palavras-chave: clima; *Fragaria x ananassa* Duch.; mercado in natura; genótipos



Introduction

The national strawberry producing poles depend almost exclusively on varieties obtained from breeding programs outside Brazil. However, the introduction of new cultivars in the country should be preceded by studies to evaluate the adaptability of these plants in Brazilian regions, exposed to the different existing climatic conditions, including those that are also adverse to the environmental conditions in which they were selected ([Galvão et al., 2017](#)). Therefore, it is of great importance to conduct studies with new genetic sources, encouraging the national breeding programs to introduce and create materials adapted to the producing regions, expanding the genetic resources available for commercial cultivation ([Cocco et al., 2020](#)).

The diversity of materials with distinct fruit characteristics, necessitate studies of adaptation to different growing systems and different locations ([Zanin, 2019](#)). Environmental factors have a major influence on the growth, development, and quality of the fruit. Temperature is one of the main factors that affect the production and quality of strawberries, and is considered the main limiting factor of the crop. The influence of temperature on the fruit, besides being physical (shape, color, firmness), also directly affects their flavor and aroma. Rainfall, solar radiation, and air humidity are environmental factors that can also affect the quality of strawberry fruit ([Gonçalves et al., 2016](#)).

Strawberry quality is directly related to volatile compounds, soluble sugars, amino acids, and organic acids that impart flavor to the fruit ([Taiz et al., 2017](#); [Farnezi et al., 2020](#)). Although there are several studies on the quality and nutritional content of strawberry, there is still a gap in studies evaluating the quality of strawberry fruit as a function of different genetic materials and growing locations with distinct environmental conditions ([Zanin, 2019](#)).

The production of the plant is of great importance for strawberry growers, but more than this is the quality of the fruit, since their commercialization depends directly on the acceptance of the consumer market, which is based largely on the appearance of the fruit. In addition, the consumption habit is due to the fruit flavor, constituted basically from sugars and organic acids contained in the fruit ([Farnezi et al., 2020](#)).

With this, it is important to emphasize that the proper choice of a cultivar is not only supported by the productive aspects, but also by materials that produce quality fruit and meet the demands of the consumer market. The Italian genetic material, besides its productive characteristics, is selected for the quality of its fruits. The study of these materials, cultivated in different locations, will enable the indication of new cultivars, with options of quality fruits, with firmness, color, and differentiated flavor, increasing the supply of fruit in the south Brazilian region. Due to this, the present study aimed to evaluate the fruit quality of advanced strawberry genotypes with Italian genetic basis in the municipality of Farroupilha, located in the mountainous region of the state of Rio Grande do Sul, Brazil.

Materials and Methods

The trials were conducted in the strawberry seedling production nursery PASA, in an agricultural area located at 29° 12' 16" S latitude and 51° 19' 03" W longitude, at an altitude of 720 m, in the municipality of Farroupilha, state of Rio Grande do Sul, Brazil. The climate is classified as humid subtropical mesothermal Cfb, according to Köppen. The annual rainfall is approximately 1,837 mm and the average annual temperature is 16.2 °C, the experiment being carried out in their harvests. More details about the maximum and minimum average temperature data and monthly rainfall during the conduction of the trials in the municipality of Farroupilha, can be seen in the [Table 1](#).

In the 2018/2019 cycle, the experiment was conducted with 21 treatments, composed of American cultivars, Spanish cultivar, genotypes of Italian origin from the Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria Centro di Olivicoltura, Frutticoltura e Agrumicoltura (CREA-OFA) and Italian-based genotypes selected in Brazil by the Universidade do Estado de Santa Catarina. The seedlings used in the trial were produced in a commercial nursery located in Farroupilha, RS, Brazil, from stolons collected in the field and rooted in 72-cell trays.

The 21 treatments were composed of the short day genotypes: Jonica, Pircinque, Sabrina, FRF LAM 269.18, FRF PIR 075.08, FRF PIR 256.04, FRF PA 109.02, FRF PIR 079.06, ITA 10.133.02, ITA 10.133.07, ITA 13.079.01, ITA 13.079.02, ITA 13.097.05, ITA 10.107.12, ITA 10.107.07, ITA 10.107.06, ITA 12.103.06, ITA 12.103.12, ITA 12.103.15, ITA 12.103.22, and ITA 10.128.09.

The experiment was installed in a system of growing beds, suspended one meter from the ground, 20 cm wide and 20 cm deep, which were filled with substrate, composed of 60% carbonized rice husk and 40% peat, and covered with 25 cm thick white and black double-sided mulching. The covering of the beds was individual, every two planting rows, in the format of low tunnels, covered with transparent polyethylene plastic. The seedlings were transplanted in June, using randomized block design, with four repetitions, each experimental unit consisting of 10 plants, with spacing of 0.15 m between plants and 0.30 m between rows, in a double row.

The cultivation system and plant management was entirely carried out by the producer. The irrigation system used was via 10 cm drippers and fertilization was done via fertigation with formulation according to chart 3, recommended commercially (Yara®) for strawberry crops, using salt compounds already formulated in order to maintain the pH always in the range of 5.5 to 6.5 and electrical conductivity of the drainage of 1.2 to 1.5 mS cm⁻¹. The cleaning of the plants was done manually, as needed, removing diseased and senescent leaves. Weed control, as well as phytosanitary control was carried out as needed, with the use of products recommended and registered for the crop by the Ministério da Agricultura in Agrofitt.

In the 2019/2020 cycle, the experiment consisted of 23 treatments, consisting of the short day genotypes: Jonica, Pircinque, Camino Real, Oso Grande, Merced, Fronteras, Sabrina, FRF PIR 256.04, FRF PIR 075.08, FRF LAM 269.18,

Table 1. Average maximum and minimum temperature and monthly rainfall during the conduction of the trials in the municipality of Farroupilha, RS, Brazil, 2020.

2018/2019 harvest										
	May/18	Jun/18	Jul/18	Aug/18	Sept/18	Oct/18	Nov/18	Dec/18	Jan/19	Feb/19
Average - maximum temp. (°C)	16.0	12.3	13.6	12.5	17.5	17.7	20.7	21.8	24.1	21.7
Average - minimum temp. (°C)	15.1	11.4	12.7	11.5	16.5	16.7	19.6	20.6	23.0	20.6
Rainfall (mm)	118.6	193.2	163.0	215.8	183.0	221	191.0	134.4	138.0	66.2
Average - maximum RH (%)	82.9	86.0	85.1	81.2	82.0	80.8	74.4	75.6	93.5	79.5
Average - minimum RH (%)	79.1	81.9	81.5	76.7	77.4	76.0	68.7	69.4	88.1	74.4
2019/2020 harvest										
	May/19	Jun/19	Jul/19	Aug/19	Sept/19	Oct/19	Nov/19	Dec/19	Jan/20	Feb/20
Average - maximum temp. (°C)	15.2	16.7	12.7	14.0	15.9	19.0	20.4	23.1	22.8	22.2
Average - minimum temp. (°C)	14.6	15.8	11.8	12.9	14.8	18.0	19.3	21.7	21.8	20.9
Rainfall (mm)	70.4	69.2	44.0	97.2	72.8	258.6	158.6	37.4	144.6	67.4
Average - maximum RH (%)	91.9	80.1	80.5	76.6	77.8	79.7	77.8	64.9	75.5	73.3
Average - minimum RH (%)	89.5	76.0	87.5	76.3	72.8	75.0	72.7	58.6	69.9	67.6

Source: [INMET \(2020\)](#). Station A840 - Bento Gonçalves. Latitude: -29,16481. Longitude: -51,534202. Altitude: 623 m.

FRF PA 109.02, FRF PIR 079.06, ITA 10.133.02, ITA 13.079.02, ITA 13.097.05, ITA 12.190.02, ITA 10.107.12, ITA 10.107.07, ITA 10.107.06, ITA 12.103.06, ITA 12.103.12, ITA 12.103.22, and ITA 10.128.09. The trial used rootstock seedlings produced in a commercial nursery located in Farroupilha, RS, Brazil, from stolons collected in the field and rooted in 72-cell trays. With the exception of the cultivars Oso Grande, Camino Real, Merced, and Fronteras, for which cold storage seedlings made available by Bioagro® were used.

The experiment was conducted in the same system as last season, in suspended growing beds with substrate, but with plastic covering in the form of an umbrella. The seedlings were transplanted in June, in a randomized block design, with four repetitions and each experimental unit formed by 10 plants, using spacing of 0.15 m between plants and 0.30 m between rows.

The substrate was composed of 40% peat and 60% carbonized rice husk. Fertigation was localized, using 10 cm drippers, according to the commercial formulation specified in chart 7, incorporated in the irrigation water, keeping the electrical conductivity of the drainage from 1.2 to 1.5 mS cm⁻¹ and pH in the range of 5.5 to 6.5. The weed control was done with a manual brush cutter and the phytosanitary treatments were done according to the recommendations for the crop. The cleaning of the plants was done manually, as needed.

In both harvests, the experiment was accompanied and visually evaluated in a field report. In each of the flowerings, the fruits were collected with a predominance of 75% of the

red epidermis, and a sample of 10 uniform fruits was collected per plot. Afterwards, these fruits were packed and taken to Lages, SC, Brazil, at Universidade do Estado de Santa Catarina biotechnology laboratory, in styrofoam refrigerated boxes with ice. The samples were weighed on a semi-analytical balance and the estimated average mass per fruit was calculated.

The physical-chemical analyses were performed in samples of 10 fruits per repetition, for which the coloration of the fruit epidermis was analyzed with the aid of a Minolta digital colorimeter, through which the parameters of luminosity (L*), chroma (C*), and °hue (color angle) were evaluated; and pulp firmness, expressed in grams of force necessary to break the fruit epidermis, using a Texture Analyser TA.XT.plus texturometer (Stable Micro Systems Ltd, Vienna Court, UK). We also analyzed the soluble solids content, expressed by the concentration of sugars present in the fruits (°Brix) and quantified with the aid of a digital refractometer; the titratable acidity content, expressed by the content of citric acid present in the fruits, determined by means of an automatic titrator TITRONIC®, diluting 5 mL of juice in 45 mL of distilled water, followed by titration with a NaOH 0.1 M solution until pH 8.1, the SS/TA ratio, calculated by the ratio between the content of soluble solids and titratable acidity and the estimated average mass of commercial fruits by dividing the weight of the sample by the total number of fruits.

The data were analyzed separately for each of the harvests. Within each situation, the Shapiro-Wilk normality test was performed using R software ([R Core Team, 2013](#)) via

the Action Stat interface. However, for some variables, it was necessary to perform the transformations described below:

For the 2018/2019 harvest, titratable acidity data for the short day genotypes and flesh firmness and average commercial fruit mass data for the neutral day genotypes were transformed by the formula $Y = \sqrt{x + 0.5}$.

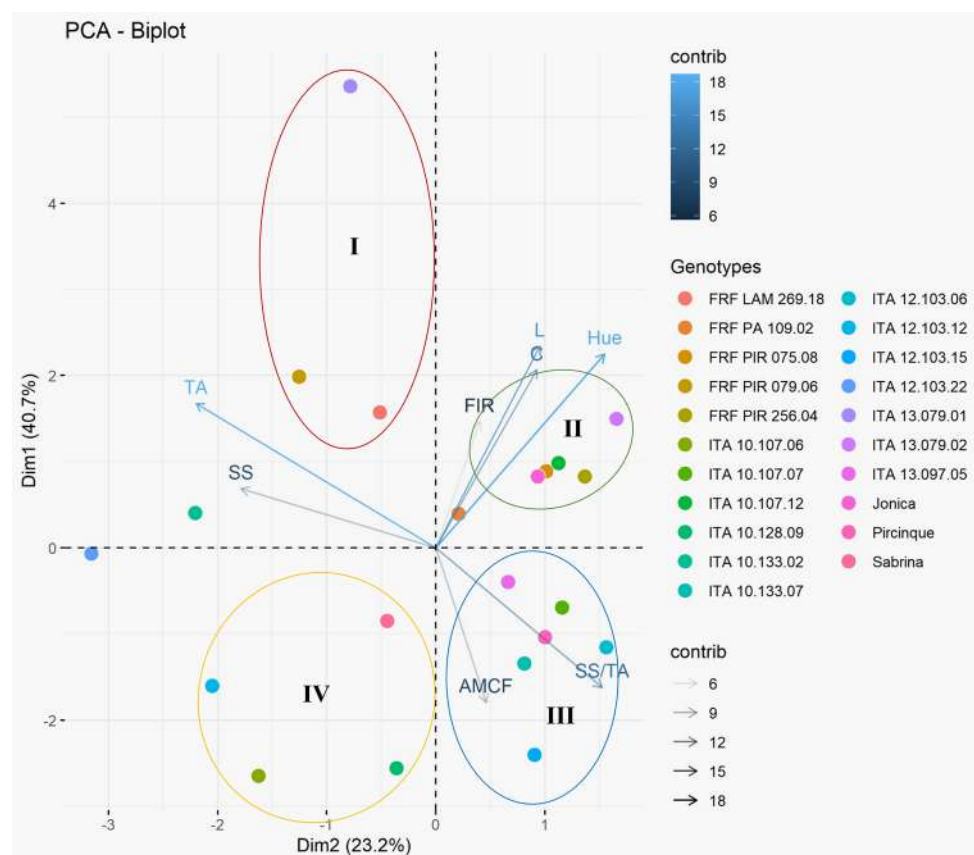
When normality conditions were met, the data were subjected to univariate and multivariate analysis. For the multivariate analysis we performed a Principal Component Analysis (PCA), which was used as the basis for interpretation and further discussion of the data, because it allows a better understanding of the distribution and composition of the treatments, as well as their interaction with the variables analyzed. The univariate analysis of variance and the comparison of means compared by the Scott Knott test at 5% error probability, were also performed, however, as a means to prove significant differences throughout the interpretations performed from the PCA. For univariate analysis the statistical software SISVAR (Ferreira, 2011) and for PCA the software Fitopac 2.1 (Shepherd, 2010) was used.

Results and Discussion

For the 2018/2019 harvest, the PCA for the short day genotypes resulted in the identification of mainly three groups (Figure 1).

Group I was composed of the genotypes FRF LAM 269.18, ITA 13.079.01, and FRF PIR 079.06, which showed a positive correlation with the SS variable, the latter showing the highest value among them (Table 2). However, it was not enough to reach high values of SS/TA ratio, due to its high positive correlation, also with the titratable acidity vector, for which it reached levels close to the maximum limit of $0.8 \text{ g } 100\text{g}^{-1}$ of citric acid, for strawberry fruits, considered by Chitarra & Chitarra (2005). It is also worth noting that in addition to the influences cited above, the genotype ITA 13.079.01, in particular, correlated strongly with the coloration attributes, a factor that most strongly influenced its disposition in the PCA. This is due to the high luminosity and chroma values of the epidermis seen in the fruits of this genotype, resulting in a high hue angle as well, tending toward a lighter red coloration, but with high brightness and color purity (Castricini et al., 2017).

The positive correlation that occurred between the genotypes ITA 13.079.01 and PIR 079.06 and the SS variable vector, is due to the fact that these genotypes produced fruits with higher concentration of soluble sugars, on average, 22.9% higher than the overall average obtained (Table 2). It was found that these genotypes, in the present harvest exceeded the sugar concentration of the cultivars under study (Pirquinque, Jonica, and Sabrina), selected and known for the sweetness of their fruits (Faedi et al., 2014; Morello, 2014;



L - epidermis luminosity; C - epidermis chroma; Hue - epidermis Hue angle; SS - soluble solids; TA - titratable acidity; SS/TA - soluble solids/titratable acidity ratio; FIR - pulp firmness; AMCF - average mass of commercial fruits.

Figure 1. Principal component analysis for the short day genotypes and parameters studied in the fruit quality trial, in the 2018/2019 harvest in the municipality of Farroupilha, RS, Brazil. Lages, SC, Brazil, Udesc, 2021.

Table 2. Average mass of commercial fruits (AMCF) (g fruit⁻¹), fruit pulp firmness (FIR) (g fruit⁻¹), epidermis luminosity (L*), epidermis chroma (C*), hue angle (°Hue), soluble solids (SS) (°Brix), titratable acidity (TA) (g 100g⁻¹ of citric acid), and soluble solids/titratable acidity ratio (SS/TA), of short and neutral day strawberry cultivars and advanced genotypes. Lages, SC, Brazil, Udesc, 2020.

2018/2019 harvest								
Genotype	AMCF	FIR	L*	C*	°Hue	SS	TA	SS/TA
Short day								
Jonica	20.76 c	140.50 c*	35.90 c*	44.08 d	31.03 e	6.3 c	0.55 b	11.32 c
Pircinque	29.72 a	141.57 c	34.98 c	42.29 e	30.05 e	6.9 b	0.52 b	13.17 b
Sabrina	25.74 b	148.37 c	31.77 f	42.49 e	27.84 c	6.6 c	0.61 c	10.75 c
FRF LAM 269.18	24.50 b	219.90 a	35.03 c	42.62 e	29.53 e	6.2 c	0.74 d	8.25 d
FRF PIR 075.08	27.98 a	160.07 b	36.89 b	44.55 d	30.39 e	5.4 d	0.63 c	8.60 d
FRF PIR 256.04	20.65 c	137.00 c	34.28 d	46.44 b	32.12 f	6.4 c	0.52 b	12.17 b
FRF PA 109.02	23.93 b	122.62 d	37.04 b	43.69 d	28.53 d	6.5 c	0.61 c	10.72 c
FRF PIR 079.06	19.86 c	152.55 b	36.70 b	44.31 d	29.81 e	8.0 a	0.74 d	10.75 c
ITA 10.133.02	24.18 b	163.65 b	33.03 e	41.57 f	27.32 c	7.4 b	0.80 d	9.22 d
ITA 10.133.07	25.95 b	161.37 b	34.32 d	42.53 e	26.77 c	7.2 b	0.48 a	14.97 a
ITA 13.079.01	19.12 c	137.92 c	40.93 a	51.64 a	34.59 g	8.2 a	0.90 e	9.05 d
ITA 13.079.02	20.79 c	167.70 b	36.57 b	45.28 c	33.07 f	6.6 c	0.52 b	12.45 b
ITA 13.097.05	21.77 c	136.75 c	35.80 c	41.63 f	28.47 d	6.6 c	0.51 b	12.77 b
ITA 10.107.12	18.83 c	164.87 b	36.34 b	41.60 f	32.04 f	6.2 c	0.53 b	11.67 c
ITA 10.107.07	28.30 a	101.45 d	35.53 c	46.29 b	28.56 d	6.5 c	0.52 b	12.42 b
ITA 10.107.06	26.29 b	106.47 d	30.42 g	39.53 h	24.32 b	7.2 b	0.61 c	11.90 c
ITA 12.103.06	24.67 b	144.07 c	32.93 e	43.91 d	28.68 d	5.9 d	0.45 a	13.10 b
ITA 12.103.12	22.59 c	109.87 d	31.77 f	41.66 f	22.44 a	7.2 b	0.65 c	10.92 c
ITA 12.103.15	27.50 a	91.50 d	32.07 f	43.22 d	26.84 c	5.9 d	0.47 a	12.67 b
ITA 12.103.22	21.31 c	115.75 d	32.39 f	40.98 g	25.06 b	7.2 b	0.85 e	8.45 d
ITA 10.128.09	26.21 b	97.40 d	33.61 e	41.12 g	23.87 b	7.3 b	0.51 b	14.22 a
Overall average	23.84	139.11	34.66	43.40	28.63	6.7	0.61	11.40
CV (%)	11.10	8.54	2.19	1.71	2.74	6.04	2.02**	8.87

* Means followed by the same letter in the column do not differ by the Scott-Knott test ($p \geq 0.05$).

** Data transformed by the formula $Y = \sqrt{x + 0.5}$.

[Ahmadi et al., 2017](#); [Fagherazzi et al., 2017](#)). Fruit sweetness is a fundamental characteristic in the marketing of the fruit, because it is attributed by the consumer as a positive characteristic to strawberry flavor, thus being a parameter of great relevance in the launch of new cultivars ([Richter, 2018](#)).

Sugar content in fruit, besides being a genetic trait can be largely influenced by plant management and climatic conditions ([Costa et al., 2019](#)). These lower SS values obtained in the present study, may be related to the number of cloudy and rainy days that occurred mainly during the months of September, October, and November in the 2018/2019 harvest and to an excess of irrigation and nitrogen fertilization, performed by the producer, which resulted in good sized fruits. However, these became more “watery”, with less flavor and consequently less pulp firmness, as shown earlier. Lower sun exposure, brings damage to net photosynthesis of plants, consequently decreasing the accumulation of sugars and directly reflecting in lower sweetness in the fruit ([Taiz et al., 2017](#)).

The genotype FRF LAM 269.18, on the other hand, despite also belonging to group I, showed less influence of the SS and coloration vector, unlike the other genotypes belonging to this group. However, it correlated positively with the TA vector, as did the others, but with greater influence from the pulp firmness vector. It also produced large fruits, with considerable fresh mass, also influenced by the AMCF vector. The genotype

FRF LAM 269.18, showed the highest pulp firmness among the genotypes, with its fruits being 58.1% firmer than the general average obtained. [Cocco et al. \(2017\)](#), studying the agronomic performance of different Italian genotypes, also in the municipality of Farroupilha, SC, Brazil, found a high firmness value for the genotype FRF LAM 269.18, of 544.0 g of strength, an average higher than the one found in this study. In a study conducted by [Zanin et al. \(2019\)](#), in the municipality of Lages, SC, Brazil, a high value of firmness was also verified for this genotype, of 5.67 N, corresponding to 578.18 g of strength, however, without differing from the other genotypes tested by them. Still, the value was higher than that found in the present study ([Table 2](#)). The maintenance of fruit firmness is an important quality parameter, since it is directly related to texture aspects and postharvest conservation ([Chitarra & Chitarra, 2005](#)).

Different factors can influence the firmness of strawberry fruit, from genetic and management characteristics, factors that can be controlled, to environmental factors ([Zanin, 2019](#)), which is beyond the grower control, or the method of analysis used. A possible explanation for the difference in pulp firmness of the genotype FRF LAM 269.18 compared to the cited studies, may be the environment and climatic conditions in the different agricultural cycles. An example of this is the study conducted by [Cocco et al. \(2017\)](#), also in the municipality of Farroupilha, who evaluated the fruit only in

the month of November, when there is still no occurrence of very high temperatures on most days. In the present study four analyses were performed, one in December and another at the end of the cycle in January, when temperatures are already higher ([Table 1](#)), using the average of these four analyses to arrive at the final value, which may have resulted in a lower final firmness of these fruits. High temperatures shorten the interval between flower fertilization and fruit maturation, resulting in a lower rate of cell division. With that, when the fruit grows in size, it increases the cell content, which can dilute the calcium content inside the cells, decreasing the strength of the cell wall and consequently the fruit epidermis ([Taiz et al., 2017](#)).

It is also worth noting the strong influence of acidity on the fruit flavor of these genotypes, briefly highlighted earlier, which resulted in a reduction in the average value of the SS/TA ratio not only for the genotypes LAM 269.18, ITA 13.079.01, and PIR 079.06, but all the genotypes studied, since the contents of soluble solids were not very high in this harvest. Titratable acidity represents the concentration of organic acids present in the fruit, which when in balance (SS/TA ratio), represents an important quality attribute, since many of these, being volatile also confer aroma to the fruit ([Farnezi et al., 2020](#)).

In group II remained allocated the genotypes ITA 13.079.02, ITA 10.107.12, FRF PIR 256.04, FRF PIR 075.08, and Jonica, which correlated mainly with the qualitative variables of coloration (brightness, chroma, and hue angle). This clear separation from the other genotypes, in this harvest, is due to the fruits of these genotypes having presented a lighter, orange color, which is not a very desirable characteristic in the consumer market, since they correlate the coloration to the flavor of the fruit ([Zanin, 2019](#)). This was not confirmed for the genotype ITA 13.079.01 that despite having the highest soluble solids content among the short day old genotypes tested, was also strongly and positively correlated with the color attributes, with the fruits being more orange, as previously mentioned, despite producing fruits with higher sugar content, showing the need for further studies to prove its characteristics in different locations and environmental conditions.

The genotypes ITA 12.103.12, ITA 10.107.06, and ITA 10.128.09 and the cultivar Sabrina composed the group number IV, which were responsible for the production of fruits with more intense red coloration, which explains the opposite disposition of these genotypes to the color vectors, showing a negative correlation with them. The more intense red tone in the epidermis of the fruits is related to the content of anthocyanins, which the higher their concentration, the lower the hue angle of the fruits tends to be, that is, the red coloration becomes more intense, and the content of anthocyanins in the fruits varies according to the genotype. Anthocyanins are directly linked to the nutraceutical quality of strawberries, as they are functional compounds, responsible for the antioxidant property contained in the fruit and adding value to strawberry consumption ([Kovačević et al., 2015](#)). However, it is worth noting that in addition to the correlation

described above, they suffered influence from other vectors, as is the case of the genotypes ITA 10.107.06, ITA 10.128.09, and the cultivar Sabrina that correlated positively, also with the AMCF vector and the genotype ITA 12.103.12 that suffered influence from the SS vector.

Group III was formed by the genotypes ITA 12.103.06, ITA 12.103.15, ITA 10.133.07, ITA 10.107.07, ITA 13.097.05, and the cultivar Pircinque, this group being more closely related to the average mass of commercial fruits, due to most of them producing fruits with larger size. The average fruit mass variable is very important in strawberry marketing, since it is directly related to the size of the fruit ([Farnezi et al., 2020](#)), so the higher the average mass, the greater the tendency of that fruit to have a high size as well.

However, the largest fruits, with the highest average mass achieved, were observed in the cultivar Pircinque, but with an average mass very similar to the fruits of the genotypes ITA 10.107.07, FRF PIR 075.08, and ITA 12.103.15. This high average fruit mass of the Pircinque cultivar corroborates with that found by [Fagherazzi et al. \(2012\)](#), who verified a value very close to that found in this study, of 30.6 g fruit⁻¹. The genotype ITA 10.107.07 that showed the second highest average mass, was selected in Brazil, coming from a cross, in which one of its genitors is the cultivar Pircinque ([Zanin, 2019](#)), which explains this good performance in fruit size and quality, visibly inherited from it. The cultivar Pircinque was selected for southern Italy due to the good adaptability demonstrated in that region, a result of its low cold requirement ([Fagherazzi et al., 2012](#)), which allowed the good adaptability of this cultivar also in Brazilian regions, with high fruit quality ([Fagherazzi, 2017](#)). It is worth noting that although the genotype FRF PIR 075.08 stood out in terms of the average mass of its commercial fruits, it suffered greater influence of the color variables, causing it to remain allocated closer to the vectors of these variables, in relation to the vector of the AMCF variable.

It is also worth noting that the genotypes ITA 10.128.09, ITA 12.103.06, ITA 12.103.15, ITA 10.133.07, ITA 10.107.07, ITA 13.097.05, ITA 13.079.02, FRF PIR 256.04, and Pircinque were also strongly influenced by the SS/TA ratio vector, being responsible for producing fruits with better flavor balance, with SS/TA ratio well above the minimum expected value, which is 8.75 for strawberry fruits ([Chitarra & Chitarra, 2005](#)).

However, among the aforementioned genotypes, the fruits with the lowest titratable acidity contents were produced by the genotypes ITA 12.103.06, ITA 12.103.15, and ITA 10.133.07. [Zanin \(2019\)](#) found similar acidity values for genotype ITA 12.103.15, with 0.44 g 100g⁻¹ of citric acid, however for genotype ITA 12.103.06, the author found higher values with 0.56 g 100g⁻¹ of citric acid. In field analyses, the fruits of the genotype ITA 10.133.07 always presented excellent flavor, with balanced acidity and excellent sweetness, as we can see in laboratory analyses. Because it is a genotype resulting from the crossing of the cultivars Pircinque and Primoris, which have fruits with high flavor and sweetness ([Medina et al., 2014](#)), more balanced acidity contents were expected for this genotype.

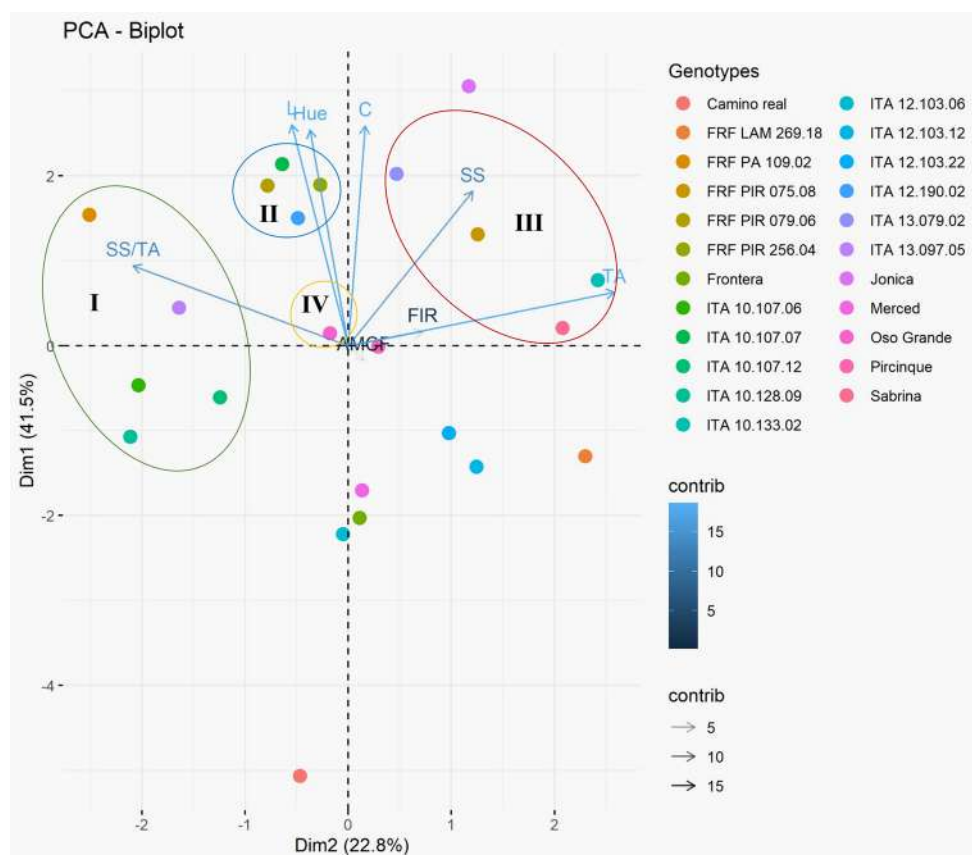
It is also worth mentioning that it was also in the genotype ITA 10.133.07 that the highest soluble solids/titratable acidity (SS/TA) ratio was verified, very similar to that also found for the genotype ITA 10.128.09, producing both, on average, fruits 27.9% sweeter than the general average, since the SS/TA ratio allows us to evaluate the flavor of the fruits (Backes et al., 2020). The genotype ITA 10.133.07 comes from a cross between two Italian cultivars, one of them being Pircinque, as previously described, which, despite not showing high SS/TA ratio values in this vintage, is widely known for the flavor and sweetness of its fruits (Faedi et al., 2014; Fagherazzi et al., 2017), a characteristic visibly inherited by this genotype. Zanin (2019) in a new genotype selection study also obtained high SS/TA ratio values for genotype ITA 10.128.09, with 14.33, very close to that found in the present study. We can see in this case the importance of quantifying not only the sugar content of a fruit, but also its acidity content, a parameter that influenced to a greater extent the SS/TA ratio of most genotypes, as we can see through the strength of the titratable acidity vector in the principal components analysis performed (Figure 1).

In the second cycle of cultivation 2019/2020, we had the insertion of new cultivars for comparison and also of genotypes, as well as the exclusion of some as is common in trials carried out within genetic improvement programs, when genotypes, already in an advanced stage, do not demonstrate sufficient positive characteristics to continue in the study.

In this harvest, by performing principal component analysis (Figure 2), we obtained the identification of mainly three groups for the short day genotypes.

Group I was formed by the genotypes FRF PA 109.02, ITA 10.107.06, ITA 10.128.09, ITA 10.107.12, and ITA 13.097.05. These genotypes correlated positively with the SS/TA ratio variable, a very important attribute for determining fruit flavor, since it corresponds to the balance between acidity levels and sugar concentration, thus the higher the SS/TA ratio, the greater their acceptance (Farnezi et al., 2020). These genotypes, then, present the fruits with the highest sensory quality and flavor balance.

It is worth noting then that the tastiest fruits, with the highest SS/TA ratio among the genotypes tested, were produced by the genotype ITA 10.128.09. However, the genotypes ITA 10.107.06, FRF PA 109.02, and ITA 10.107.12, also stood out regarding this parameter, having a variation of 6.54% among them (Table 3). It is worth noting that the genotype ITA 10.128.09 had already stood out regarding the SS/TA ratio in the previous harvest, demonstrating a good capacity to adapt to the study site. When fruit quality is evaluated, the SS/TA ratio is one of the most important ways to determine fruit flavor, being more representative than the isolated measurements of soluble solids and acidity, because it shows the balance between these two factors, necessary to have fruits with high flavor (Backes et al., 2020).



L - epidermis luminosity; C - epidermis chroma; Hue - epidermis Hue angle; SS - soluble solids; TA - titratable acidity; SS/TA - soluble solids/titratable acidity ratio; FIR - pulp firmness; AMCF - average mass of commercial fruits.

Figure 2. Principal component analysis for the short day genotypes and parameters studied in the fruit quality trial, in the 2019/2020 harvest in the municipality of Farroupilha, RS. Lages, SC, Brazil, Udesc, 2021.

Table 3. Average mass of commercial fruits (AMCF) (g fruit⁻¹), fruit pulp firmness (FIR) (g fruit⁻¹), epidermis luminosity (L*), epidermis chroma (C*), hue angle (°Hue), soluble solids (SS) (°Brix), titratable acidity (TA) (g 100g⁻¹ of citric acid), soluble solids/titratable acidity ratio (SS/TA), of cultivars and advanced short day strawberry genotypes. Lages, SC, Brazil, Udesc, 2021.

2019/2020 harvest								
Genotype	AMCF	FIR	L*	C*	°Hue	SS	TA	SS/TA
Short day								
Jonica	19.69 c	139.82 e*	40.11 a	47.62 a	34.37 e	6.5 a	0.61 d	10.60 b
Pircinque	27.42 a	236.92 a	36.61 e	43.23 c	31.34 c	5.6 c	0.50 b	11.20 b
Camino real	19.64 c	134.77 f	31.39 g	35.45 e	26.27 a	4.4 d	0.45 a	9.60 c
Oso Grande	19.42 c	130.05 f	37.34 d	44.37 b	33.08 d	5.0 d	0.51 b	9.70 c
Merced	18.14 d	185.15 c	35.29 f	40.51 d	28.73 b	5.3 c	0.50 b	10.52 b
Fronteras	26.80 a	114.25 g	35.29 f	40.87 d	30.37 c	4.7 d	0.51 b	9.20 c
Sabrina	21.19 c	204.17 b	37.11 d	44.73 b	31.75 d	5.4 c	0.61 d	8.87 c
FRF LAM 269.18	23.40 b	146.27 e	34.96 f	42.32 c	29.12 d	5.6 c	0.63 d	8.85 c
FRF PIR 075.08	20.92 c	191.72 b	37.92 c	45.77 b	32.71 d	5.9 b	0.58 c	10.20 c
FRF PIR 256.04	23.09 b	110.32 g	38.94 b	47.03 a	33.41 e	5.9 b	0.53 b	11.10 b
FRF PA 109.02	25.57 a	156.27 d	40.02 a	46.58 a	34.17 e	4.9 d	0.40 a	12.22 a
FRF PIR 079.06	19.78 c	158.45 d	39.84 a	47.03 a	33.42 e	5.5 c	0.49 b	11.25 b
ITA 10.133.02	20.44 c	163.10 d	37.12 d	45.38 b	30.77 c	6.2 a	0.65 d	9.52 c
ITA 13.079.02	18.48 d	175.97 c	39.42 a	45.39 b	33.63 e	6.1 b	0.55 c	10.85 b
ITA 13.097.05	20.38 c	171.10 c	38.81 b	45.77 b	32.75 d	4.6 d	0.42 a	10.80 b
ITA 12.190.02	20.23 c	120.90 g	39.97 a	45.84 b	33.90 e	5.3 c	0.51 b	10.22 c
ITA 10.107.12	21.06 c	159.35 d	36.67 e	42.28 c	29.99 c	5.4 c	0.45 a	11.92 a
ITA 10.107.07	18.14 d	145.42 e	39.19 b	48.28 a	33.86 e	5.6 c	0.50 b	11.15 b
ITA 10.107.06	17.95 d	129.60 f	36.48 e	41.17 d	30.93 c	5.5 c	0.43 a	12.65 a
ITA 12.103.06	20.21 c	152.80 d	34.92 f	42.15 c	30.06 c	4.3 d	0.48 b	8.85 c
ITA 12.103.12	17.87 d	182.02 c	34.25 f	43.06 c	29.43 b	5.4 c	0.53 b	9.10 c
ITA 12.103.22	24.81 b	125.72 f	35.08 f	42.64 c	30.03 c	5.4 c	0.59 c	10.15 c
ITA 10.128.09	20.14 c	147.15 e	35.97 e	41.60 d	29.32 b	5.3 c	0.41 a	12.70 a
Overall average	21.08	155.71	37.07	43.87	31.45	5.4	0.51	10.48
CV (%)	6.66	7.19	1.64	2.12	3.04	6.01	6.10	8.84

* Means followed by the same letter in the column do not differ by the Scott-Knott test ($p \geq 0.05$).

In group II remained allocated the genotypes FRF PIR 256.04, ITA 10.107.07, ITA 12.190.02, and PIR 079.06, which correlated positively with the fruit color vectors. This result is due to the fact that most of these genotypes have presented the highest hue angle values, not tending towards dark red, but with a bright red coloration and high color saturation, resulting in fruits of high visual quality.

Therefore, in relation to these colorimetric characteristics of the fruits, the highest epidermis luminosities were obtained by the genotypes Jonica, FRF PA 109.02, FRF PIR 079.06, and ITA 12.190.02, which configured lighter fruits, however with a very vivid coloration, with high saturation, due to the high chroma contents also observed in most of these genotypes. The chroma was higher in the fruits of genotypes Jonica, FRF PIR 256.04, FRF PA 109.02, FRF PIR 079.06, and ITA 10.107.07, showing higher color purity. The distinct patterns of fruit coloration is an intrinsic characteristic of the genotype, i.e., a genetic response, and may in certain agricultural cycles be influenced by climatic and cultural factors (Castricini et al., 2017). It is worth noting that although the genotype FRF PA 109.02, presents high luminosity and chroma in its fruits, this genotype suffered greater influence from the SS/TA ratio vector, remaining allocated near the vector of this variable, thus composing group I.

In group III, the genotypes ITA 10.133.02, ITA 13.079.02, FRF PIR 075.08, and Jonica were allocated, which correlated

positively to the SS vector, producing the fruits with the highest sugar contents. However, they also obtained a positive correlation with the titratable acidity vector, resulting in fruit with lower SS/TA ratios. Among them, the Jonica cultivar and the genotype ITA 10.133.02, obtained the highest sugar contents in their fruits, on average 17.6% higher than the general average obtained (Table 3). Jonica is an Italian cultivar, known for having high sugar content in its fruit (Morello, 2014). The genotype ITA 10.133.02, as well as the genotype ITA 10.133.07, which stood out in sweetness in the previous cycle, has as one of its genitors the cultivar Primoris, which also has high levels of soluble solids in its fruits (Medina et al., 2014). This characteristic is inherited by both materials, but visibly affected by the genotype factor. It is important to note that the genotype ITA 10.133.07, is not present in this harvest in question, due to a problem with seedling multiplication, and it is necessary to reevaluate the response of this genotype in more growing cycles, in this and other locations.

In this harvest cycle (2019/2020), the genotypes in general, showed low soluble solids contents if observed the previous harvest (2018/2019). A factor that may have influenced this context, may have been the change of the installation site of the experiment, within the producer property, which was installed in a greenhouse very close to large trees, which made the environment more shaded during periods of the day. When there is less sunlight on the fruit, there is a decrease in

the accumulation of sugars in the tissues, a consequence of less intensity in the photosynthetic process, which ultimately compromises the sweetness of the fruit (Taiz et al., 2017).

What also drew attention in this study is that genotypes that usually present high contents of soluble solids such as the cultivars Pircinque and Sabrina, presented relatively low contents in both harvests when compared to other studies already conducted with them (Faedi et al., 2014; Ahmadi et al., 2017; Richter, 2018; Zanin, 2019). This makes clear the influence of the phenotype factor and also the management factor in the expression of the characteristics of each genotype.

It is worth noting that acidity contents were lower in the fruit of the genotypes Camino Real, FRF PA 109.02, ITA 13.097.05, ITA 10.107.12, ITA 10.107.06, and ITA 10.128.09, on average, 21.42% lower than the average obtained from all genotypes (Table 3). The titratable acidity parameter is an indication of the amount of organic acids present in the fruit, which when in balance with the sugar contents, confers flavor and makes it an important quality attribute (Farnezi et al., 2020). This low titratable acidity value, for some of the genotypes mentioned above, resulted in a higher SS/TA ratio, when compared to the other genotypes studied, as previously described.

Again in this cycle, the greatest influence on SS/TA ratio values was by acidity contents in the fruit, since sugar contents were relatively low overall. There are reports in the literature that the acidity content in the fruit throughout the harvest can change due to the increase in temperature and sun exposure, especially in summer, causing the internal temperature of the fruit to increase by up to 8 °C compared to the air temperature, increasing acidity levels for certain materials that tend to suffer more from high temperatures (Taghavi et al., 2019).

Group IV was formed only by the Pircinque cultivar, which, among all the genotypes, presented the best balance among all the qualitative characteristics evaluated, improving its quality in relation to the previous harvest. However, it suffered more positive influence from the firmness and AMCF vectors. It is worth noting that as well as the cultivar Pircinque also suffered a positive and moderate influence of the SS/TA vector. The genotype FRF PA 109.02 and the Sabrina cultivar were also influenced by the vector of the AMCF ratio variable, but did not remain close to this vector due to other variables influencing these genotypes more strongly.

It is also worth noting that although the average mass values found are not so high for these genotypes in general, the ability to produce fruits of excellent size by some of these genotypes has already been reported in the literature (Fagherazzi et al., 2012; Faedi et al., 2014; Cocco et al., 2017, 2020). We can also point out that the cultivars Pircinque and Sabrina had already correlated to this variable in the last harvest, maintaining, even under different climatic and handling conditions, the size of their fruits. Fruits of larger size are desired by producers to the detriment of an exacerbated number of fruits of smaller size, since, it facilitates the harvest, has better market acceptance and unburdens the production (Farnezi et al., 2020).

The cultivar Pircinque also stood out regarding the firmness of its fruits, differing from the other genotypes evaluated, with fruits 52.15% firmer than the general average firmness obtained (Table 3), surpassing the firmness obtained in the previous harvest. Fagherazzi et al. (2017) found a pulp firmness value of 373 g, which was even higher than the value obtained in this study. One of the attributes for which the Italian cultivar Pircinque was introduced in Brazil and gained consumer preference is the high firmness of its fruit (Fagherazzi et al. 2012), when compared to commercial cultivars, which was evident in this study.

Pulp firmness is a characteristic of great relevance in maintaining fruit quality, along with sugar content, acidity, and the SS/TA ratio, since fruit strength, determined by the pressure force that the fruit supports, increases shelf life, a very important factor in in natura commercialization, besides enabling transportation over long distances to distribution centers (Fagherazzi et al., 2012). Besides this, the firmness of the fruits may suffer variation according to the management adopted by the producer in the different agricultural cycles. An example of this is the Pircinque cultivar itself, which in the previous cycle did not show its characteristic firmness of pulp, which may have occurred due to excessive nitrogen fertilization used by the producer. Excess nitrogen can cause overgrowth of the vegetative part of the plants, leading to competition between fruits and leaves for calcium, thus decreasing the concentration of this nutrient in the fruits, due to the greater drainage strength of the leaves (Taiz et al., 2017).

The fruits of Pircinque also, presented the highest average mass among the genotypes, which was visible by its proximity to the AMCF vector, which had already occurred in the 2018/2019 harvest, however, with fruit mass very similar to that obtained by the genotype FRF PA 109.02, surpassing the average mass obtained by the fruits of the American commercial cultivars used as a comparison. This result is opposite to that verified by Zanin et al. (2019), who obtained an average mass for the fruits of Pircinque and genotype FRF PA 109.02 of 20.81 and 20.66 g fruit⁻¹, respectively, not surpassing the average values obtained by the commercial cultivars used as comparison in the study by the authors. In visual and tactile evaluations carried out in the field, during the production cycle, both genotypes have always demonstrated an expressive quality of their fruits, which is now proven by laboratory analyses.

Fruit fresh mass is a very relevant characteristic in commercial strawberry production, since it is directly related to the size of the fruit, as previously pointed out. Large fruits tend to facilitate harvesting and packing, optimizing labor, besides having a higher market valuation, increasing the producer earnings (Farnezi et al., 2020). In the 2019/2020 crop cycle, the growing site and umbrella-shaped cover enabled the plants to maintain temperature compared to the low tunnels used in the previous cycle, which promoted the production of larger and better quality fruit by the plants (Gonçalves et al., 2016).

Conclusions

Under the environmental conditions of the study, the cultivar Pircinque and the genotype FRF PIR 075.08 produce fruits with good firmness and high visual quality.

The Jonica cultivar, and the genotypes FRF PIR 256.04, FRF PIR 075.08, ITA 10.107.07 FRF PIR 079.06, and ITA 13.079.02 produce fruits with high visual quality, with more balanced red coloration, high brightness and high color saturation.

The genotypes Pircinque and ITA 10.128.09 maintained good fruit flavor in both harvests, with high SS/TA ratio averages, making them promising for the consumer market.

Among the genotypes evaluated for the Farroupilha region, SC, Brazil, the genotypes FRF PIR 075.08 and ITA 10.128.09 have the greatest potential to become cultivars and, together with the Pircinque cultivar, may be recommended for cultivation in the Serra Gaúcha region.

Compliance with Ethical Standards

Author contributions: Conceptualization: PDW, AAK, LR; Data curation: PDW, MFSS, DPR, LR; Formal analysis: PDW, MFSS, DPR; Investigation: PDW, JML, MFSS; Methodology: PDW, JML, MFSS; Project administration: AAK, LR; Resources: AAK, LR; Supervision: AAK, LR; Validation: AAK, LR, DPR; Visualization: AAK, LR, PDW; Writing - original draft: PDW, DPR; Writing - review and editing: AAK, LR, DPR.

Conflicts of interest: The authors declare that there are no conflicts of interest between the parties.

Financing source: The Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - Finance Code 001.

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Productive and qualitative characteristics of strawberry genotypes in the Plateau of the State of Santa Catarina, Brazil

Características produtivas e qualitativas de genótipos de morangueiro no Planalto Catarinense

Daniel Suek Zanin^{1*}, Juliana Martins de Lima², Marllon Fernando Soares dos Santos², Katiana Vanusa Tillwitz², Antonio Felipe Fagherazzi², Adrik Francis Richter², Aike Anneliese Kretzschmar², Leo Rufato²

¹Universidade Estadual de Londrina, Londrina, PR, Brasil. *Author for correspondence: dsuekzanin@gmail.com

²Universidade do Estado de Santa Catarina, Lages, SC, Brasil.

Submission: 08/08/2019 | Acceptance: 06/03/2020

ABSTRACT

To produce strawberries on a commercial scale, it is necessary to choose the cultivars best adapted to the growing site. This work aimed to compare strawberry genotypes regarding production and fruit quality, in the municipality of Lages, State of Santa Catarina, Brazil, during the 2017/2018 harvest season. In this work, 15 genotypes were evaluated, five commercial cultivars and ten advanced selections. The experimental design was in randomized blocks, with four replicates and plots of 11 plants. The cultivation system used was in the soil of an open field, in beds of approximately 90 centimeters, with three rows per bed. Planting distance was of 30 centimeters between rows and plants. The Sabrina cultivar showed the highest production (1,231.77 g plant⁻¹) and number of fruits (78.48 fruits plant⁻¹). The highest quality fruits were obtained from the selections FRF PIR 256.4, FRF 104.1, FRF 57.6, FRF LAM 119.1 and cultivar Pircinque, characterized by soluble solids/titratable acidity ratios above 15. In the productive cycle in question, cultivar Sabrina presented the best performance, demonstrating the potential for recommendation to the producers of the South Plateau of State of Santa Catarina.

KEYWORDS: *Fragaria x ananassa* Duch, adaptation, advanced genotypes, soil cultivation.

RESUMO

Para produzir morangos em escala comercial, é necessário escolher as cultivares melhor adaptadas ao local de cultivo. Objetivou-se com este trabalho confrontar genótipos de morangueiro quanto a aspectos de produção e qualidade de frutos, no município de Lages, em Santa Catarina, no ciclo agrícola 2017/2018. Foram avaliados 15 genótipos, sendo cinco cultivares comerciais e dez seleções avançadas. O delineamento experimental utilizado foi em blocos casualizados, com quatro repetições, e parcelas constituídas por 11 plantas. O sistema de cultivo utilizado foi no solo, em campo aberto, em canteiros com aproximadamente 90 centímetros de largura, com três linhas de plantio por canteiro. A distância de plantio foi de 30 centímetros, entre fileiras e plantas. A cultivar Sabrina obteve a maior produção (1.231,77 g planta⁻¹) e número de frutos (78,48 frutos planta⁻¹). Com as seleções FRF PIR 256.4, FRF 104.1, FRF 57.6, FRF LAM 119.1 e a cultivar Pircinque se obtiveram os frutos de qualidade superior, caracterizados por médias acima de 15 para a relação sólidos solúveis / acidez titulável. No ciclo produtivo em questão, a cultivar Sabrina apresentou o melhor desempenho, demonstrando potencial para ser recomendada aos produtores da região do Planalto Sul Catarinense.

PALAVRAS-CHAVE: *Fragaria x ananassa* Duch, adaptação, genótipos avançados, cultivo no solo.

INTRODUCTION

Strawberry (*Fragaria x ananassa* Duch) is the most important socioeconomic species within the berries group at a global level, with 395,844 hectares harvested in 2017, followed by raspberries (118,219 ha) and blueberries (109,541 ha) (FAO 2019). According to the Food and Agriculture Organization, in 2017, the major strawberry-producing countries were China (3,717,283 t); the United States of America (1,449,280 t); Mexico (658,436 t); Egypt (407,240 t), and Turkey (400,167 t).

In the 2015/2016 harvest season, Brazil produced 155,440 t of strawberries in approximately 4,300 ha, resulting in a yield of 36.15 t ha⁻¹ distributed between the states of Minas Gerais (74,000 t), Paraná (21,450

t), Rio Grande do Sul (20,350 t), São Paulo (9,900 t), and Santa Catarina (9,900 t) (FAGHERAZZI et al. 2017a). This culture demands intensive management and high investment in inputs and infrastructure. Although it allows a good financial return, strawberry cultivation can be a risky activity, especially when carried out in areas inferior to one hectare (RONQUE et al. 2013).

One of the determinants of success in strawberry production is the choice of correct cultivar, considering that interactions between genotypes and environments may occur (COSTA et al. 2016). The adaptability of a strawberry cultivar is defined mainly by the following factors: temperature, photoperiod, and the interaction between them. These factors control the beginning and end of the productive phase since flowering and fruiting only occur under certain temperature and photoperiod ranges, which vary for each cultivar (HONJO et al. 2016). Cultivar selection also interferes in all aspects of the productive chain, such as planting season, use of correctives and fertilizers, spacing adequacy, harvesting point, and shelf life (FAGHERAZZI 2017).

The strawberry cultivars used in Brazil originate mostly from the United States, especially from breeding programs developed in the universities of California and Florida. To a lesser extent, there are also cultivars originated of Spanish breeding programs. Import is done by companies that buy seedlings from Chilean and Argentine nurseries (ANTUNES & PERES 2013). Under Brazilian conditions, these cultivars do not always express their maximum yield potential and fruit quality and are often very susceptible to phytosanitary issues (OLIVEIRA & BONOW 2012).

Furthermore, some cultivars are introduced in Brazilian territory without previous studies on their adaptability, which may result in losses to farmers (PÁDUA et al. 2015). This happens because, the strawberry culture is affected by the natural conditions of the production site, and the cultivars tend to present the maximum productive performance only in conditions similar to where they were developed (HANCOCK et al. 2008). Thus, germplasm is a tool used to increase the number of cultivars available to producers, improving the chances of obtaining genotypes adapted to the different producing regions (FAGHERAZZI et al. 2017b).

In this sense, in 2012, the Universidade do Estado de Santa Catarina (UDESC) has established a cooperation agreement with the institution 'Consiglio per la Ricerca in Agricoltura e L'Analisi Dell'Economia Agraria - Centro di Ricerca Olivicoltura, Frutticoltura e Agrumicoltura' (CREA-OFA-FRF) from Italy, to perform adaptability studies with Italian genotypes under Brazilian conditions (FAGHERAZZI 2013). These genotypes are evaluated by several productive cycles at different locations to confirm or discard their potential for commercial use. Through this project, in 2016, two strawberry cultivars were made available for use in Brazil, Pircinque and Jonica, both developed in Italy and successfully tested in Brazil (FAGHERAZZI 2017).

This work aimed to evaluate strawberry genotypes, from Italian, North American, and Spanish origin, in the South Plateau of the state of Santa Catarina, Brazil, regarding production characteristics and physical-chemical quality of fruits.

MATERIAL AND METHODS

The experiment was carried out at the Center of Agroveterinary Sciences of the Universidade do Estado de Santa Catarina (CAV/UDESC), in the municipality of Lages, SC, Brazil, during the 2017/2018 harvest season. The area is at the coordinates 27°47'05" South, 50°18'08" West, at an altitude of 906 meters above the sea level. The average maximum and minimum temperatures, as well as the monthly rainfall during the period in which the experiment was conducted are described in Table 1.

The experiment consisted of 15 genotypes, of which five were commercial cultivars, namely Albion (North American); Sabrina (Spanish); Irma, Jonica, and Pircinque (Italian). The remaining ten genotypes were advanced selections from CREA-OFA-FRF (Italy), namely FRF 57.6, FRF 104.1, FRF 191.2, FRF LAM 263.1, FRF LAM 269.18, FRF LAM 119.1, FRF PA 109.2, FRF PIR 256.4, FRF PIR 79.6, and FRF PIR 75.8. These genotypes are hybrids produced by averages of biparental crosses.

Regarding the photoperiod response, these genotypes are classified as follows: A) short-day genotypes – Jonica, Pircinque, Sabrina, FRF LAM 119.1, FRF LAM 263.1, FRF LAM 269.18, FRF PA 109.2, FRF PIR 75.8, FRF PIR 79.6, and FRF PIR 256.4; B) day-neutral genotypes – Albion, Irma, FRF 57.6, FRF 104.1, and FRF 191.2.

Table 1. Average minimum and maximum monthly temperatures (°C) and monthly precipitation (mm) during the period in which the experiment was conducted, in the municipality of Lages, SC, Brazil.

	May/17	Jun/17	Jul/17	Aug/17	Sep/17
Mean maximum temperature (°C)	17.9	16.2	17.9	17.4	22.0
Mean minimum temperature (°C)	12.3	9.4	7.9	10.2	14.1
Precipitation (mm)	105	0	3	106	20
	Oct/17	Nov/17	Dec/17	Jan/18	Feb/18
Mean maximum temperature (°C)	20.1	22.2	24.9	24.1	23.8
Mean minimum temperature (°C)	13.2	12.7	16.4	16.7	15.3
Precipitation (mm)	78	65	142	182	58

Legend: Jun/17 = June/2017. Jul/17 = July/2017. Aug/17 = August/2017. Sep/17 = September/2017. Oct/17 = October/2017. Nov/17 = November/2017. Dec/2017 = December/2017. Jan/18 = January/2018. Feb/18 = February/2018. Source: INMET (2019).

Among the genotypes studied, cultivars Albion, Jonica, and Pircinque have already been evaluated in the South Plateau of the state of Santa Catarina by FAGHERAZZI (2017) and RICHTER (2018). Selections FRF 57.6, FRF 104.1, FRF LAM 119.1, FRF LAM 269.18, and FRF PA 109.2, in turn, have been evaluated in the same region by ZANIN et al. (2019). Genotypes FRF 57.6 and FRF 104.1 were studied by RICHTER (2018). The remaining genotypes were tested in the South Plateau of the state of Santa Catarina for the first time, in this work.

The experimental design was in randomized blocks, with four replicates and plots of 11 plants. The cultivation system used was in the soil of an open field, using beds of approximately 90 cm in length and 15 cm of elevation, prepared using an implement coupled to a tractor. The beds were coated with black polyethylene film. The planting spacing adopted was 30 cm between rows and plants, in a triangle, with three planting rows per bed.

Soil correction and basic fertilization were done based on the recommendations contained in the Manual of Fertilization and Liming for the States of Rio Grande do Sul and Santa Catarina (CQFS-RS/SC 2004). Cover fertilizations were performed weekly by fertigation, using the following products: monoammonium phosphate (MAP) (387.4 g 1000 plants⁻¹); potassium sulfate (K₂SO₄) (312.5 g 1000 plants⁻¹); calcium nitrate [Ca(NO₃)₂] (99.2 g 1000 plants⁻¹); magnesium sulfate (MgSO₄) (45.5 g 1000 plants⁻¹), and a liquid fertilizer containing 51% phosphorus (73 mL 1000 plants⁻¹).

Planting was carried out on May 5th, 2017, using bare root fresh plants. A drip irrigation system was adopted, with three dripping hoses per bed, provided with drip holes spaced 15 cm apart. Weed control was done by weeding between the beds and manual scratch in the planting pits. Pest and disease control were performed when necessary using products registered for the crop. Other product used were the acaricide abamectin, insecticide thiametoxan, and fungicides methyl thiophanate (only before the harvest period), fluazinam, iprodione, pyrimethanil, and azoxystrobin + diphenconazole.

Harvesting was carried out from September 21th, 2017 to February 6th, 2018. The fruits were picked when presenting at least 80% of red epidermis. There were a total of 28 harvestings. Intervals between harvesting ranged from three to seven days, according to the availability of ripe fruits. After each harvesting, the fruits were brought to the Food Technology Center (NUTA 2) of the CAV/UDESC, where they were counted and weighed, being discriminated according to the following criteria: A) commercial - fruits with 10 g or more, without deformities or rotting that depreciate commercial quality; B) small fruits of less than 10 g; C) rotten - fruits containing fungi disease symptoms; D) misshapen - fruits with deformations in the epidermis.

In terms of production, the following variables were obtained at the end of the harvest season: A) total and commercial production (g plant⁻¹), consisting of the sum of the results of all the harvests, dividing the production in grams by the number of plants present in each plot; B) total estimated yield (t ha⁻¹), obtained by multiplying the production per plant by planting density, which was 58,533.64 plants per hectare; C) number of total and commercial fruits per plant (fruits plant⁻¹); D) average commercial fruit mass (g fruit⁻¹), obtained by dividing the variable commercial production (g plant⁻¹) by the variable number of commercial fruits (fruits plant⁻¹); E) percentage of commercial, small, rotten, and misshapen fruits (%), estimated by dividing the fruit production of each category by the total production, and multiplying by 100.

The fruits were qualitatively analyzed in the following dates: September 29th and November 10th, 2017, and January 10th, 2018, corresponding to the beginning, middle, and end of the productive period, respectively. The following evaluations were carried out: A) Color of the epidermis - evaluated using a Konica Minolta® colorimeter. All fruits from each plot were evaluated, consisting of two readings per fruit, one on each side and close to the equatorial diameter, obtaining the variables lightness (L), chroma (c), and hue angle (°hue). B) Pulp firmness - performed using a bench penetrometer, evaluating ten fruits per plot, two readings per fruit, one on each side. The results were expressed in Newtons (N). C) Titratable acidity - obtained by titrating a 5 mL sample of fruit juice from each plot, using NaOH 0.1 N and phenolphthalein as acid-base indicator (IAL 2008). The results were expressed in grams of citric acid per 100 grams of pulp; D) Soluble solids content - analysis performed using a manual refractometer, providing the results in degrees Brix (°Brix). E) Soluble solids/titratable acidity ratio - obtained by the ratio between the soluble solids content values and the titratable acidity of each sample.

The results were submitted to the Shapiro-Wilk normality test and Levègne variance homogeneity, using the R software (R CORE TEAM 2013). When these conditions were met, the data were submitted to analysis of variance and the averages were grouped by the Scott-Knott test at 5% probability using the Sisvar software (FERREIRA 2011). The statistical model used was as follows: $Y_{ij} = \mu + T_i + B_j + \varepsilon_{ij}$; in which Y_{ij} correspond to the observed value of the dependent variable; μ is the general average for the variable in question; T_i is the treatment effect (genotype); B_j correspond to the block effect; and ε_{ij} is the residual error.

The data of total and commercial production (g plant^{-1}), total and commercial yield (t ha^{-1}), number of fruits per plant (fruits plant^{-1}), titratable acidity ($\text{g } 100 \text{ g}^{-1}$ of citric acid), total soluble solids (°Brix), and soluble solids/titratable acidity ratio were transformed using the formula $Y = x^{0.5}$. The data on percentage of fruits classified as commercial and small (%) were transformed by the formula $Y = \arcsin (x/100)^{0.5}$, and the percentage of rotten and misshapen fruit (%) were transformed by the formula $Y = (x+1)^{0.5}$.

RESULTS AND DISCUSSION

The evaluated cultivars and selections differed for all production variables analyzed. Four groups of averages for total and commercial production per plant, and yield per hectare were formed (Table 2). The Sabrina cultivar showed the best results, differing from all genotypes evaluated. The total and commercial production estimates obtained from the Sabrina cultivar were, respectively, 65.8% and 77.0% higher than general averages for these variables. The second group with best results for total production were composed by Pircinque, FRF PA 109.2, FRF PIR 79.6, and Jonica. For commercial production, a second group with the best results was formed by FRF PA 109.2, Pircinque, and FRF PIR 79.6.

RONQUE et al. (2013) state that high yields are important to ensure the economic return necessary to make crops viable, especially in crops typically farmed in small areas, as is the case for strawberries. In many family farms the area planted with strawberries has approximately 0.3 hectare. According to these authors, in a cultivation area of this magnitude, it may be necessary to obtain productions superior to 800 g per plant to ensure a positive investment balance, due to the oscillations of other factors, such as the cost of seedlings and inputs and, especially, the value of commercialization.

Regarding for the total number of fruits per plant (Table 3), cultivars Sabrina, Pircinque, and Jonica composed the group with the highest averages. The Sabrina cultivar obtained the best result for number of commercial fruits, differing from all other genotypes. This cultivar also showed averages for number of total and commercial fruits per plant, respectively, 38.6% and 52.8% higher than the general averages for these variables. Genotypes Pircinque and FRF PA 109.2, in turn, composed a second group of higher averages for number of commercial fruits per plant.

Concerning the average commercial fruit mass, four groups of averages were formed. The group with the best results was composed by the genotypes Sabrina, FRF PA 109.2, and Albion. The average commercial fruit mass obtained by the Sabrina cultivar was 17.1% higher than the general average for this variable. FAGHERAZZI (2017) also found one of the highest average fruit masses in the cultivar Albion, among 21 genotypes evaluated.

Table 2. Fruit production in different cultivars and advanced selections of strawberry. Lages, SC, CAV/UDESC, 2018.

Genotype	Production (g plant ⁻¹)		Yield (t ha ⁻¹)	
	Total*	Commercial*	Total*	Commercial*
Jonica (SD)	800.69 b	568.94 c	46.87 b	33.30 c
Pircinque (SD)	936.59 b	708.31 b	54.82 b	41.46 b
Sabrina (SD)	1,231.77 a	1,016.00 a	72.10 a	59.47 a
FRF LAM 119.1 (SD)	680.32 c	511.78 c	39.82 c	29.96 c
FRF LAM 263.1 (SD)	683.19 c	496.58 c	39.99 c	29.07 c
FRF LAM 269.18 (SD)	711.60 c	530.07 c	41.65 c	31.03 c
FRF PA 109.2 (SD)	919.98 b	761.95 b	53.85 b	44.60 b
FRF PIR 75.8 (SD)	635.16 c	552.89 c	37.18 c	32.36 c
FRF PIR 79.6 (SD)	840.99 b	665.67 b	49.23 b	38.96 b
FRF PIR 256.4 (SD)	555.64 d	450.83 d	32.52 d	26.39 d
Albion (DN)	641.11 c	509.90 c	37.53 c	29.85 c
Irma (DN)	542.70 d	382.90 d	31.77 d	22.41 d
FRF 57.6 (DN)	759.94 c	578.55 c	44.48 c	33.86 c
FRF 104.1 (DN)	688.05 c	488.51 c	40.27 c	28.59 c
FRF 191.2 (DN)	515.18 d	387.64 d	30.16 d	22.69 d
Mean	742.86	574.03	43.48	33.60
CV (%)	8.30	8.75	8.30	8.75

Means followed by equal letters in the column belong to the same group by the Scott-Knott test ($p \leq 0.05$).

*Data transformed by the formula $Y = x^{0.5}$. Legend: SD = Short Day Genotypes; DN = Day-neutral Genotypes.

Table 3. Number of total and commercial fruits per plant, and average weight of commercial fruits of cultivars and advanced selections of strawberry. Lages, SC, CAV/UDESC, 2018.

Genotype	NF (fruits plant ⁻¹)		AWCF (g fruit ⁻¹)
	Total*	Commercial*	
Jonica (SD)	73.87 a	30.56 c	18.62 b
Pircinque (SD)	74.24 a	40.37 b	17.65 c
Sabrina (SD)	78.48 a	48.00 a	21.10 a
FRF LAM 119.1 (SD)	53.95 b	29.75 c	17.18 c
FRF LAM 263.1 (SD)	64.81 b	31.89 c	15.58 d
FRF LAM 269.18 (SD)	54.27 b	28.34 c	18.68 b
FRF PA 109.2 (SD)	59.30 b	36.91 b	20.57 a
FRF PIR 75.8 (SD)	42.65 c	30.58 c	18.17 b
FRF PIR 79.6 (SD)	57.21 b	33.23 c	18.69 b
FRF PIR 256.4 (SD)	35.24 c	23.66 d	18.93 b
Albion (DN)	38.63 c	25.91 d	19.67 a
Irma (DN)	44.00 c	24.11 d	15.89 d
FRF 57.6 (DN)	64.31 b	33.67 c	17.31 c
FRF 104.1 (DN)	61.77 b	30.49 c	15.93 d
FRF 191.2 (DN)	46.78 c	23.84 d	16.28 d
Mean	56.63	31.42	18.02
CV (%)	8.23	8.21	5.89

Means followed by equal letters in the column belong to the same group by the Scott-Knott test ($p \leq 0.05$).

*Data transformed by the formula $Y = x^{0.5}$. Legend: NF = number of fruits per plant; AWCF = average weight of commercial fruits; SD = Short Day Genotypes; DN = Day-neutral Genotypes.

The number and weight of fruits are the main components of strawberry production (OLIVEIRA & BONOW 2012). According to SINGH et al. (2018), the number of flowers per plant, length and width of the fruit, and plant vigor also correlate positively with the yield. The same authors found that the yield had the highest genotypic coefficient of variation and genetic advance among many characteristics studied. MISHRA et al. (2015) obtained heritability values in the broad sense of 74.81 and 85.17% for number of fruits per plant and average fresh weight of fruits, respectively, indicating that these characteristics are strongly influenced by the genotype, and that the correct selection of cultivars is essential to achieve high production parameters.

Regarding fruit production in different categories, there was a significant difference between the cultivars and selections evaluated for the four classification categories (Table 4). Two groups of averages were formed for the fruits classified as commercial. The best group was composed by the genotypes FRF PIR 75.8, FRF PA 109.2, Sabrina, FRF PIR 256.4, Albion, and FRF PIR 79.6. The genotypes that provided a higher number of small fruits, in turn, were FRF 104.1, Írma, FRF LAM 263.1, and Jonica. Higher percentages of misshapen fruits were observed in FRF LAM 269.18, FRF LAM 119.1, Albion, FRF PIR 256.4, and FRF 191.2, and rotten fruits, in FRF PIR 256.4, FRF LAM 119.1, Jonica, and Pircinque.

Table 4. Percentage of total production in different categories for strawberry genotypes. Lages, SC, CAV/UDESC, 2018.

Genotype	Percent of fruits in different categories (%)			
	Commercial*	Small*	Misshapen**	Rotten**
Jonica (SD)	71.10 b	24.45 a	0.79 b	3.67 a
Pircinque (SD)	75.57 b	19.03 b	1.76 b	3.64 a
Sabrina (SD)	82.43 a	14.88 c	1.00 b	1.69 b
FRF LAM 119.1 (SD)	75.40 b	14.65 c	4.71 a	5.24 a
FRF LAM 263.1 (SD)	72.74 b	25.53 a	0.34 b	1.39 b
FRF LAM 269.18 (SD)	74.32 b	17.18 c	6.44 a	2.07 b
FRF PA 109.2 (SD)	83.00 a	12.78 d	1.69 b	2.54 b
FRF PIR 75.8 (SD)	86.87 a	10.20 d	0.28 b	2.64 b
FRF PIR 79.6 (SD)	79.60 a	20.49 c	2.02 b	1.38 b
FRF PIR 256.4 (SD)	80.87 a	10.44 d	3.03 a	5.66 a
Albion (DN)	79.75 a*	13.90 c	3.75 a	2.59 b
Írma (DN)	71.04 b	25.89 a	1.66 b	1.42 b
FRF 57.6 (DN)	76.01 b	20.25 b	1.20 b	2.54 b
FRF 104.1 (DN)	70.61 b	26.65 a	0.90 b	1.85 b
FRF 191.2 (DN)	74.92 b	23.63 b	2.68 a	1.92 b
Mean	76.95	18.22	2.15	2.68
CV (%)	4.62	10.89	28.50	25.58

Means followed by equal letters in the column belong to the same group by the Scott-Knott test ($p \leq 0.05$).

*Data transformed by the formula $Y = \arcsin(x / 100)^{0.5}$. ** Data transformed by the formula $Y = (x + 1)^{0.5}$.

Legend: SD = Short Day Genotypes; DN = Day-neutral Genotypes.

The percentage of marketable fruits is one of the main production parameters, given that it directly interferes with the economic viability of the investment. The large size and the appropriate external appearance value the fruits in the market and facilitate commercialization, considering that the external aspect is the first factor consumers look to when choosing the product (CARPENEDO et al. 2016). Moreover, it is more advantageous for the farmer to obtain high yields of large fruits than with a high number of small fruits per plant (RICHTER 2018). This is because the exaggerated production of small fruits makes harvesting more expensive and time consuming, and can also increase labor costs, which is an important component in the production cost of the strawberry crop (RONQUE et al. 2013).

The production of misshapen fruits, in turn, may be a consequence of the genetic load since some genotypes are more likely than others to obtain fruits of this type, regardless of the environmental conditions

(ARIZA et al. 2012). Environmental factors, on the other hand, seem to exert little influence on this parameter since the main environmental cause of this problem is failure in pollination, which for strawberry crops is done mainly by wind and hymenoptera insects (MALAGODI-BRAGA & KLEINERT 2007). Considering that the experiment was conducted without cover, the wind and insects had free reign throughout the cycle. Regarding fruits with rot, the genotypes with the highest production of fruits in this category are possibly more susceptible to the fungi *Botrytis cinerea* and *Colletotrichum acutatum*, important causal agents of fruit rot in strawberry crops (CORDOVA et al. 2017).

There was a difference between the evaluated genotypes for all qualitative variables. The epidermis color was evaluated by considering three variables (Table 5). Cultivars Jonica and Pircinque obtained the highest average of lightness, whereas Albion showed the darkest fruits. Fruits with higher averages for chroma were observed in FRF 57.6, Jonica, Pircinque, FRF PIR 79.6, FRF LAM 119.1, FRF PIR 256.4, FRF PA 109.2, and FRF PIR 75.8. Three groups of averages were formed for hue angle. The group with the highest average was composed by genotypes Jonica, Irma, Pircinque, FRF LAM 119.1, FRF PIR 79.6, FRF PIR 256.4, FRF PA 109.2, and FRF LAM 263.1.

Table 5. Color of the epidermis in fruits of cultivars and advanced selections of strawberry. Lages, SC, CAV/UDESC, 2018.

Genotype	Epidermis color		
	Lightness	Chroma	Hue
Jonica (SD)	40.25 a	48.69 a	34.98 a
Pircinque (SD)	39.55 a	48.13 a	34.11 a
Sabrina (SD)	35.60 c	44.81 b	29.93 c
FRF LAM 119.1 (SD)	37.93 b	47.18 a	33.82 a
FRF LAM 263.1 (SD)	34.55 c	44.17 b	32.16 a
FRF LAM 269.18 (SD)	34.26 c	43.89 b	29.40 c
FRF PA 109.2 (SD)	37.15 b	46.91 a	33.01 a
FRF PIR 75.8 (SD)	36.49 b	46.54 a	29.83 c
FRF PIR 79.6 (SD)	37.28 b	47.43 a	33.70 a
FRF PIR 256.4 (SD)	36.30 b	47.03 a	33.09 a
Albion (DN)	31.68 d*	42.00 b	28.16 c
Irma (DN)	37.86 b	45.56 b	34.33 a
FRF 57.6 (DN)	38.34 b	48.72 a	31.68 b
FRF 104.1 (DN)	35.59 c	45.80 b	31.60 b
FRF 191.2 (DN)	34.21 b	44.43 b	30.42 c
Mean	36.47	46.09	32.01
CV (%)	3.82	4.05	4.09

*Means followed by equal letters in the column belong to the same group by the Scott-Knott test ($p \leq 0.05$).

Legend: SD = Short Day Genotypes; DN = Day-neutral Genotypes.

The cultivars with fruits of lighter epidermis, that is, higher average values for the L index, also had a more lively or saturated coloration (higher chroma) and a tonality closer to light red or orange (higher hue angle). This fact was well observable in the Pircinque and Jonica cultivars, which are Italian cultivars characterized by epidermis with a very uniform red-orange coloration. On the other hand, the Albion cultivar presented fruits with darker epidermis and lower values of hue angle, typical of shades closer to dark red.

Fruits with more intense red and bright red color are preferred for *in natura* consumption (CARPENEDO et al. 2016). According to the same authors, the external coloration of the epidermis is one of the first factors that consumers consider when deciding on a purchase. According to NUNES (2015), fruits with better color are better accepted and present higher content of vitamin C.

The red coloration of the strawberry fruits is due to the presence of pigments belonging to the anthocyanins group. Among the main anthocyanins present in strawberries, pelargonidine 3-glucoside stands out, followed by cyanidin 3-glucoside. COCCO (2014) states that higher concentrations of

pelargonidin 3-glucoside responsible for the coloration of the dark red epidermis. According to the author, anthocyanins are among the main functional compounds with antioxidant power in strawberries. The effect of genotypes is greater than the environmental effect on the content of these compounds.

Three groups of averages were formed for pulp firmness (Table 6). Most of the evaluated genotypes were arranged in the group with the highest averages. In this sense, the highest average was observed in selection FRF PIR 75.8, which did not differ from other nine genotypes. This selection obtained a result 10.6% higher than the general average. The group with the lowest scores, in turn, was formed by FRF LAM 119.1 and Albion.

Table 6. Main characteristics of fruit quality in strawberry cultivars and selections. Lages, SC, CAV/UEDESC, 2018.

Genotype	PF (N)	TA (g 100 g ⁻¹ of citric acid)*	SST (°Brix)*	RT (SS/AT)*
Jonica (SD)	5.22 a	0.60 b	8.58 a	14.47 c
Pirquinque (SD)	5.26 a	0.56 c	8.94 a	15.92 b
Sabrina (SD)	5.30 a	0.61 b	7.88 b	12.89 c
FRF LAM 119.1 (SD)	4.44 c	0.55 c	8.43 a	15.40 b
FRF LAM 263.1 (SD)	4.91 b	0.60 b	7.14 b	11.99 c
FRF LAM 269.18 (SD)	5.27 a	0.68 a	8.22 b	12.17 c
FRF PA 109.2 (SD)	5.35 a	0.54 c	7.58 b	14.12 c
FRF PIR 75.8 (SD)	5.56 a	0.64 a	8.00 b	12.47 c
FRF PIR 79.6 (SD)	5.39 a	0.66 a	8.93 a	13.59 c
FRF PIR 256.4 (SD)	4.79 b	0.47 d	9.26 a	20.87 a
Albion (DN)	4.49 c	0.68 a	8.46 a	12.49 c
Irma (DN)	4.81 b	0.66 a	7.84 b	11.96 c
FRF 57.6 (DN)	5.21 a	0.50 d	7.98 b	15.87 b
FRF 104.1 (DN)	5.02 a	0.49 d	8.67 a	17.79 b
FRF 191.2 (DN)	5.22 a	0.59 b	7.79 b	13.21 c
Mean	5.08	0.59	8.24	14.35
CV (%)	5.23	7.56	9.17	5.69

Means followed by equal letters in the column belong to the same group by the Scott-Knott test ($p \leq 0.05$). * Data transformed by the formula $Y = x^{0.5}$. Legend: PF = pulp firmness; TA = titratable acidity; SST = soluble solids content; RT = soluble solids / titratable acidity ratio; SD = Short Day Genotypes; DN = Day-neutral Genotypes.

For titratable acidity, four groups of averages were formed. The group with higher averages was composed by the genotypes Albion, FRF LAM 269.18, Irma, FRF PIR 79.6, and FRF PIR 75.8. The group with the lowest results was formed by FRF PIR 256.4, FRF 104.1, and FRF 57.6. There was a difference of 44.7% between the lowest average, verified in the selection FRF PIR 256.4 (0.47 g 100 g⁻¹ of citric acid) and the highest averages, obtained with Albion and FRF LAM 269.18 (0.68 g 100 g⁻¹ of citric acid).

The content of soluble solids formed two groups of averages. Genotypes FRF PIR 256.4, Pirquinque, FRF PIR 79.6, FRF 104.1, Jonica, Albion, and FRF LAM 119.1 composed the groups with the best results. Selection FRF PIR 256.4 presented soluble solid content 12.4% higher than the general average. The same genotype obtained the highest average for the soluble solids/titratable acidity ratio, with a result 45.4% higher than the general average, and differed from all other treatments. The second group with the best results for soluble solids/titratable acidity ratio was composed by FRF 104.1, Pirquinque, FRF 57.6, and FRF LAM 119.1.

The high soluble solids/titratable acidity ratio in the Pirquinque cultivar has already been reported by FAGHERAZZI (2017). Regarding selections FRF 57.6, FRF 104.1, FRF LAM 119.1, and FRF PIR 256.4, even if not registered as new cultivars, they can be used in new hybridizations aiming at incrementing fruit quality.

The firmness of pulp is one of the most important characteristics and is among the most sought after in the genetic improvement of strawberry. Firm fruits are more resistant to damages during transport and have

longer post-harvest durability and resistance to rot (OLIVEIRA & BONOW 2012). The possibility of storing the product for an extended time and marketing to more distant locations is a great advantage for producers, especially in the case of highly perishable fruits such as strawberries and other small fruits (BRACKMANN et al. 2011).

Additionally, all the most productive genotypes studied in this paper – Sabrina, FRF PA 109.2, Pircinque, and FRF PIR 79.6 – were allocated in the group with the highest averages of pulp firmness. This result suggests that it is possible to select cultivars that are both productive and bear firm fruits.

The acidity of the strawberry pulp is conditioned by the presence of several organic acids, among which are the citric and ascorbic acids (HANCOCK et al. 2008). The organic acids are degraded during the ripening process, reducing their content concomitantly with the increase in the concentration of soluble sugars (MATARAZZO et al. 2013). For *in natura* consumption, the acidity of the pulp cannot be very high since it can compromise consumer acceptance of the fruits (RESENDE et al. 2008).

The content of soluble solids, on the other hand, is conditioned by the presence of several polysaccharides, among which are glucose, fructose and sucrose (HANCOCK et al. 2008). The concentration of these compounds in fruits increases during the preharvest maturation process, when the reserve starch is converted into simpler, water-soluble carbohydrates (MATARAZZO et al. 2013). Since the strawberry is a non-climacteric fruit, the values of total acidity, soluble solids content, and soluble solids/titratable acidity ratio fluctuate slightly during the storage period (ANDRADE JÚNIOR et al. 2016).

The soluble solids/titratable acidity ratio, in turn, is one of the most important qualitative variables. In a commercial cultivar, it is imperative that there is an adequate balance between acidity and soluble solids content (CARPENEDO et al. 2016). RESENDE et al. (2008) reported that strawberries with higher soluble solids/titratable acidity ratio are the most accepted for *in natura* consumption. Strawberry cultivars must present the following parameters for fresh fruit commercialization: at least 7.0 °Brix for soluble solids content; maximum of 0.80 g 100 g⁻¹ of citric acid for titratable acidity; and minimum of 8.75 for soluble solids/titratable acidity ratio (KADER 2002, cited by SOUZA et al. 2017). Following these concepts, all genotypes evaluated in this paper can be considered adequate for *in natura* commercialization.

CONCLUSION

The cultivar Sabrina had the highest yield among genotypes evaluated, followed by FRF PA 109.2, Pircinque and FRF PIR 79.6. In turn, Sabrina, FRF PA 109.2 and Albion had the largest fruits.

The selections FRF PIR 256.4, FRF 104.1, FRF 57.6 and FRF LAM 119.1, and the cultivar Pircinque present good fruit quality, expressed by high values for soluble solids / titratable acidity ratio.

In the conditions in which the study was carried out, the genotypes Sabrina, Pircinque and PA 109.2 presented promising agronomic characteristics for commercial scale cultivation.

ACKNOWLEDGEMENTS

The first author thank to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the award of the scholarship.

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Agronomic performance of new strawberry cultivars in southern Brazil

Desempenho agrônômico de novos cultivares de morango no sul do Brasil

Marllon Fernando Soares dos Santos*, Antonio Felipe Fagherazzi, Juliana Martins de Lima, Bruna Miranda Costa, Francine Regianini Nerbass, Aike Anneliese Kretzschmar, Leo Rufato

State University of Santa Catarina, Lages, SC, Brazil. * Author for correspondence: marllon.soares@outlook.com

Submission: 07/01/2021 | Acceptance: 26/03/2021

ABSTRACT

The choice of cultivars to be used by strawberry farmers is essential since it could determine the success of the crop. The present study aimed to evaluate the productive and qualitative performance of strawberry genotypes grown in Vacaria, RS, Brazil. Twelve strawberry genotypes were compared, constituting the different treatments: cultivars Strawberry Festival, Oso Grande, Jonica, and Pircinque, and selections FRF PA3, FRF CE 51, FRF CE 56, FRF PIR 29, FRF PIR 54, FRF 85.04, FRF 149.18, and FRF 102.21. The seedlings were transplanted on May 13, 2014, in a semi-hydroponic cultivation system, adopting a randomized block design with four blocks and an experimental unit of ten useful plants. The variables evaluated were the number of fruits, total production per plant, productivity, commercial productivity, fresh fruit mass, commercial percentage, soluble solids, titratable acidity, soluble solids to total acidity ratio, pulp firmness, and production seasonality. The mean values were subjected to an analysis of variance and multivariate analysis, and their means were compared by the Scott-Knott test at a 5% error probability. Cultivar Strawberry Festival and selection FRF 102.21 showed higher productions (1138 g plant⁻¹ and 1019 g plant⁻¹, respectively) and quantities of fruits produced (85 un plant⁻¹ and 87 un plant⁻¹, respectively). Cultivar Jonica and selection FRF 85.4 showed higher percentages of marketable fruits. The Pircinque cultivar was prominent for sugar content, presenting a value 24% superior to the general average of the cultivars. Cultivars Strawberry Festival, Jonica, and Pircinque and selection FRF 102.21 showed the highest qualitative and quantitative gains for the region of Vacaria, RS, Brazil.

KEYWORDS: *Fragaria x ananassa* Duch; adaptability; productivity.

RESUMO

A escolha dos cultivares a serem utilizadas pelos produtores de morangos é fundamental, pois pode determinar o sucesso da cultura. O presente estudo tem como objetivo avaliar o desempenho produtivo e qualitativo de genótipos de morangueiro cultivados em Vacaria, RS, Brasil. Foram comparados 12 genótipos de morangueiro, constituindo os diferentes tratamentos: cultivares Strawberry Festival, Oso Grande, Jonica e Pircinque, e seleções FRF PA3, FRF CE 51, FRF CE 56, FRF PIR 29, FRF PIR 54, FRF 85,04, FRF 149,18, e FRF 102,21. As mudas foram transplantadas em 13 de maio de 2014, em sistema de cultivo semi-hidropônico, adotando-se o delineamento em blocos casualizados, com quatro blocos e unidade experimental de dez plantas úteis. As variáveis avaliadas foram número de frutos, produção total por planta, produtividade, produtividade comercial, massa fresca do fruto, porcentagem comercial, sólidos solúveis, acidez titulável, relação (sólidos solúveis/acidez total), firmeza da polpa e a sazonalidade da produção. Os valores médios foram submetidos à análise de variância e análise multivariada, e suas médias comparadas pelo teste de Scott-Knott a 5% de probabilidade de erro. O cultivar Strawberry Festival e seleção FRF 102,21 apresentaram maior produção (1138 e 1019 g planta⁻¹) e quantidade de frutos produzidos (85 e 87 un planta⁻¹). A cultivar Jonica e a seleção FRF 85,4 apresentaram maior porcentagem de frutos comerciáveis. O cultivar Pircinque se destacou-se pelo seu teor de açúcares, apresentando um valor 24% superior à média geral dos cultivares. As cultivares Strawberry Festival, Jonica e Pircinque e seleção FRF 102,21 apresentaram os maiores ganhos qualitativos e quantitativos para a região de Vacaria, RS.

PALAVRAS-CHAVE: *Fragaria x ananassa* Duch; adaptabilidade; produtividade.

INTRODUCTION

The national fruit production generates a cultivated area of approximately 2.70 million hectares, a production of roughly 40 million tons, and around five million jobs, making Brazil the third largest fruit producer worldwide, standing out in Latin America as the second-largest producer of small fruits according to FAOSTAT (2019).

The fruit production chain is one of the agribusiness sectors that most generate jobs and income. According to the FAOSTAT (2019) strawberry is a main species was represented the small fruits in cultivation in Brazil, with approximately 4,500 hectares and an annual production around 165,440 tons.

Regarding total production, strawberry is the main fruit produced and consumed among the species that make up small fruits in Brazil (FAGHERAZZI et al. 2017a). The commercial interest in the fruit is due to the notable demand by the consumer market and the possibility of diversification since the product may be used both for fresh marketing and processing in the form of sweets, yogurts, juices, liquors, and other products that use the striking characteristics of the fruit, such as its aroma, color, and flavor. Furthermore, strawberry is an important source of vitamin C (58.8 mg in 100 g), vitamin A (12 IU in 100 g), potassium (170 mg in 100 g), folates, and calcium (2% of the recommended daily dose), also presenting other beneficial compounds, such as the high content of ellagic acid, a compound with high biological potential representing approximately 50% of the phenol content (HAKKINEN et al. 1999, CASALI 2004, QUINATO 2007, DUARTE FILHO et al. 2007, ROCHA et al. 2008).

In Brazil, strawberry cultivation is spread in temperate and subtropical climates, where the fruit is produced for fresh consumption and industrialization (SANTOS & MEDEIROS 2003). The primary factors for commercially exploiting this crop are the high profitability when compared to other species such as corn and soybean, and the comprehensive knowledge and acceptance by the consumer due to the diversity of commercialization and fruit processing options (REICHERT & MADAIL 2003, SANHUEZA et al. 2005, THIMOTEO et al. 2006).

Strawberry is a crop of high economic expression for Brazilian producers, representing most of the South American production, with 155 thousand tons and 4300 hectares produced in 2017 alone. Although Brazil is not present in FAO reports, some experts claim it occupies a position among the twenty largest world producers (ANTUNES 2018). The states of Minas Gerais, Paraná, and Rio Grande do Sul represent approximately 75% of the cultivated area and national strawberry production (FAGHERAZZI et al. 2017b).

The Vale do Rio Caí region in the state of Rio Grande do Sul is the main producer of table strawberries, followed by Caxias do Sul and Farroupilha. Pelotas and neighboring municipalities stand out in the production of strawberries for the industry, totalizing an annual production of approximately 11 thousand tons (ANTUNES & REISSER JÚNIOR 2007, ANTONIOLLI et al. 2007). However, many table strawberry producers are moving to higher altitudes, which present a favorable climate and soil for cultivation. In this sense, the municipality of Vacaria, located in the Campos de Cima da Serra region, stands out with low temperatures favorable to the vegetative period of winter fruits, according to WREGE et al. (2007).

Oso Grande, Camarosa, and Strawberry Festival (short day) and Albion, San Andreas, Monterey, and Portola (neutral day), all developed in the United States, stand out among the main strawberry cultivars used in southern Brazil. When new strawberry cultivars are selected in breeding programs under local edaphoclimatic conditions and are subsequently disseminated to producing poles with different conditions, many do not express the same characteristics they presented where they were developed. In these cases, the cultivar will hardly produce high-quality fruit (CONTI et al. 2002, OLIVEIRA & BONOW 2012).

One possible solution to compensate for the lack of fully adapted cultivars is the introduction of new cultivars. Some cultivars were introduced with few studies on their performance under Brazilian conditions in previous years, causing losses to farmers (PADUA et al. 2015). In this sense, new materials must be adequately assessed for adaptability in the region to which they will be introduced to ensure they meet the requirements of local producers and consumers (ASSIS 2004). Therefore, the choice of cultivars is one of the factors that largely determine the success of strawberry crops and must be linked to the climate characteristics of each location (DUARTE FILHO et al. 2007). For RUAN et al. (2013), the choice of cultivar is a crucial issue for the success of strawberry crops in different cultivation systems. To FAGHERAZZI (2013), success in strawberry cultivation is linked to several factors, such as the level of technical knowledge of the producers, the management, the edaphoclimatic conditions, and, especially, the choice of cultivars adapted to local conditions, to, therefore, satisfy producers and consumers.

Given the above, this study aimed to evaluate the productive and qualitative variables and the production seasonality of strawberry genotypes grown under the Campos de Cima da Serra Region (RS) conditions.

MATERIAL AND METHODS

The research was developed from May 2014 to March 2015 in an experimental area in the municipality of Vacaria, RS, Brazil, in the Campos de Cima da Serra region, at latitude 28°30' South and longitude 50° 56' West, at an altitude of 922 meters. The climate of the region is temperate (Cfb1) according to the Köppen classification (MORENO 1961). The strawberries were cultivated in a fixed greenhouse with a side opening and a transparent polyethylene film cover 150 µm thick.

The cultivars used were Strawberry Festival, Oso Grande, Jonica, and Pircinque, selections FRF PA3, FRF CE 51, FRF CE 56, FRF PIR 29, and FRF PIR 54 (short day), and selections FRF 85.04, FRF 149.18, and FRF 102.21 (neutral day), constituting the different treatments. A national nursery produced the "fresh" bare-root seedlings, and the transplant took place on May 13, 2014, in a semi-hydroponic production system in a greenhouse covered with UV diffuser plastic. The slab substrate was composed of 40% carbonized rice peel, 40% pine bark, and 20% vegetable cellulose. The slab had dimensions of 15 cm wide and 20 cm deep.

The planting density was 50 thousand plants per hectare, with a spacing of 0.15 m between plants. The basic fertilization was conducted according to the substrate analysis, using the recommendations described by PASSOS & TRANI (2013). Drip irrigation was performed using one drip tape per cultivation line, with drippers spaced 10 cm apart. The nutrients were supplied via fertigation using the following products: potassium sulfate (K_2SO_4), magnesium sulfate ($MgSO_4$), monoammonium phosphate (MAP), calcium nitrate [$Ca(NO_3)_2$], potassium nitrate (KNO_3), P 51 (liquid fertilizer containing 51% phosphorus), and a micronutrient-based mixture. The electrical conductivity was maintained between 1 mS.cm⁻¹ and 1.2 mS.cm⁻¹, and its monitoring in the drained liquid was performed weekly. Pest and disease control was conducted using fungicides and insecticides recommended for the crop, when necessary.

Harvest began in October 2014, approximately five months after planting, and occurred weekly in the coolest hours of the day, when 80% of the epidermis was red. After harvesting, the fruits were evaluated at the Food Technology Center II (NUTA II) at the UDESC Center for Agroveterinary Sciences (CAV). Harvesting ended in March 2015, when the high temperatures of the summer period promoted the end of the production cycle for some genotypes and the sharp decrease in production for others.

The productive variables regarding the number of fruits (un plant⁻¹), production (g plant⁻¹), fresh fruit mass (g fruit⁻¹), classification of production in the percentage of commercial fruits, deformed fruits (fruits with deformation of the epidermis), small fruits (fruits with fresh mass ≤ 10 g fruit⁻¹), and rotten fruits (presence of *Botrytis cinerea* and *Colletotrichum fragariae*) were evaluated. The distribution of monthly production seasonality during the harvest period was also estimated. The qualitative parameters analyzed were the contents of soluble solids expressed in °Brix (determined using a digital bench refractometer), titratable acidity obtained by titration with a standardized 0.1 N sodium hydroxide solution, soluble solids to titratable acidity ratio, and pulp firmness obtained using a portable digital penetrometer with a No. 2 tip, with results expressed in N.

The experimental design adopted was randomized blocks, with four blocks and one experimental unit of ten useful plants. The data collected were submitted to an analysis of variance and, when significant, their means were compared by the Scott-Knott test at 5% error probability. Subsequently, the multivariate analysis was performed for the principal component analysis (PCA) and correlation.

RESULTS AND DISCUSSION

A significant effect was found for all variables evaluated when comparing the studied genotypes. For the number of fruits per plant, cultivar Strawberry Festival and selections FRF CE 56 and FRF 102.21 showed the highest values, with 85, 76, and 87 fruits per plant, respectively. In contrast, these genotypes showed a general average of 78% or lower regarding the production considered fit for *in natura* fruits (%), unlike cultivar Jonica and selection FRF 85.4, which presented the highest commercial production (approximately 90%). FAGHERAZZI (2013) reported that, for other cultivars, a lower number of fruits produced per plant is consistent with a higher fresh weight and, consequently, a larger caliber.

Cultivars Strawberry Festival and selection FRF 102.21 showed the highest average production per plant: 1119.6 and 1138.5, respectively. A study conducted in Pelotas, RS, showed production values of 799.21 g.plant⁻¹ for cultivar Strawberry Festival, representing the most productive cultivar (CARVALHO et al., 2013). This result indicated that the production of S. Festival was superior compared to the other cultivars and selections. The productive difference found is approximately 22g plant⁻¹, 20% lower than in the study conducted by CARVALHO et al. (2013). These variations can be of biotic origins, such as a pathogen attack, or abiotic, such as climatic conditions like the high level of relative air humidity and the low light intensity, disfavoring plant development (VIDA et al. 2004). The climatic data regarding the average temperature (°C)

and rainfall (mm) were monitored through the meteorological station of the National Institute of Meteorology (Table 1).

Table 1. Average values of the environmental variables measured in the 2014/2015 production cycle.

	Mean Temperature (Tmed; °C)	Maximum Temperature (Tmax; °C)	Minimum Temperature (Tmin; °C)	Rainfall (mm)
2014/2015				
May	13.5	19	8	76
June	11.5	17	6	92
July	11.5	17	6	159
August	12.5	18	7	131
September	14	19	9	176
October	16.5	22	11	145
November	18	24	12	107
December	19.5	25	14	138
January	20.5	26	15	121
February	20.5	26	15	127
March	19	24	14	114
April	15.5	21	10	75
Average	16.04	21.50	10.58	121.75

The same was observed for commercial productivity in cultivar Strawberry Festival and selection FRF 102.21, both with commercial production of 39 t.ha⁻¹, 40% superior to the general average. BRUGNARA et al. (2017) obtained similar average productivity values, ranging from 30 to 60, for Strawberry Festival, with a plant population of 5.53 plants per squared meter, in a study conducted in the west of Santa Catarina for the 2017/2018 harvest.

The neutral day selections FRF 85.4, FRF 149.18, and FRF 102.21 showed good harvest distributions (Table 2) since their average production in October, November, and December was 25%. This characteristic must be explored because cultural techniques are a viable solution for the excess of fruit produced in a short time when there is little qualified labor to harvest, thus facilitating the flow of production with labor optimization (REIS et al. 2011).

Table 2. Production seasonality (%) of the cultivars and selections evaluated in Vacaria, RS, Brazil, 2015.

Genotype	Production Seasonality					
	% OCT	% NOV	% DEC	% JAN	% FEB	% MAR
Jonica (SD)	36 b	21 d	30 d	09 e	01 e	02 ^{ns}
Oso Grande (SD)	39 a	19 e	29 e	10 e	01 e	02
Pircinque (SD)	30 b	18 f	33 c	11 d	06 b	02
Strawberry Festival (SD)	27 b	19 e	35 b	11 d	05 c	02
FRF PA3 (SD)	39 a	16 f	36 b	06 f	01 e	02
FRF CE 51 (SD)	35 a	21 d	34 b	06 f	01 e	02
FRF CE 56 (SD)	19 c	22 d	40 a	13 c	04 c	03
FRF PIR 29 (SD)	39 a	20 e	35 b	03 g	02 e	01
FRF PIR 54 (SD)	35 a	28 a	23 g	09 e	02 d	02
FRF 85.4 (ND)	29 b	24 c	27 f	11 d	07 a	03
FRF 149.18 (ND)	18 c	22 d	29 e	19 a	08 a	04
FRF 102.21 (ND)	27 b	26 b	20 h	18 b	05 c	03
Mean	31	21	31	11	04	02
CV (%)	8.4	3.9	2.4	5.4	13.9	28.5

*Means followed by the same letter do not differ significantly by the Scott-Knott test at 5% of error probability.

ND = Neutral Day; SD = Short Day.

For the percentage of production classified as commercial, cultivar Jonica and selections FRF 85.4, FRF PA3, FRF PIR 29, and FRF PIR 54 stood out, with an average of 85%. This parameter is decisive for real production because of losses due to fungal diseases that may reach 100%, according to COSTA et al. (2011).

When considering the fresh weight values, two groups were formed, one containing three of the commercial cultivars, namely Jonica, Oso Grande, and Pircinque, and selections FRF PIR 29, FRF PIR 54, and FRF 85.4, with an average fresh weight of 19.6 g fruit⁻¹, and the other formed by cultivar Strawberry Festival and selections FRF PA3, FRF CE 51, FRF CE 56, FRF 149.18, and FRF 102.21, with an average fresh mass of 14.8 g fruit⁻¹ (Table 3).

Table 3. Assessment of the productive characteristics of the evaluated genotypes separated according to their classifications in total (fruits per plant, production in grams per plant, and productivity tons per hectare) and commercial production (fresh mass in grams per fruit, commercial percentage, and productivity in tons per hectare). Vacaria, RS, Brazil, 2015.

Genotype	Total production			Production classified as commercial		
	Fruits (un plant ⁻¹)	Production (g plant ⁻¹)	Productivity (t ha ⁻¹)	Fresh Mass (g fruit ⁻¹)	(%)	Productivity (t ha ⁻¹)
Jonica (SD)	49.1 c	727.7 b	36.44 b	21.9 a	85 a	30.9 b
Oso Grande (SD)	58.2 b	834.1 b	41.7 b	18.19 a	77 c	32.0 b
Pircinque (SD)	63.3 b	878.3 b	43.9 b	21.1 a	72 d	32.0 b
Strawberry Festival (SD)	85.1 a	1019.6 a	51.0 a	15.5 b	78 c	39.7 a
FRF PA3 (SD)	56.7 b	567.9 c	28.4 c	12.3 b	82 b	23.3 c
FRF CE 51 (SD)	66.4 b	784.4 b	39.2 b	15.3 b	78 c	30.6 b
FRF CE 56 (SD)	75.9 a	779.2 b	39.0 b	13.5 b	74 d	28.7 b
FRF PIR 29 (SD)	36.1 d	506.8 c	25.3 c	18.0 a	80 b	20.2 c
FRF PIR 54 (SD)	47.2 c	708.9 b	35.4 b	18.0 a	81 b	28.7 b
FRF 85.4 (ND)	28.4 d	475.8 c	23.8 c	20.3 a	90 a	21.4 c
FRF 149.18 (ND)	61.7 b	821.4 b	41.1 b	16.1 b	76 c	31.1 b
FRF 102.21 (ND)	87.1 a	1138.5 a	57.0 a	16.3 b	69 d	39.3 a
Mean	59.6	770.2	38.5	17.2	78	29.8
CV (%)	12.7	11.9	11.9	13.1	3.8	12.3

*Means followed by the same letter do not differ significantly by the Scott-Knott test at 5% of error probability.

ND = Neutral Day; SD = Short Day.

The separate acidity values indicate that the FRF 102.21 selection has high acidity, 23% higher than the average, and commercial cultivars below average. Consequently, the SS to TA ratio of the FRF 102.21 selection was 26% below the average. For commercial cultivars, the average value is 15% superior to the average. Strawberry fruits with acceptable flavor must have a minimum of 7% soluble solids and a maximum of 0.8% titratable acidity (KADER 1991).

High levels of soluble solids are desirable in qualitative assessments, both for fresh consumption and for processing. Average levels are around 8% in ripe fruits (FARNEZI et al. 2020). Cultivar Pircinque stood out with an average value of 7.9 °Brix for the soluble solids content, which is positive since palatability is directly linked to the sugar content concerning acids, given by the antagonistic relationship cited by BRACKMANN et al. (2011).

Most cultivars reached an average of 3.2 N for pulp firmness, apart from cultivar Oso Grande and selections FRF 149.18, FRF CE 51, and FRF CE 56, which were below average (3.2 N) (Table 4). The FRF 85.4 genotype stood out with an average of 4.7 N, presenting the highest values of pulp firmness, 33% superior to the other genotypes. Pulp firmness is a determining factor for the success of a cultivar since it allows a longer postharvest period and long-distance transport. This work showed a significant correlation between pulp firmness and commercial percentage (0.62), finding that a lower firmness is consistent with the fruit disposal rate, thus directly influencing the results of the commercial percentage described by FAGHERAZZI (2017a).

Table 4. Assessment of the qualitative aspects of the fruits regarding the mean values for soluble solids (SS), total acidity (TA), SS to TA ratio, pulp firmness, and luminosity (L), chroma (C), and hue angle (h°) of the epidermis color of the fruits of the evaluated genotypes. Vacaria, RS, Brazil, 2015.

Genotype	SS (°Brix)	TA (% citric acid)	Ratio SS/TA	Firmness (N)	Color		
					L	C	h°
Jonica (SD)	6.2 d	0.62 c	10.00 d	3.4 b	20.55 a	24.27 c	17.56 c
Oso Grande (SD)	5.8 e	0.47 e	12.27 b	2.4 c	17.96 b	24.11 c	17.28 c
Pircinque (SD)	7.9 a	0.57 d	13.86 a	3.4 b	19.24 b	24.54 c	16.39 d
Strawberry Festival (SD)	6.4 d	0.57 d	11.15 c	3.3 b	18.69 b	23.31 d	17.52 c
FRF PA3 (SD)	7.4 b	0.61 c	12.10 b	3.2 b	20.21 a	26.37 b	17.50 c
FRF CE 51 (SD)	6.6 c	0.63 c	10.40 d	2.9 b	21.60 a	27.98 a	17.81 c
FRF CE 56 (SD)	6.3 d	0.68 b	9.33 d	3.0 b	20.59 a	26.89 b	18.49 b
FRF PIR 29 (SD)	6.1 e	0.63 c	9.62 d	3.6 b	21.72 a	25.10 c	19.38 a
FRF PIR 54 (SD)	6.2 d	0.63 c	9.83 d	3.2 b	19.17 b	25.80 b	17.53 c
FRF 85.4 (ND)	6.6 c	0.67 b	9.81 d	4.7 a	19.21 b	25.93 b	17.51 c
FRF 149.18 (ND)	5.8 e	0.58 d	9.88 d	2.6 c	19.47 b	24.30 c	18.48 b
FRF 102.21 (ND)	5.9 e	0.76 a	7.77 e	3.2 b	16.40 c	22.12 d	15.88 d
Mean	6.4	0.62	10.5	3.2	19.57	25.06	17.61
CV (%)	2.6	3.7	5.2	7.4	4.8	3.3	2.3

*Means followed by the same letter do not differ significantly by the Scott-Knott test at 5% of error probability.

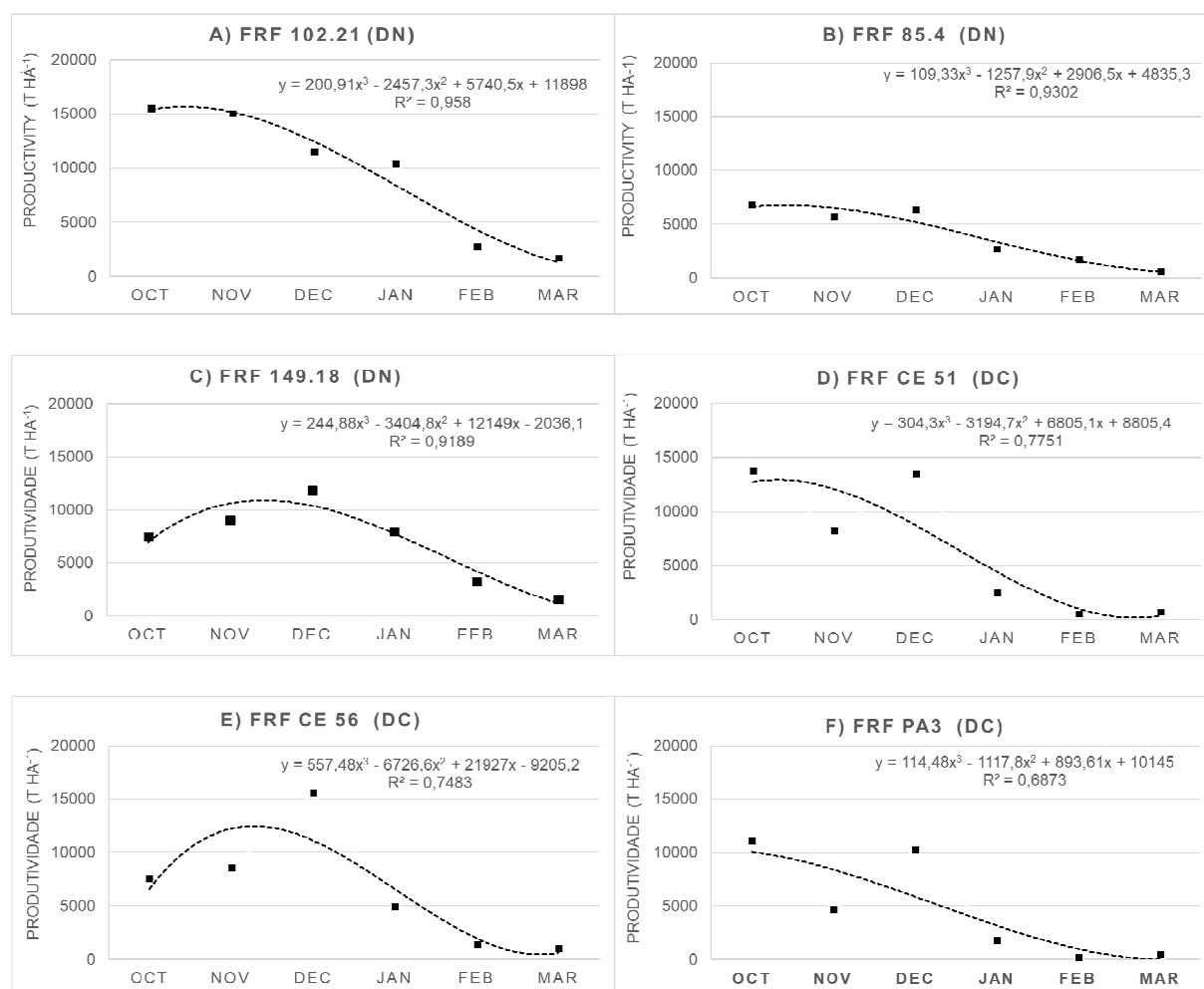
ND = Neutral Day; SD = Short Day.

When considering the epidermis color, the luminosity parameter was divided into three groups (Table 4), where cultivar Jonica and selections FRF PA3, FRF CE 51, FRF CE 56, and FRF PIR 29 were above the average. None of the commercial cultivars presented epidermis saturation above the average (25.06) regarding the chroma variable, and the same behavior was observed for the hue angle. Only selections FRF CE 51 and FRF PIR 29 differed from the others regarding the degree of saturation (chroma) and hue angle, respectively. Luminosity, chroma, and hue had a direct, negative, and significant correlation ($< 5\%$) with production and productivity. Therefore, higher production is consistent with a greater dilution of the epidermis pigments, so cultivars with high production commonly produce fruits with depigmented or little pigmented interiors (CASTRO 2004, DUARTE FILHO et al. 2007).

Among the short-day commercial cultivars (Jonica, Oso Grande, Pircinque, and Strawberry Festival), only cultivar Oso Grande had considerable production in October, representing 39% of its total production. This is consistent with the data obtained by GONÇALVES et al. (2016), who demonstrated that this cultivar has a high precocity under the conditions of the municipality of Pelotas, RS, compared with other commercial cultivars. The production of the other commercial cultivars (Pircinque, Jonica, and Strawberry Festival) was diluted over the evaluated months, presenting a significant drop from February, with average production decreasing around 50% per month.

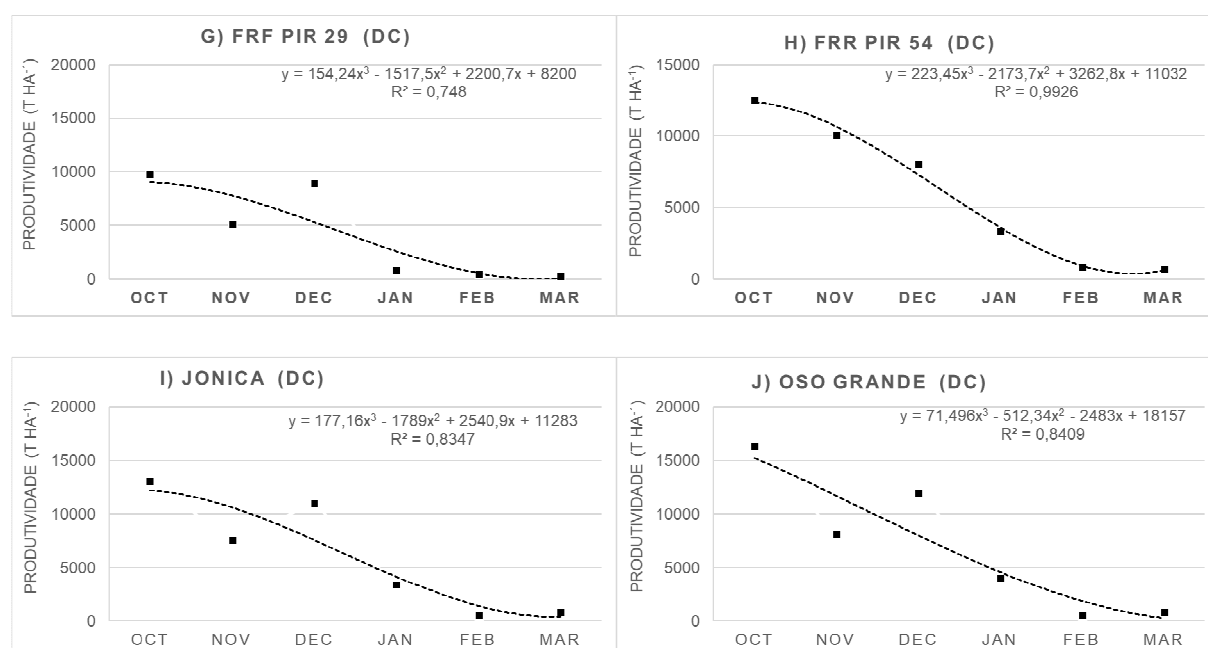
Four of the five short-day selections (FRF PA3, FRF CE 51, FRF PIR 29, FRF PIR 54) had an average production of 37% in October. Selection FRF CE 56 produced 40% of its total production in December. Selections FRF PIR 54 (23%) and FRF 102.21 (20%) were the only selections that presented production peaks in December compared to the average of the other selections (33%).

Figures 1 and 2 show the divergence between neutral-day and short-day cultivars. Most of the short-day cultivars and selections presented low production in January, given that they suffer a strong influence of the photoperiod. When referring to adaptation, strawberries are directly affected by two environmental factors: temperature, neutral-day (ND) and short-day (SD) cultivars, and photoperiod for SD cultivars, since the temperature may affect floral induction differentiation and fruit development, consequently influencing the productivity and quality of the fruits (HONJO et al. 2016).

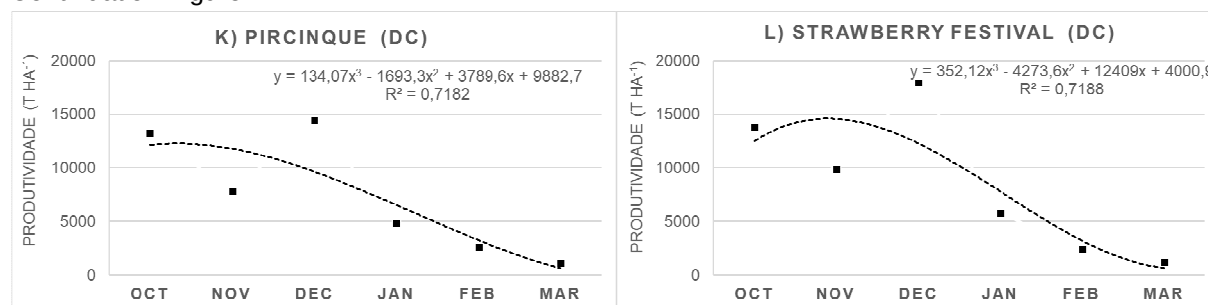


ND = Neutral Day; SD = Short Day. Source: The author, 2019.

Figure 1. Seasonal variation of the commercial production (g plant^{-1}) for genotypes (a) Jonica, (b) Oso Grande, (c) Pircinque, (d) Strawberry Festival, (e) FRF PA3, and (f) FRF CE 51 during the 2015/2016 cycle. Vacaria, RS, Brazil, 2020.



Continuation Figure 2.



Caption: ND = Neutral Day; SD = Short Day. Source: The author, 2019.

Figure 2. Seasonal variation of the commercial production (g plant^{-1}) for genotypes (g) FRF CE 56, (h) FRF PIR 29, (i) FRF PIR 54, (j) FRF 85.4, (k) FRF 149.18, and (l) FRF 102.21 during the 2015/2016 cycle. Vacaria, RS, Brazil, 2020.

The principal component analysis (PCA) (Figure 3) showed four distinct groups. Group I, included in principal component 1 (CP2), consisted of cultivars Pircinque and Oso Grande, genotypes correlated with °Brix, SS to TA ratio, and fresh weight. Group II, arranged on the CP1 axis, consisted of cultivar Jonica and selections FRF PA3, FRF CE 51, FRF PIR 29, FRF PIR 54, and FRF 85.4, presenting a correlation for commercial production percentage, pulp firmness, luminosity, Chroma, and hue angle, with colors far from red. Group III was formed by selections FRF CE 56 and FRF 149.18, grouped with the acidity variable in the CP2 axis. Group IV, arranged in CP1, was composed by selection FRF 102.21 and cultivar Strawberry Festival, both arranged contrary to the chemical and physical fruit quality parameters (soluble solids, soluble solids to titratable acidity ratio, epidermis color) highly correlated with productive parameters (fruits per plant, production per plant, productivity, commercial productivity).

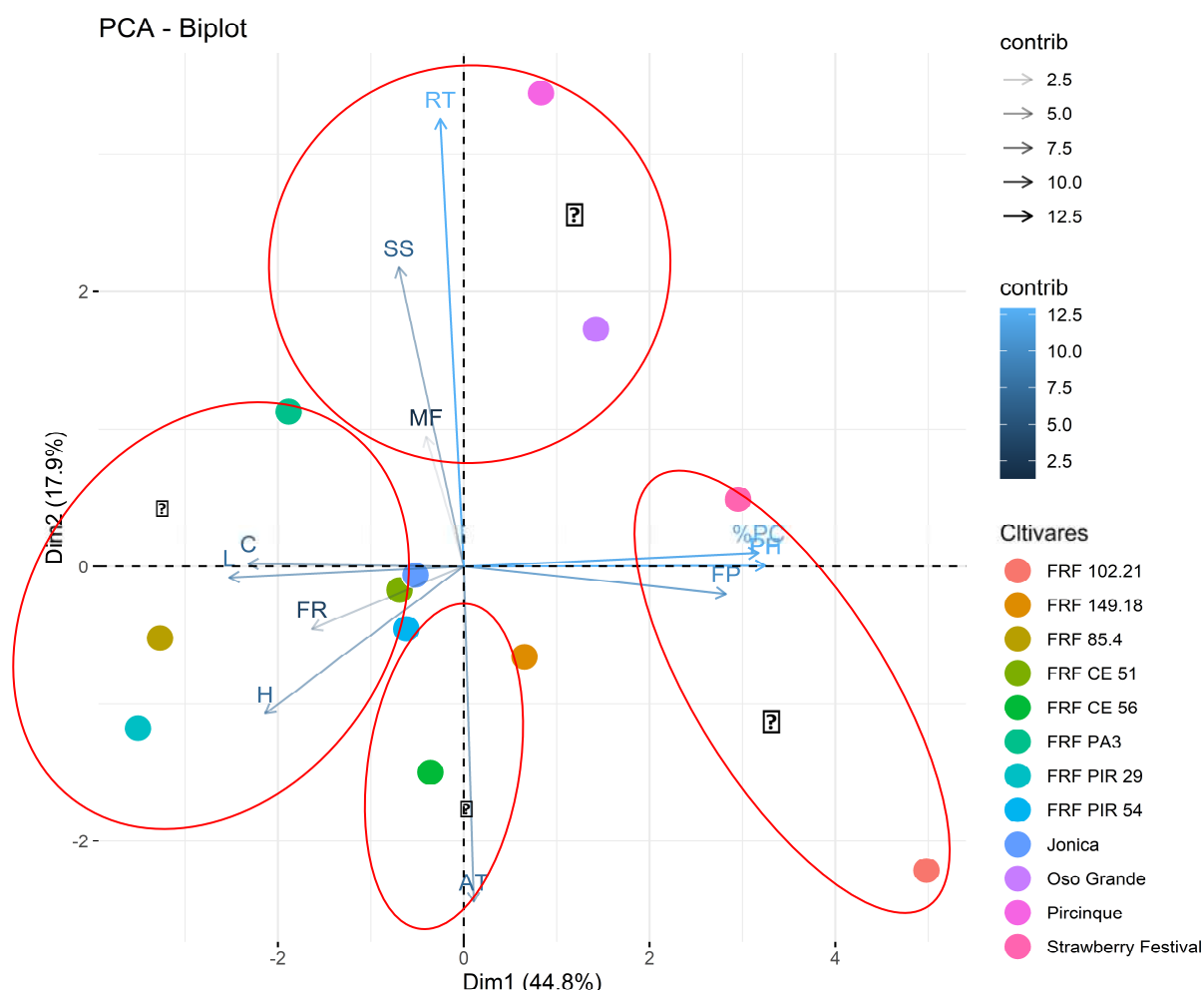
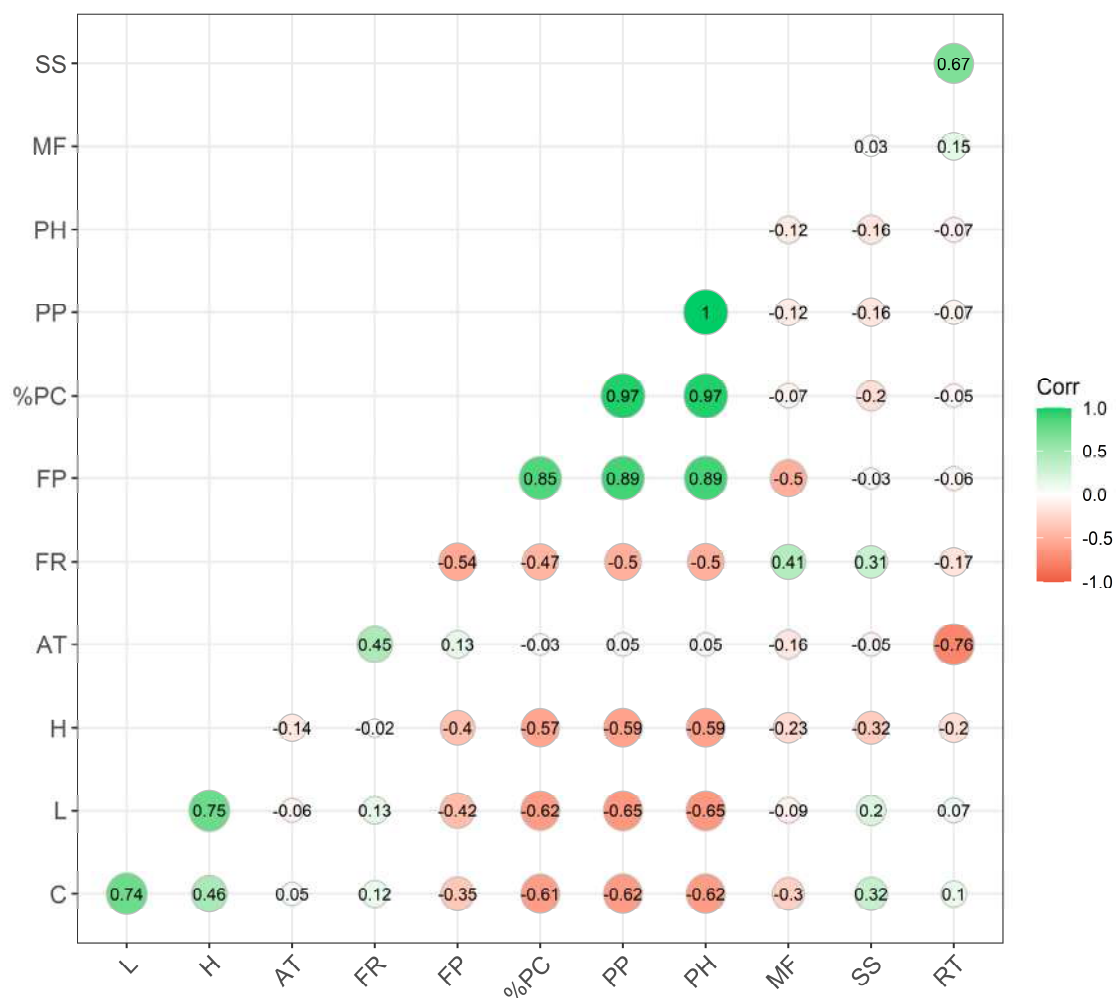


Figure 3. Principal component analysis for the variables, cultivars, and selections evaluated in Vacaria, RS, Brazil, 2015.

Total soluble solids (Figure 4) have a significant (0.67) positive correlation with the SS to TA ratio because it is the numerator of said ratio. On the other hand, the correlation between TA and the SS to TA ratio is highly significant and negative (-0.77), given that it is the ratio denominator. ZANIN et al. (2019) had previously reported similar values (-0.71) for the same correlation in a study with sixteen strawberry genotypes conducted in the municipality of Lages, Santa Catarina.

The number of fruits per plant has a high correlation with dependent variables or even those derived from it, such as commercial production. The same is true for production per plant and productivity and percentage of commercial fruits, also reported by FAGHERAZZI (2017b) and ZANIN et al. (2019).



Correlation matrix, positive correlations are displayed in blue and negative correlations in red color. Color intensity and the size of the circle are proportional to the correlation coefficients.

Caption: FP = fruits per plant. PP = production per plant. PH = productivity per hectare. FM = fresh mass. %CP = commercial percentage. SS = content of soluble solids. FR = firmness. TA = titratable acidity. RT = soluble solids/titratable acidity ratio. LM = epidermis luminosity. CR = epidermis chroma. H = epidermis hue angle.

Figure 4. Pearson correlation matrix among the variables obtained in the adaptability study of the cultivars and selections evaluated in Vacaria, RS, Brazil, 2015.

CONCLUSION

The Strawberry Festival, Jonica, and Pircinque cultivars and the FRF 102.21 selection were best adapted to the climate conditions of Vacaria, RS, Brazil, concerning both qualitative and quantitative data. The Strawberry Festival cultivar and the FRF 102.21 selection presented the highest productivities per hectare.

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Productive Performance and Fruit Quality of Short Days Italian Genetic-based Strawberry Cultivars and Genotypes in Southern Brazil

**Paola Daiane Welter ^a, Juliana Martins de Lima ^a,
Antônio Felipe Fagherazzi ^a, Daiana Petry Rufato ^b,
Leo Rufato ^a, Aike Anneliese Kretzschmar ^a,
Geanluca Baruzzi ^c and Amauri Bogo ^{a*}**

^a Crop Production Graduate Program, Santa Catarina State University/UDESC. Avenida Luis de Camões, 2090, CEP 88520-000, Lages-SC, Brazil.

^b Department of Environmental Engineering, University of Santa Catarina State. Avenida Luis de Camões, 2090, CEP 88520-000, Lages-SC, Brazil.

^c Istituto Sperimentale per la Frutticoltura, Sezione di Forlì, Via Punta di Ferro 2, 47100 Forlì, Italy.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JEAI/2023/v45i122277

Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/111023>

Original Research Article

Received: 17/10/2023

Accepted: 21/12/2023

Published: 30/12/2023

ABSTRACT

When grown under different climatic conditions, short days Italian genetic-based strawberry (IGBS) cultivars and genotypes present variations in productive performance and fruit quality. The objective of this study was to assess different productive performance and fruit quality of IGBS

*Corresponding author: E-mail: amauri.bogo@udesc.br;

cultivars and genotypes grown in highland regions of southern Brazil. The experiment were conducted in randomized block design using three cultivars and 21 genotypes during the 2019, 2020 and 2021 growth seasons. The data were subjected to multivariate analysis using principal component analysis (PCA). IGBS cultivars and genotypes differed significantly in terms of productive and fruit quality parameters, according to PCA data. The first and second main components of PCA, respectively, were responsible for 61.9% and 72.4% of the productive performance and fruit quality parameters. The Pircinque cultivar and FRF PIR 256.04, ITA 13.097.05, ITA 12.103.22, ITA 10.107.07, and ITA 10.133.02 genotypes showed the highest indices of productive parameters of total production per plant, commercial production per plant, total fruit number per plant and commercial fruits number per plant. Among these, the Pircinque cultivar and the FRF PIR 256.04 genotypes demonstrated the best fruit quality parameters of fruit color (skin luminosity, chroma, and hue angle), flavor (soluble solids/ titratable acidity ratio), and fresh commercial fruit mass in highland regions of southern Brazil during the 2018, 2019 and 2020 growth seasons.

Keywords: *Fragaria x ananassa* Duch.; agronomic performance; adaptability; yield; productivity.

1. INTRODUCTION

In the last 20 years, global strawberry (*Fragaria x ananassa* Duch.) production has more than doubled to over 3.6 million tons. The Northern Hemisphere accounts for (98%) of production, with genetic and climatic barriers preventing expansion to the south hemisphere [1]. Strawberry crop development in Brazil began in the mid-1960s, with the launch of the Campinas cultivar [2], and production of the crop has increased in the country since then. Currently, production is around 165,000 tons in about 4,500 hectares of cultivated land, with an average productivity of 36.6 tons per hectare [1].

Strawberry cultivation progress is linked to the introduction of new cultivars to the market, improvement of cultivation techniques and systems, as well as climatic adaptation. Strawberry cultivation has been concentrated primarily on family properties in southern Brazil, particularly in temperate and subtropical regions [3].

Currently, national strawberry production is almost entirely dependent on imported cultivars from the University of California, United States of America (USA) strawberry breeding programs. Many of these cultivars, however, are grown without any prior research into climatic adaptation and productive requirements for different producing regions in southern Brazil. Brazil has a diverse climate and can produce strawberries almost every month of the year. However, due to the country's edaphoclimatic diversity, the small number of available cultivars has been one of the main barriers to the development of the strawberry crop. National breeding programs are essential for encouraging

the development and introduction of new cultivars developed in other countries [4,5].

A cultivar's climatic adaptation to a specific producing region is expressed through the interaction among genotype, environment, and genetic feature, which influences production, productivity, and fruit quality. Thus, the responses of cultivars to fruit yield and quality are primarily determined by the interaction of two factors, photoperiod and temperature [4].

Adaptability studies of cultivars and genotypes are extremely important and necessary, not only in new producing regions, but also in traditional ones, which often, for cultural reasons, do not seek new cultivars that enable better agronomic performance, which is essential for producers' decision-making regarding the best material to be grown in different regions [6].

As a result, the adaptability study with short days Italian genetic-based strawberry cultivars and genotypes in southern Brazil regions is important for obtaining new materials, increasing the cultivars offer in the producing market, and materials that are more productive and have better fruit quality. Thus, the objective of this study was to assess the productive performance and fruit quality of short days Italian genetic-based strawberry cultivars and advanced genotypes grown under edaphoclimatic conditions in highland regions of southern Brazil during the 2019, 2020, and 2021 growth seasons.

2. MATERIALS AND METHODS

The experiments were conducted in Lages Municipality (27°47'05" S, 50°18'08" W), at an altitude of 922 m above sea level, in Santa

Catarina State, Southern Brazil, from May to December of the 2019, 2020, and 2021 growing seasons. According to Köppen classification, the climate of the region is subtropical humid mesothermal Cfb, and soil type is Clay Auric Cambisol [7]. The average annual temperature and rainfall are around 15.6 °C and 1,500 mm, respectively. Daily rainfall, relative humidity, and hourly temperatures were recorded from May to December of the 2019, 2020, and 2021 growth seasons by the Santa Catarina Hydrology and Environmental Resources Center (Epagri). The weather station (Onset Computer Corp., ProCasset, MA, USA; Davis Pro2-6153) was 500 m away from the vineyard.

The experiments included 24 treatments involving three Spanish and Italian cultivars and 21 Italian short days genetic-based genotypes from Consiglio per la Ricerca in Agricoltura-Centro di Olivicoltura, Frutticoltura e Agrumicoltura – CREA-OFA/Italy and Santa Catarina State University (UDESC). Strawberry seedlings used in all experiments were grown field-collected stolon's and rooted in 72 cells trays in a commercial nursery in the Farroupilha Municipality of Rio Grande do Sul State, southern Brazil. The cultivars Jonica, Sabrina, and Pircinque, and the genotypes FRF LAM 269.18, FRF PIR 075.08, FRF 256.04, FRF LAM 263.01, FRF PA 109.02, FRF PIR 079.06, ITA 10.133.02, ITA 13.079.01, ITA 13.079.02, ITA 13.097.05, ITA 12.190.02, ITA 10.107.12, ITA 10.107.07, ITA 10.107.06, ITA 12.103.04, ITA 12.103.06, ITA 12.103.12, ITA 12.103.15, ITA 10.103.22, ITA 10.128.06, and ITA 10.128.09 were evaluated.

A conventional soil cultivation system in low tunnels was used in an experimental randomized blocks design with four replications and eleven plants in each experimental unit. Strawberry seedlings were planted by hand beginning in May of each year of 2019, 2020, and 2021. Soil correction and fertilization were carried out in accordance with soil analysis [8]. Fertilization was done weekly with fertigation, which included: calcium nitrate (9.92 g/100 plants⁻¹); monoamonic phosphate (38.74 g/100 plants⁻¹), P51 (liquid fertilizer containing 51% phosphorus) (7.3 mL/100 plants⁻¹); magnesium sulfate (4.55 g/100 plants⁻¹), and potassium phosphate (31.25 g/100 plants⁻¹).

The experimental beds were 1.00 × 27 × 0.20 m in size for each cultivar and genotype (L × C × H). The beds were covered with 30-micron thick

black polyethylene plastic ('mulching'). Strawberry plants were grown in three rows in a "V" or quinconic system, with 30 cm between plants and 60,000 plants per ha. The irrigation system was drip, with 0.15 m spacing between drippers and a flow rate of 1.5 liters per hour, with three hoses per bed.

When necessary, pest and disease control was carried out using crop-specific products. Acaricide abamectin, insecticide thiametoxan, and fungicides methyl thiophanate (only before harvest), fluazinam, iprodione, pyrimethanil, and azoxystrobin + diphenconazole were also used. Weeds were controlled by weeding between the beds and manual tillage in the planting pits, and old and diseased leaves were removed with pruning shears.

Beginning at the end of August and lasting until the middle of February the following year, harvest were carried out every three days when the fruits displayed epidermis with approximately 70%–80% of the red color. Strawberry fruits were counted, weighed on a semi-analytical scale, and classified using the following criteria:

- 1) Commercial fruits are those that weight more than or equal to 10 grams and are free of injuries, deformations, or rots;
- 2) Small fruits weighing less than 10 grams and free of injuries, deformations, or rots;
- 3) Discarded fruits are those with injuries, deformations, or rots.

2.1 Productive Parameters

The following productive parameters were quantified using the number and weight of analyzed fruits.

a) total plant production (TPP) (g/plant⁻¹); b) commercial production per plant (CPP) (g/plant⁻¹); c) total productivity (TPT) (t/ha⁻¹); d) commercial productivity (CPT) (t/ha⁻¹); e) number of total fruits per plant (NTF) (fruits/plant⁻¹); f) number of commercial fruits per plant (NCF) (fruit/plant⁻¹); g) percentage of commercial production (PCP) (%); h) percentage of small fruit per plant (PSF) (%); and, i) percentage of discard fruits per plant (PDF) (%).

2.2 Fruit Quality Parameters

The following fruit quality parameters were quantified using the number and weight of analyzed fruits. a) fruit pulp firmness (FPF) (g/fruit⁻¹); b) epidermis luminosity (L*); c)

epidermis chroma (C*); d) hue angle (°hue); e) soluble solids (SS) (°Brix); (f) titratable acidity (TA) (g. 100g citric acid); g) soluble solids/titratable acidity ratio (SS/TA); h) average fresh mass of commercial fruits (AMCF) (g/fruit¹).

The physicochemical analysis was carried out using uniform samples of ten fruits per repetition, at each new plant flowering, for a total of four analyses per plant productive cycle. The physicochemical analyses were carried out in accordance with the following methodologies:

- a) Texture Analyzer TA texturometer (Stable Micro Systems Ltd., Vienna Court, UK) was used to measure the L*, C*, °hue (color angle), and FPF parameters expressed in grams;
- b) SS are measured using a digital refractometer and expressed as the concentration of sugars in fruits (°Brix); TA is measured using an automatic TITRONIC titrator® with 5 mL of juice in 45 mL of distilled water and titration in sodium hydroxide solution 0.1N at pH 8.1; and the SS/TA ratio was calculated as the ratio of SS content and TA.

2.3 Data Analysis

The analyses were carried out with data from harvest in 2019, 2020, and 2021, and were carried out by the Shapiro-Wilk normality test, using the Software R [9], via the Action Stat interface. The univariate analysis was carried out using analysis of variance and a Scott-Knott test with a 5% probability of error using the statistical program SISVAR [10]. Fitopac 2.1's statistical program used the PCA for the multivariate analysis [11].

3. RESULTS

The Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes were significantly more productive and had higher fruit quality. The Pircinque cultivar and the FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes had a significant influence on the productive parameters of CPP, NTF, NCF and, AMCF, as well as the fruits quality parameters of L, C*, °hue, SS (°Brix), and SS/TA ratio. The Pircinque cultivar and the FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes did not

show significant differences in fruit quality parameters, which were related to the sweet taste of the fruits and considered very promising cultivar and genotypes for the Brazilian market (Table 1).

The Pircinque and Sabrina cultivars and the FRF PIR 256.04 and ITA 12.103.22 genotypes, produced significant fruits with high FPF and SS and were found to be positively related to the fruits quality parameters L, C, °hue, and SS/TA, indicating fruits with higher sugar content (Table 1). The Pircinque and Sabrina cultivars and the FRF PIR 256.04, ITA 10.107.07, and ITA 12.103.22 genotypes, produced significantly higher-quality fruits with SS/TA ratios that were 25% higher on average than the other cultivars and genotypes, indicating high tasty fruits (Table 1).

Figs. 1 and 2 depicted the PCA data of the cultivars and genotypes productive and fruit quality parameters, respectively. The PCA data of all harvests occurring during the 2019, 2020, and 2021 growth seasons revealed, via vectors, the formation of two major groups of cultivars and genotypes with a positive correlation with productive and fruit quality parameters.

In Fig. 1, both main components were responsible for 85.4% (61.9% plus 23.5%) of the cultivars and genotypes differentiation, according to productive parameters. According to TPP, CP, NTF, and NCF productive parameters, the first main component was responsible for 61.9% of the differentiation of cultivars and genotypes. Thus, the Pircinque cultivar and the FRF PIR 256.04, ITA 13.097.05, ITA 12.103.22, ITA 10.107.07, and ITA 10.133.02 genotypes, highlighted in Fig. 1, were differentiated by showing the highest productive parameters and consequently, more productive plants. The second main component was responsible for 23.5% in the cultivars and genotypes differentiation, according to PSF and PDF productive parameters. Thus, the Pircinque cultivar and the FRF PIR 256.04, ITA 13.097.05, ITA 12.103.22, ITA 10.107.07, and ITA 10.133.02 genotypes, highlighted in Fig. 1, were differentiated by the fruit classification, considered non-commercial fruits because they are either small or discarded fruits. The Pircinque cultivar and the FRF PIR 256.04 genotype produced more discarded fruits than small fruits per plant, whereas the ITA 10.107.07 and ITA 10.133.02 genotypes produced more small fruits than discarded fruits per plant.

Table 1. Analysis of variance (ANOVA) of productive parameters of a) total production per plant (TPP) (g plant⁻¹); b) commercial production per plant (CPP) (g plant⁻¹); c) total productivity (TPT) (t ha⁻¹); d) commercial productivity (CPT) (t ha⁻¹); e) number of total fruits per plant (NTF) (fruits/plant⁻¹); f) number of commercial fruits per plant (NCF) (fruit/ plant⁻¹); g) percentage of commercial production (PCP) (%); h) percentage of small fruit production (PSF) (%); i) percentage of discard fruits (PDF) (%), and fruit quality parameters of a) fruit pulp firmness (FPF) (g fruit⁻¹); b) epidermis luminosity (L*); c) epidermis chroma (C*); d) hue angle (°hue); e) soluble solids (SS) (°Brix); (f) titratable acidity (TA) (g/100g citric acid) and, g) soluble solids/titratable acidity ratio (SS/TA); h) average fresh mass of commercial fruits (AMCF) (g fruit⁻¹), of experiments conducted with short days Italian genetic-based strawberry cultivars and genotypes, during the 2019, 2020 and 2021 growth seasons, at the Lages/SC Municipality, southern Brazil.

Cultivars/genotypes	TPP	CPP	TPT	CPT	NTF	NCF	AMCF	FPF	PSF(%)	PDF(%)	PD(%)	L*	C*	°hue	SS	TA	SS/TA
Jonica	392,58* a	208,32 b	23,55 a	12,50 b	28,05 b	13,30 b	15,65 b	222,56 b	52,57 e	11,87 c	35,57 d	35,24 b	41,77 d	32,47 d	6,6 b	0,48 c	13,80 b
Pircinque	398,99 a	263,43 a	23,94 a	15,80 a	31,45 a	14,95 a	19,00 a	293,63 a	75,32 a	6,57 a	18,07 b	38,11 a	47,70 a	22,13 a	7,8 a	0,41 a	16,87 a
Sabrina	296,04 c	122,17 c	11,76 d	7,33 d	13,15 d	6,71 d	18,57 a	321,72 a	62,55 c	6,62 a	30,80 d	35,14 b	42,08 c	27,70 a	7,9 a	0,47 c	16,46 a
FRF LAM 269.18	337,50 b	219,94 b	20,25 b	13,19 b	22,53 c	11,45 b	19,32 a	193,22 c	65,15 c	5,35 a	29,55 d	33,86 c	41,16 d	29,95 b	7,2 b	0,54 d	13,27 b
FRF PIR 075.08	331,33 b	218,49 b	19,87 b	13,11 b	25,31 b	13,18 b	16,52 b	241,08 b	65,70 c	8,07 b	26,22 c	34,83 b	43,63 c	31,06 c	7,8 a	0,58 e	13,65 b
FRF PIR 256.04	412,66 a	279,43 a	24,76 a	16,79 a	32,88 a	15,11 a	18,95 a	282,30 a	67,95 c	5,17 a	26,90 c	37,16 a	46,18 a	21,73 a	7,9 a	0,38 a	16,07 a
FRF LAM 263.01	264,90 c	170,12 c	15,89 c	10,20 c	23,63 c	11,39 b	15,27 b	220,29 c	63,82 c	12,70 c	23,47 c	34,57 c	39,69 e	32,70 d	5,8 c	0,51 c	11,47 c
FRF PA 109.02	366,25 b	216,35 b	21,97 b	12,97 b	28,14 b	12,02 b	18,12 a	218,82 c	58,97 d	9,32 b	31,72 d	33,56 c	39,71 e	31,33 c	6,5 b	0,44 b	13,84 b
FRF PIR 079.06	276,19 c	164,54 c	16,57 c	9,87 c	20,37 c	9,32 c	17,42 a	197,06 c	58,77 d	8,15 b	33,07 d	38,60 a	46,87 a	34,87 e	8,2 a	0,67 e	13,38 b
ITA 10.133.02	377,73 a	273,61 a	19,06 b	13,41 b	28,67 a	14,87 a	17,41 a	228,79 c	70,35 b	13,60 c	16,05 b	34,34 c	40,86 d	30,80 c	6,8 b	0,70 e	9,54 c
ITA 13.079.01	179,59 d	81,95 d	10,77 d	4,91 e	16,67 d	5,04 e	16,21 b	247,90 b	45,67 f	14,95 c	39,35 d	35,13 b	43,09 c	33,92 e	6,8 b	0,67 e	10,06 c
ITA 13.079.02	228,35 c	143,49 c	13,69 c	8,61 c	21,63 c	9,25 c	15,56 b	263,93 b	63,00 c	25,40 d	11,60 a	35,58 b	41,00 d	33,74 e	5,4 c	0,57 d	9,39 c
ITA 13.097.05	388,22 a	262,10 a	22,09 b	13,92 b	29,86 a	15,07 a	17,87 a	164,41 d	63,10 c	7,72 b	29,20 d	34,03 c	42,23 c	32,15 d	4,9 d	0,45 b	10,74 c
ITA 12.190.02	75,49 e	49,05 e	4,53 e	2,94 f	6,16 e	3,14 f	15,84 b	98,40 e	64,90 c	9,97 b	25,15 c	39,30 a	44,39 b	34,90 e	5,8 c	0,54 d	10,81 c
ITA 10.107.12	250,47 c	147,60 c	15,02 c	8,85 c	20,84 c	7,83 d	18,66 a	249,62 b	58,42 d	19,10 d	22,50 c	34,02 c	40,10 e	31,18 c	4,6 d	0,39 a	11,60 c
ITA 10.107.07	391,36 a	284,30 a	21,68 b	13,46 b	29,55 a	13,99 a	18,78 a	153,04 d	61,95 c	15,47 c	22,55 c	39,27 a	47,80 a	20,85 a	4,8 d	0,35 a	15,82 a
ITA 10.107.06	242,83 c	157,09 c	14,57 c	9,42 c	18,01 d	8,85 c	17,56 a	153,93 d	63,97 c	12,07 c	23,90 c	32,06 d	38,42 e	29,63 b	5,7 c	0,45 b	12,87 b
ITA 12.103.04	252,19 c	143,78 c	15,13 c	8,62 c	20,31 c	8,84 c	16,17 b	212,86 c	56,82 d	9,00 b	34,17 d	30,94 d	40,47 d	27,66 a	5,7 c	0,52 c	11,07 c
ITA 12.103.06	209,75 c	168,33 c	12,58 c	10,09 c	13,75 d	9,19 c	18,23 a	235,67 b	79,67 a	9,47 b	10,85 a	30,64 d	38,33 e	26,62 a	5,4 c	0,49 c	10,86 c
ITA 12.103.12	174,98 d	109,91 d	10,50 d	6,59 d	14,35 d	6,33 d	17,39 a	266,44 b	63,00 c	15,80 c	21,25 c	33,66 c	43,35 c	30,85 c	4,6 d	0,43 b	10,63 c
ITA 12.103.15	315,13 b	201,20 b	18,90 b	12,07 b	20,25 c	10,27 b	19,68 a	192,92 c	63,85 c	6,45 a	29,67 d	33,23 c	42,62 c	30,93 c	5,4 c	0,47 c	11,46 c
ITA 12.103.22	419,13 a	292,15 a	25,14 a	17,53 a	30,75 a	18,35 a	17,97 a	304,23 a	69,52 b	11,85 c	18,62 b	36,34 a	46,19 a	25,79 a	7,6 a	0,40 a	16,62 a
ITA 10.128.06	258,77 c	188,78 c	15,52 c	11,32 c	24,33 c	11,65 b	12,44 c	251,65 b	72,90 b	11,22 c	15,87 b	33,96 c	40,60 d	32,09 d	5,9 c	0,54 d	10,78 c
ITA 10.128.09	267,68 c	169,83 c	16,06 c	10,18 c	19,60 c	9,08 c	18,87 a	214,73 c	63,35 c	8,62 b	28,07 c	33,84 c	39,46 e	31,93 d	6,2 c	0,52 c	11,75 c
Average	284,98	181,78	17,09	17,44	21,82	10,61	17,31	220,33	63,46	10,89	25,64	34,23	41,76	31,24	6,2	0,52	12,22
C.V***, %	13,17	3,45**	13,17	7,64**	6,86**	7,78**	3,73**	9,93	6,81	9,36**	5,24**	3,14	2,99	3,21	7,97	2,82**	8,53

* Means followed by the same letter in the column are not significantly different (Scott-knott test, $P < 0.05$);

** Data transformed by the formula $Y = \log(x)$;

*** Coefficient of variation.

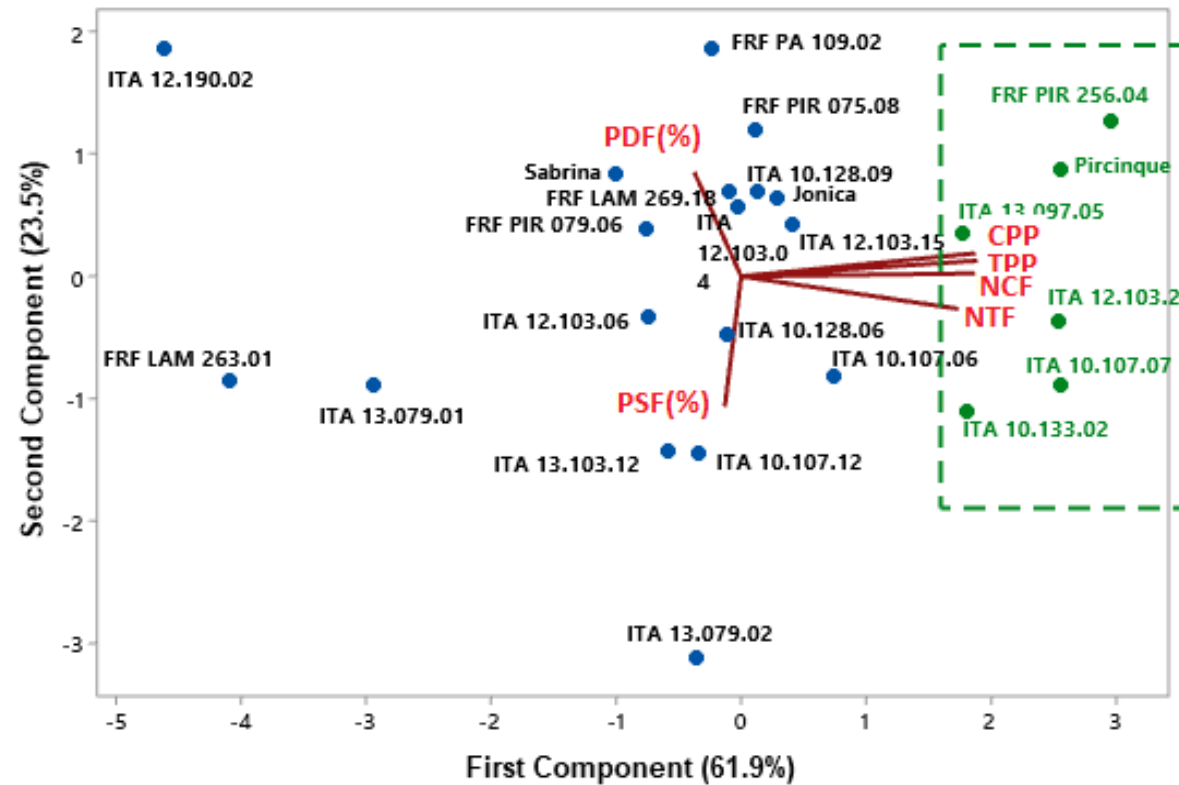


Fig. 1. Principal Component Analysis (PCA) of the productive parameters of a) total production per plant (TPP) (g/plant^{-1}); b) commercial production per plant (CPP) (g/plant^{-1}); c) number of total fruits per plant (NTF) (fruits/plant^{-1}); d) number of commercial fruits per plant (NCF) (fruit/plant^{-1}); e) percentage of small fruit production per plant (PSF) (%), and, f) percentage of discard fruits per plant (PDF) (%) of experiments conducted with short days Italian genetic-based strawberry cultivars and genotypes, during the 2019, 2020 and 2021 growth seasons, at the Lages/SC Municipality, southern Brazil

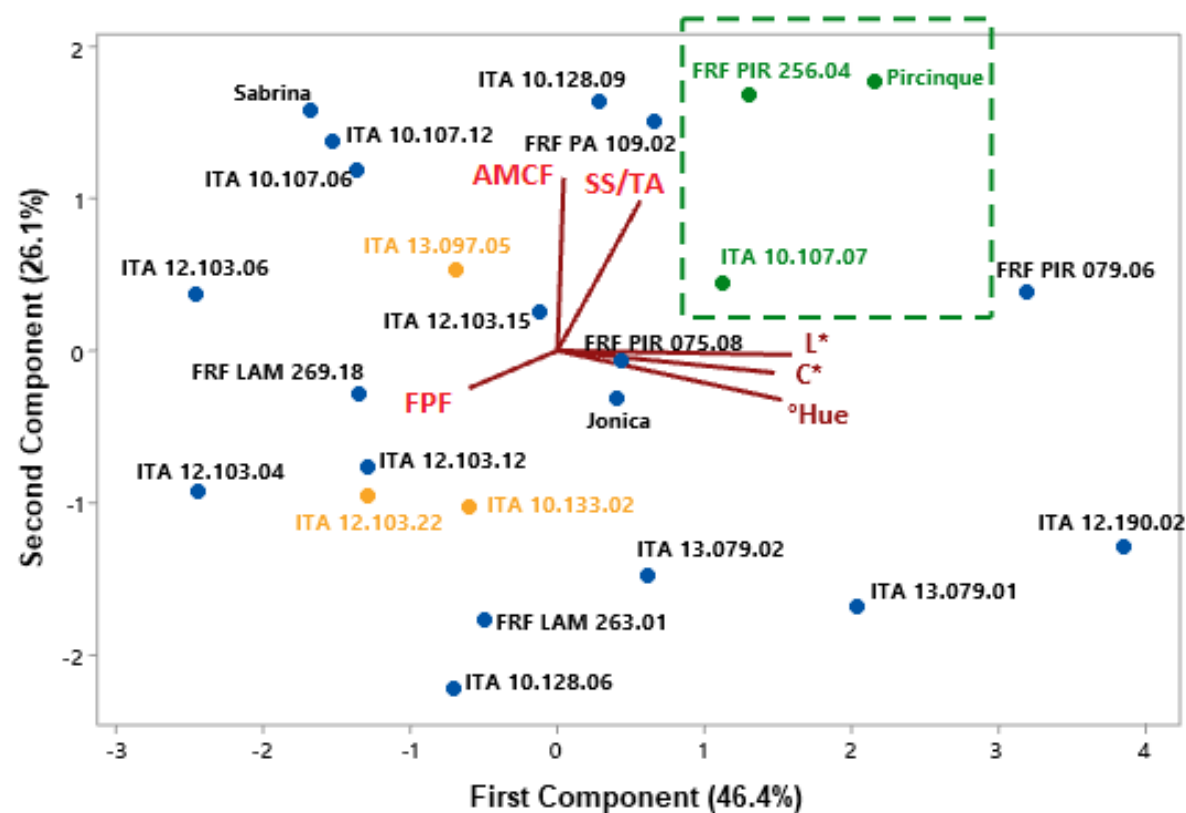


Fig. 2. Principal Component Analysis (PCA) of the fruit quality parameters of a) fruit pulp firmness (FPF) (g/fruit^{-1}); b) epidermis luminosity (L^*); c) epidermis chroma (C^*); d) hue angle ($^\circ\text{hue}$); e) soluble solids/titratable acidity ratio (SS/TA), and f) average fresh mass of commercial fruits (AMCF) (g/fruit^{-1}) of experiments conducted with short days Italian genetic-based strawberry cultivars and genotypes, during the 2019, 2020 and 2021 growth seasons, at the Lages/SC Municipality, southern Brazil

In Fig. 2, both main components were responsible for 72.5% (46.4% plus 26.1%) of the cultivars and genotypes differentiation, according to fruit quality parameters. According to fruit color L^* , C^* , and $^{\circ}\text{hue}$, the first main component was responsible for 46.4% of cultivars and genotypes differentiation. According to fruit flavor SS/TA and AMCF parameters, the second main component was responsible for 26.1% of the differentiation between cultivars and genotypes. The FPF did not show significance for any of the main components (first and second) and was not regarded as a good and reliable parameter in the differentiation of cultivars and genotypes.

The Pircinque cultivar and FRF PIR 256.04, ITA 13.097.05, ITA 12.103.22, ITA 10.107.07, and ITA 10.133.02 genotypes showed the highest productive parameters of CPP, TPP, NCF and NTF (Fig. 1). Among them, the Pircinque cultivar and FRF PIR 256.04 and ITA 12.103.22 genotypes, highlighted in Fig. 2, demonstrated the highest color, flavor, and AMCF parameters, with the highest value for the Pircinque cultivar and FRF PIR 256.04 genotype. Despite having high productive parameters, the ITA 13.097.05, ITA 12.103.22, and ITA 10.133.02 genotypes showed significantly lower fruit color parameters when compared to the Pircinque cultivar and FRF PIR 256.04 and ITA 12.103.22 genotypes that differed by the SS/TA and AMCF parameters. However, the ITA 13.097.05 genotype showed the highest SS/TA and AMCF, indicating a high sweet taste than ITA 12.103.22 and ITA 10.133.02 genotypes (Fig. 2).

4. DISCUSSION

The Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes showed a positive correlation between the productive and fruit quality parameters. This correlation is highly desirable because cultivars and genotypes that combine high production and sweet fruit quality are difficult to find. These findings are consistent with Zanin et al. [12], who identified these cultivars and some of these genotypes for production in some regions of southern Brazil and other climate areas. The Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes demonstrated high NTF and AMCF, which are important parameters for strawberry yield [4, 5].

Strawberry fruit size stability is an important criterion in the plant breeding selection process

for new commercial cultivars. Thus, the AMCF parameter is directly related to fruit size, because large fruits facilitate harvesting and packaging, lowering production and general service costs [3].

The TPT average of the Jonica and Pircinque cultivars, as well as the FRF PIR 256.04 and ITA 12.103.22 genotypes, was 24.35 t ha^{-1} , which was higher than the world TPT average of 22.7 t ha^{-1} (Table 1) (Fao, 2018). The ITA 12.103.22 genotype progeny (parents) is the cultivar "Florida Fortuna" which has high production, productivity and fruit quality [13]. Zanin et al. [12] obtained better results with these same materials in a conventional system in the Santa Catarina State highland region of southern Brazil. The Jonica cultivar progeny is the "Kilo", a high productive cultivar that was also chosen for its early production and productivity when compared to the other cultivars and genotypes, as these characteristics can increase its productive potentiality and agronomic performance [14,5].

The Italian Pircinque cultivar, introduced in Brazil by the Santa Catarina State University (UDESC), had previously been evaluated and demonstrated a high degree of climate adaptability to the regions of southern Brazil [15,12]. The FRF PIR 256.04 genotype was developed as part of a strawberry breeding project developed at CREA-OFA/Italy with the goal of creating a series of strawberry cultivars with high fruit yield and quality. The FRF PIR 256.04 genotype was previously evaluated in Brazil by Faedi et al. [15], and its high productive performance, good environmental response, and visual fruit quality are supported by the current data.

The Pircinque cultivar and the FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes demonstrated a high NTF and AMCF of 18.47 grams. Gallace et al. [16] defines an excellent commercial fruit quality as an AMCF parameter of around 12.0 grams per fruit. Additionally, this former cultivar and genotypes group (Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes), showed the highest fruit red color intensity, especially by the L^* parameter, because L^* parameter expresses the degree of color luminosity ($L^* = 100 = \text{white}$; $L^* = 0 = \text{black}$). In this case, the red values showed by this group, indicated the tendency of the fruits to light red color. The reduction of C^* values indicate a

reduction in the saturation of fruit red pigments, which is less vivid, while the color intensity values ($^{\circ}$ hue) indicated that the red color of the fruits remained similar among the cultivar and genotypes. According to Ávila et al. (2012), lower relative of $^{\circ}$ Hue values, indicate darker coloration. Thus, in the present study, the Pircinque cultivar and the FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07 and ITA 12.103.22 genotypes showed high luminosity and consequently, light epidermis color. The fruit red external color is one of the first factors that consumers take into account in the acquisition of strawberry fruits. Fruits with intense bright red color, but not darkest, are preferable to the public consumers [17]. The epidermis luminosity (L^*) can range from 0 (dark) to 100 (light), instead in the case of C^* or also color purity, the lower of C^* value, higher is the degree color impurity and lower the pigments saturation, while high C^* values increase pigment saturation, generating a pure color [18].

The Pircinque and Sabrina cultivars, as well as the FRF PIR 079.06, FRF PIR 256.04, and FRF PIR 075.08 ITA 12.103.22 genotypes, had the highest fruit SS concentrations, a quantitative feature that may be influenced by climate conditions [19,20]. Plant photosynthesis generates SS with at least 85% sugars in their composition. The higher the SS content, the sweeter are the fruits [14]. The SS content is determined by genetic characteristics [21,19] and is influenced by climate conditions, which explains the differences observed among the cultivars and genotypes studied. Strawberry SS contents variation range from 4.0°–11.0°Brix [19], and all data presented in this study fell within this range.

Pircinque and Sabrina cultivars and the FRF PIR 075.08, ITA 10.107.07 and ITA 12.103.22 FRF PIR 075.08, ITA 10.107.07, and ITA 12.103.22 genotypes, demonstrated the highest SS/TA ratio and, as a result, high fruits sweetness, correlating with the data obtained by et al. [22] and Ahmadi et al. [23], particularly with Pircinque and Sabrina cultivars conducted under different nutritional management. A high SS/TA ratio reflects the quality of fruit flavor/aroma, which is the result of the fruit's sugar content and acidity being balanced. As a result, the higher the fruit SS/TA ratio, the more balanced the flavor/aroma and the greater the sensory fruit acceptance Barankevicz et al., 2015). The fruit SS/TA ratio is more representative than sugars and acidity

alone, allowing for a more accurate assessment of fruit flavor/aroma [24].

Pircinque cultivar and the FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes produced not only a large number of fruits, but also a large number of marketable fruits with ideal size and visual quality, making these cultivar and genotypes potential options for commercial fresh fruits. When it comes to purchasing decisions, most consumers prioritize fruit size and appearance over flavor [12]. When developing new cultivars in breeding programs, genotypes that combine fruit quality characteristics with high productivity are always sought. However, this combination is not always easy to achieve, because many of these productive and fruit quality parameters are inversely related depending on the germplasm material available [15,25,26].

5. CONCLUSION

The Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes demonstrated the highest productive and fruit quality parameters in conventional soil systems at low tunnels in edaphoclimatic conditions of highland regions of southern Brazil.

The Pircinque cultivar and FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes are potential options for producing cultivars with a high productive parameters, fruit flavor/aroma quality, and fruits SS/TA ratio for the *in natura* market.

The FRF PIR 256.04, ITA 10.133.02, ITA 13.097.05, ITA 10.107.07, and ITA 12.103.22 genotypes were the most promising in terms of fruit production and fruit quality features and may become cultivars recommended for cultivation in southern Brazil, along with Pircinque cultivar.

ACKNOWLEDGEMENTS

The authors thank CREA-OFA/Italy, Capes (Coordination for higher Education Staff Development), Fapesc (Research and Innovation Foundation of Santa Catarina State), Cnpq (National Council for Scientific and Technological Development) for funds and fellowships.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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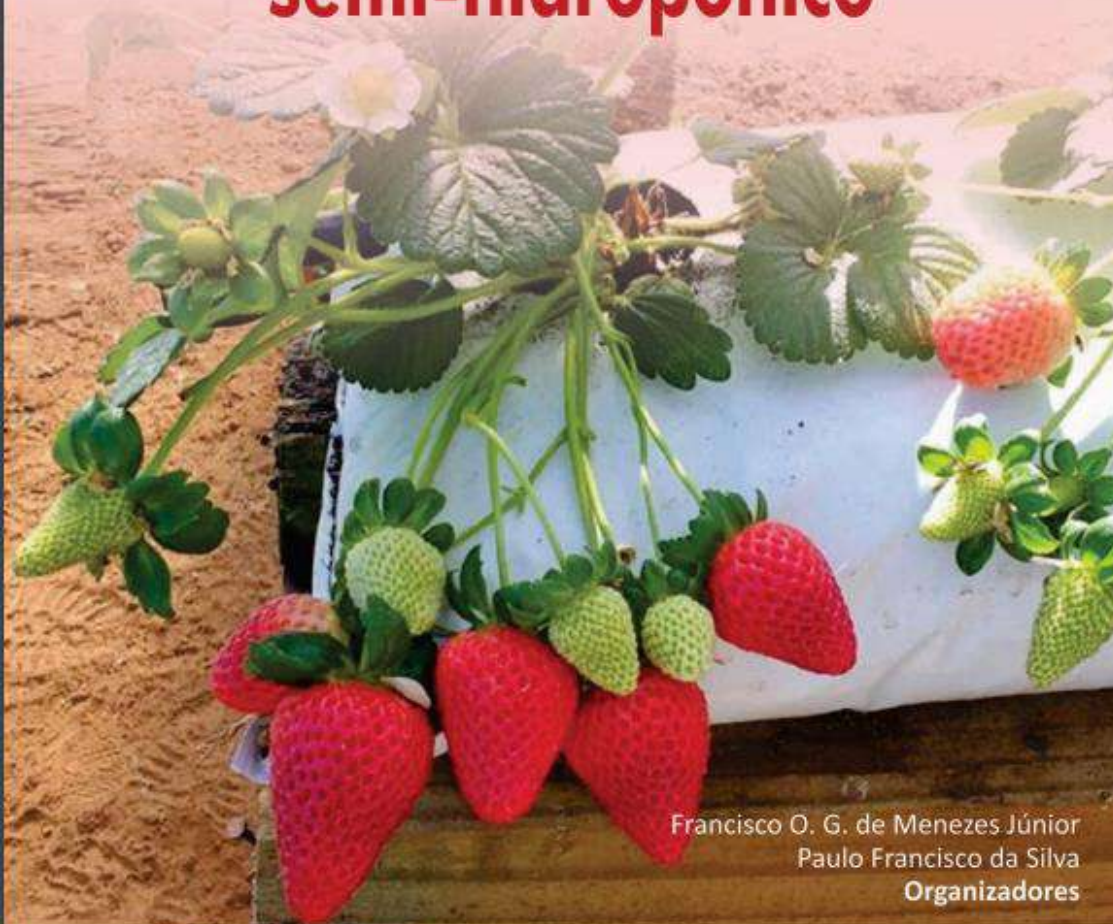
Peer-review history:

The peer review history for this paper can be accessed here:
<https://www.sdiarticle5.com/review-history/111023>

ISBN 978-85-85014-94-0

Fevereiro/2023

Cultivo do morangueiro em sistema semi-hidropônico



Francisco O. G. de Menezes Júnior
Paulo Francisco da Silva
Organizadores





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Jorginho dos Santos Mello

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e do Desenvolvimento Rural**
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Presidente da Epagri
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Desenvolvimento Institucional

Giovani Canola Teixeira
Administração e Finanças

Humberto Bicca Neto
Extensão Rural e Pesqueira

Vagner Miranda Portes
Ciência, Tecnologia e Inovação



Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (Epagri)
Rodovia Admar Gonzaga, 1.347, Itacorubi, Caixa Postal 502
88034-901 Florianópolis, Santa Catarina, Brasil
Fone: (48) 3665-5000
Site: www.epagri.sc.gov.br

Editado pelo Departamento Estadual de Marketing e Comunicação (Epagri/DEMC)

Editoração técnica: Paulo Sergio Tagliari
Revisão textual: Laertes Rebelo
Diagramação: Vilton Jorge de Souza

Primeira edição: fevereiro de 2023
Tiragem: 228 exemplares
Impressão: Gráfica CS

É permitida a reprodução parcial deste trabalho desde que a fonte citada.

Ficha catalográfica

MENEZES JR., F.O.G.; SILVA, P.F. (Orgs.). **Cultivo do morangueiro em sistema semi-hidropônico**. Florianópolis: Epagri, 2023. 316p.

Fragaria x ananassa; Sistema semi-hidropônico; Melhoramento; Produção de mudas; Fisiologia; Manejos fitotécnico, nutricional e fitossanitário; Custo de produção.

ISBN 978-85-85014-94-0



1 Panorama mundial da produção de morango

Leo Rufato
Aike Anneliese Kretschmar
Antonio Felipe Fagherazzi
Francisco Olmar Gervini de Menezes Júnior
Francine Regianini Nerbass
Juliana Martins de Lima
Marllon Fernando Soares dos Santos
Bruna Miranda Costa
Lamine Sanó
Fernanda Pereira

Introdução

Os maiores produtores mundiais de morango são: China, Estados Unidos, México, Turquia, Egito, Espanha, Rússia, Coreia do Sul, Polônia, Marrocos e Brasil, em décimo primeiro lugar. Com 3.959.668t/ha, o continente asiático lidera a produção mundial de morangos, correspondendo 46,2%. A China contribui com 3.212.814t/ha, ocupando o primeiro lugar no ranking produtivo.

Em constante ascensão, as Américas se destacam a cada ano, com a parcela de 26,2% na média da produção mundial, tendo como maiores produtores Estados Unidos, México e Brasil, que produzem 1.021.490, 861.337, 165.440t/ha, respectivamente (Figura 1).

A América do Sul ganha projeção a cada ano pelo aumento de produção de morangos. De acordo com os últimos dados fornecidos pela FAO STAT (2020), a produção subiu de 8.242.262t/ha em 2017 para 8.885.028 t/ha em 2019, aumento significativo de 642.766t/ha representando 8% deste desdobramento.



Figura 1. Maiores produtores mundiais de morango no ano de 2019

Fonte: Faostat, 2020, adaptada

4 Melhoramento genético

Leo Rufato
Aike Anneliese Kretzschmar
Antonio Felipe Fagherazzi
Francine Regianini Nerbass
Juliana Martins de Lima

Introdução

A espécie *Fragaria x Ananassa Duchesne* ($2n = 8x = 56$) mundialmente cultivada, um octoploide, é resultado da hibridização entre duas espécies progenitoras octoploides selvagens originárias da América (*Fragaria virginiana* x *Fragaria chiloensis*) há mais de 300 anos, na Europa (EDGER et al., 2019; BRAHM & OLIVEIRA, 2004; OLIVEIRA & BONOW, 2012).

Todos os cultivares de morango cultivados no Brasil no século passado eram de origem americana ou europeia, apresentando pouca adaptação às condições edafoclimáticas dos principais estados produtores (São Paulo e Rio Grande do Sul), além da baixa qualidade de frutos e baixa produtividade (OLIVEIRA & BONOW, 2012).

A situação mudou com os trabalhos de melhoramento genético no Brasil iniciados no ano de 1941, no Instituto Agrônomo de Campinas (IAC) em Campinas, SP. Graças ao cultivo dos clones geneticamente melhorados desenvolvidos no IAC, a produção de morangos em São Paulo aumentou seis vezes no final da década de 1960 (CASTRO, 2004).

O cultivo de morango se expandiu a partir de 1960 com o lançamento dos cultivares nacionais, oriundos da Estação Experimental de Pelotas, ligada ao Ministério da Agricultura, e ao IAC (FAGHERAZZI et al., 2017; OLIVEIRA & BONOW, 2012).

O Brasil, nos últimos anos, além de apresentar aumento significativo em área cultivada, também aderiu a novas tecnologias, elevando assim a produtividade e a qualidade dos frutos (ANTUNES; FAGHERAZZI; VIGNOLO, 2017).

No Brasil, contudo, as ações precisam ser direcionadas aos programas de melhoramento genético para o desenvolvimento de genótipos adaptados para cada região produtora. A adaptabilidade de um cultivar para uma determinada região produtora é uma expressão da interação entre o genótipo e o ambiente. Essa interação determina a qualidade do fruto e sua produtividade, que também são influenciadas pelas condições de solo e incidência de pragas e/ou doenças. Consequentemente, quando um cultivar é selecionado para uma área, a adaptabilidade em outras áreas depende da interação com os fatores ambientais nessas regiões, podendo assim apresentar respostas diferentes quanto à produtividade, qualidade da fruta, precocidade e suscetibilidade a pragas e doenças (ANTUNES; REISSER JÚNIOR; SCHWENGBER, 2016).

É necessário, portanto, o desenvolvimento de cultivares adaptados às condições edafoclimáticas das regiões produtoras brasileiras e aos diferentes sistemas de produção, seja eles convencionais, orgânicos, fora do solo ou hidropônicos. Busca-se então cultivares produtivos, com frutos grandes, doces, firmes, boa conservação pós-colheita e período longo de colheita (ANTUNES; REISSER JÚNIOR; SCHWENGBER, 2016).

5 Fisiologia e cultivares

Leo Rufato
Aike Anneliese Kretzschmar
Antonio Felipe Fagherazzi
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Francine Regianini Nerbass
Juliana Martins de Lima
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5.1 Fisiologia

A adaptação das plantas e a produção de frutas com qualidade estão atreladas à escolha do cultivar. Dessa forma, deve-se atentar para exigências climáticas, fatores fisiológicos e incidência de pragas e doenças em cada cultivar.

Dentre os fatores edafoclimáticos que afetam a fisiologia do morangueiro, segundo Duarte Filho et al. (1999), a temperatura e o fotoperíodo, bem como a interação entre os dois fatores, são os aspectos de maior importância, principalmente durante o florescimento da cultura, pois têm efeitos na qualidade dos frutos. Além dos dois fatores citados, durante os nove estádios fenológicos da cultura (MEIER, 1994), o crescimento e o desenvolvimento das plantas podem ser afetados pela ação de outros fatores como é o caso da disponibilidade de água, a qualidade e a intensidade luminosa, o solo e o estado nutricional das plantas.

Temperatura

A temperatura é citada na literatura como o principal fator limitante na produção do morangueiro ao afetar o desenvolvimento vegetativo, a produção e a qualidade das frutas (FILGUEIRA, 2003; COCCO, 2010). Para Tazzo et al. (2015), a temperatura desempenha um papel mais relevante na floração da cultura (TAZZO et al., 2015). Apesar de ser originário de regiões de clima temperado, o morangueiro adapta-se muito bem a climas quentes e secos.

O morangueiro é tolerante a temperaturas baixas, geadas, entretanto suas flores podem sofrer danos que ocasionam deformação das frutas (TESSARIOLI NETO et al., 2003; TAYLOR, 2002; SERÇE & HANCOCK, 2005). Para estes autores, em temperaturas baixas, a cultura possui um período de dormência, onde acumula carboidratos e interrompe temporariamente seu crescimento vegetativo. Já com a elevação da temperatura combinada com aumentos do fotoperíodo ocorre forte favorecimento no desenvolvimento de estolões e folhas, sendo que a redução dos mesmos eventos favorece a frutificação do morangueiro (FRONZA & HAMANN, 2017). Com esses fatores altos ou baixos, mesmo havendo o suprimento adequado de água e nutrientes, a produtividade e a qualidade da fruta podem sofrer alterações levando a prejuízos na produção.

6 Produção de matrizes e mudas, viveiros e legislação

Leo Rufato
Aike Anneliese Kretzschmar
Antonio Felipe Fagherazzi
Francine Regianini Nerbass
Juliana Martins de Lima
Bruna Miranda Costa
Fernanda Pereira

Introdução

Na produção de morango, ocorre ao longo do ano de cultivo o acúmulo de doenças e pragas, o que torna as plantas mais frágeis para o seguimento delas no segundo ano, o que pode acarretar baixa produtividade. Portanto, as plantas precisam ser renovadas, o que ocasiona grande demanda anual. Desta forma, a produção de mudas é de grande importância na cadeia produtiva do morango. Segundo Antunes et al. (2015), as mudas representam cerca de 25% dos gastos na produção total de morangos, um valor que corresponde a mudas com excelente qualidade fisiológica e fitossanitária, produzidas segundo o melhor método. Vale destacar que no Brasil a demanda é grande – cerca de 175 milhões de mudas por ano.

Denominada de planta jovem, a muda é a parte vegetativa da planta com todas as características da planta que lhe deu origem, a planta mãe (matriz). Sua formação ocorre a partir do encontro do nó fértil do estolão com o substrato úmido, em seguida são emitidas rapidamente raízes das gemas e uma nova planta é formada.

Para a escolha da planta mãe, portanto, é essencial observar alguns critérios, como: o vigor da planta, se é uma planta robusta, com caules e folhas sem deformações e de coloração verde uniforme; a nutrição equilibrada e a boa qualidade, sem manchas indicativas de doença e deficiência nutricional. Essas características são de grande importância para produção de mudas de qualidade, favorecendo o bom desenvolvimento e a boa produtividade em campo (NUNES, 2018).

A crescente dependência de mudas importadas (muda de raiz nua), vindas principalmente da Argentina e do Chile, deixa os produtores brasileiros à mercê da entrega, que muitas vezes pode ser tardia, podendo prejudicar a produção precoce. Além disso, essas mudas apresentam custo elevado, por causa das vistorias fitossanitárias realizadas para evitar que novas doenças entrem no território nacional (SCHMITT et al., 2016). Consequentemente, seu plantio também tende a atrasar e, por conta disso, a planta pode acabar não expressando o seu verdadeiro potencial produtivo. Dessa forma, são necessárias técnicas que permitam atrasar ou antecipar a colheita com o intuito de comercializar o produto no período de maior retorno econômico. Além disso, as mudas importadas exigem transporte rápido e oneroso, o que algumas vezes pode não ocorrer devido à logística de alguns países (NUNES, 2018).

Existem comercialmente no Brasil dois tipos de produção de mudas: as produzidas através de estolões emitidos pela planta, que podem ser enraizados no solo ou em