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Agronomic characteristics and postharvest quality of strawberry in a semi-hydroponic cultivation system

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Abstract – The objective of this work was to evaluate the influence of using a semi-hydroponic system on the agronomic and postharvest variables of strawberry cultivars. The experiment was conducted in a randomized complete block design, with cultivars Aromas, Camarosa, Festival, Merced, Oso Grande, and San Andreas, with eight plants per plot and five replicates. Agronomic and postharvest variables were evaluated. Cultivar San Andreas showed the highest values for the agronomic variables number of commercial fruits and total and commercial yield per plant, with the highest yield in October, November, and December. The postharvest variables moisture, firmness, pH, titratable acidity, and reducing sugars did not differ between cultivars. In a semi-hydroponic system, the San Andreas cultivar presents the best results for the agronomic variables related to fruit yield, with the highest yield in October and November.

Index terms: *Fragaria* x *ananassa*, cultivars, protected cultivation, yield.

Características agronômicas e qualidade pós-colheita de morango em sistema de cultivo semi-hidropônico

Resumo – O objetivo deste trabalho foi avaliar a influência do uso de sistema semi-hidropônico sobre as variáveis agronômicas e de pós-colheita de cultivares de morangueiro. O experimento foi conduzido em delineamento de blocos ao acaso, com as cultivares Aromas, Camarosa, Festival, Merced, Oso Grande e San Andreas, com oito plantas por parcela e cinco repetições. Foram avaliadas variáveis agronômicas e de pós-colheita. A cultivar San Andreas apresentou os maiores valores para as variáveis agronômicas número de frutos comerciais e produção total e comercial por planta, com as maiores produtividades em outubro, novembro e dezembro. As variáveis de pós-colheita umidade, firmeza, pH, acidez titulável e açúcares redutores não diferiram entre as cultivares. Em sistema semi-hidropônico, a cultivar San Andreas apresenta os melhores resultados para as variáveis agronômicas de produção de frutos, com as maiores produtividades em outubro e novembro.

Termos para indexação: *Fragaria* x *ananassa*, cultivares, cultivo protegido, produtividade.

Introduction

Strawberry (*Fragaria* x *ananassa* Duch.) is cultivated worldwide, with China being its largest producer (Lima et al., 2021; FAO, 2023).

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However, in South America, Brazil is responsible for most of the production of strawberries, the main species of small fruits grown in the continent (Chiomento et al., 2021; Santos et al., 2021). Strawberries are valued due to their typical flavor, aroma, and color, also being a healthy diet option, providing essential nutrients and high levels of vitamin C and folic acid when consumed in natura or in processed foods (Galvão et al., 2017; Hernández-Martínez et al., 2023).

Strawberries are currently grown in soil or in a hydroponic system with or without substrate (Oliveira et al., 2017). In conventional cultivation, soil is the used growth medium, providing support, nutrients, air, and water to the plants; however, the presence of pathogenic organisms, nematodes, poor drainage, and compaction are some of the problems reported in this system (Fussy & Papenbrock, 2022).

In the hydroponic system, cultivation is carried out either without soil or any aggregates or with the presence of inert substrates, in which plant roots reach an aerated nutrient solution that can be fluid or static (Fussy & Papenbrock, 2022). Within soilless cultivation, the use of a substrate as an inert support for plant roots differentiates the semi-hydroponic system from the hydroponic one (Fernandes et al., 2021).

The production of strawberries through soilless cultivation has increased as it is a relatively simple technique, characterized by the lack of soil diseases and a reduced incidence of pests, minimizing or eliminating the use of pesticides, as well as by readily-available nutrients to the plants and no mechanical impediment for the development of their root system (Sharma et al., 2018; Ameri et al, 2020). Furthermore, soilless cultivation is more practical since gardening can be done on benches above ground level (Miranda et al., 2014).

In this scenario, a key factor to be studied is the interaction between soilless cultivation system and planted cultivar, whose selection, in addition to consumer preference and location, also depends on the type of production system used (Lima et al., 2021; Hernández-Martínez et al., 2023). According to Wortman et al. (2016), most strawberry cultivars available to farmers are developed under soil-based field conditions in traditional strawberry production regions (Wortman et al., 2016). Therefore, the yield and fruit quality of strawberry cultivars produced in a soilless cultivation system need to be better evaluated, as these are necessary information for regions where producers are interested in this production system (Guimarães et al., 2015; Wortman et al., 2016; Diel et al., 2018).

The objective of this work was to evaluate the influence of using a semi-hydroponic system on the agronomic and postharvest variables of strawberry cultivars.

Materials and Methods

The experiment was carried out in a greenhouse, with an arched roof and open sides, at the farm of the Mape Frutas Ltda company, located in the municipality of Datas, in the Alto Jequitinhonha region, in state of Minas Gerais, Brazil (18º26'44"S, 43º39'21"W, 1,244 m above sea level). Maximum, average, and minimum temperatures during the 2018-2019 experimental period in the greenhouse are shown in the Figure 1. The shelter, without temperature control, contained benches suspended 1.0 m from the ground, on which plastic bags, filled with substrate composed of coconut fiber (slabs), were placed for the seedlings to be planted in. The climate of the region is warm to temperate, classified as Cwb according to Köppen-Geiger, with 1,416 mm precipitation.

Postharvest analyses were performed at the Cerrado Technology Laboratory of Universidade Federal dos Vales do Jequitinhonha and Mucuri (UFVJM), in the municipality of Diamantina, in the state of Minas Gerais, Brazil.

The Aromas, Camarosa, Festival, Merced, Oso Grande, and San Andreas strawberry cultivars were evaluated in a randomized complete block design, with eight plants (spaced 12 cm from each other) per plot, with five replicates. Cultivars Aromas and San Andreas are classified as neutral day, and Camarosa, Festival, Merced, and Oso Grande as short day (Chiomento et al., 2021). The commercial fruit yield was evaluated monthly per harvest in a split-plot arrangement, with the cultivars as the main plot and the harvest season as the subplot.

Class 2 strawberry seedlings, with a crown diameter between 5.1 and 8.0 mm, were used (Guimarães et al., 2015). The seedlings were planted in slabs on 6/15/2018 and fertigated with nutrients applied automatically using the HidroFerti direct injection (Hidrosense, Jundiaí, SP, Brazil), with an electrical conductivity of 1.2 mS cm^{-1}, maintaining the nutritional levels recommended for the crop (Portela et al., 2012). The fertilizers were diluted in separate boxes due to their incompatibility and to avoid precipitation and nutrient unavailability (Table 1).

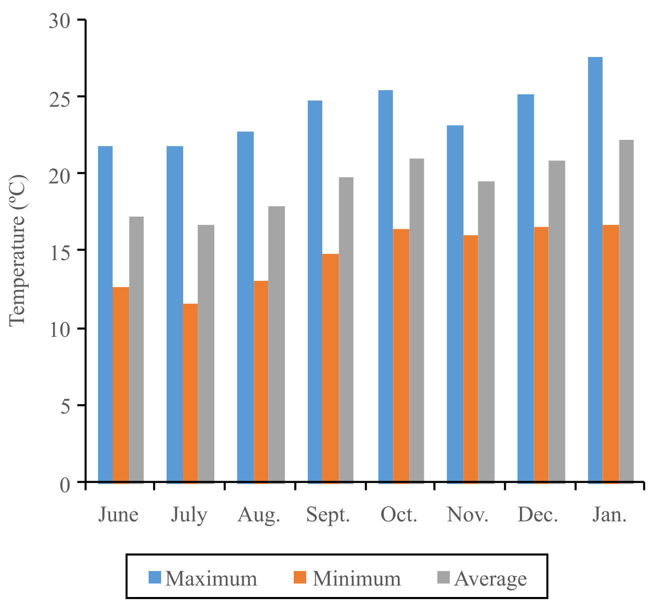

Figure 1. Maximum, average, and minimum temperatures during the 2018–2019 experimental period in a greenhouse at the farm of the Mape Frutas Ltda company, in the municipality of Datas, in the state of Minas Gerais, Brazil.

The strawberry plants were irrigated three to seven times a day, using the HidroFerti autonomous irrigation controller (Hidrosense, Jundiaí, SP, Brazil), with pulses of approximately 2 min and 40 s. Pests and diseases were controlled with pesticides registered for the strawberry crop. The stolons of the strawberry plants were removed, whenever necessary, to reduce their effect on plant development.

Strawberry fruits, at the stage of 75 to 100% maturation, were harvested weekly from 63 days after planting, between August 2018 and January 2019, and transported to the laboratory of the Olericulture Sector of UFVJM. The total yield of each plot was obtained by weighing all fruits. To determine the commercial yield of the strawberry plants, only the fruits weighing more than 10 g were considered, while the others were discarded (Guimarães et al., 2015).

The evaluated variables were: number of total and commercial fruits per harvest and experimental plot; yield per plant (g), obtained by dividing the average yield of the plot by the number of plants in the plot; commercial yield per plant (g), calculated by dividing commercial yield by the number of plants per plot; average fruit mass (g), determined by dividing yield per plant by the number of fruits; average commercial fruit mass (g), obtained by dividing the commercial yield per plant by the number of commercial fruits; total yield, considered the fruit yield per plot and treatment

Table 1. Composition of the nutritious solution for a volume of 1,000 L applied by fertigation to a strawberry (*Fragaria* x *ananassa*) crop in a semi-hydroponic cultivation system.

Planting box	Nutrient content[(1)]
Box A	60 kg calcium nitrate and 3.0 kg iron chelate
Box B	40 kg magnesium sulfate, 30 kg potassium nitrate, 23 kg potassium sulfate, 20 kg monopotassium phosphate, 8.0 kg monoammonium phosphate, 0.278 g boric acid, 0.227 g zinc sulfate, 0.185 g manganese sulfate, 0.074 g copper sulfate, and 0.054 g sodium molybdate

Source: Mape Frutas Ltda (Datas, MG, Brazil).

in all harvests; commercial fruit yield (Mg ha^{-1}), i.e., the commercial fruit yield per plot and treatment in all harvests; and fruit diameter and length (mm), measured with a digital caliper in the longitudinal and transversal directions of three fruits randomly selected among the commercial ones per plot, cultivar, and harvest.

The postharvest analyses were performed on strawberry fruits harvested in November 2018, to determine: moisture, firmness, pH, soluble solids (SS), titratable acidity (TA), total reducing sugars, and vitamin C. Moisture (%) was obtained by draining the strawberries in an oven with forced-air circulation, at 105ºC, until reaching a constant weight (Horwitz, 2000), and, then, placing them in a desiccator. Firmness was measured using with the FT 327 portable analog penetrometer (T.R. Turoni srl, Forlí, Italy), with an 8.0 mm tip, by drilling four fruits per cultivar at two opposite points in their equatorial region, with results expressed in pounds and transformed into Newton. pH was determined using the PHB 500 digital benchtop pH meter (Ionlab Equipamentos Laboratoriais e Hospitalares Ltda., Araucária, PR, Brazil), calibrated with a pH 4.0 and 7.0 buffer solution, by immersing electrodes in the pulp of each strawberry cultivar. The content of SS, expressed in ºBrix, was obtained with the r^2 mini digital refractometer (Reichert Analytical Instruments, Depew, NY, USA), which was calibrated with a drop of distilled water using a scale measured at zero. TA, expressed as percentage of citric acid, was determined by titrating the sample in a titrating solution of sodium hydroxide (NaOH) at a concentration of 0.1 N, standardized with potassium biphthalate and using phenolphthalein as a turning indicator. The SS/TA ratio represented the relationship between the values of SS and TA. Total reducing sugars, expressed in gram per 100 g of strawberry pulp, were quantified by the Somogy method, with readings performed in a spectrophotometer (Nelson, 1944). Vitamin C (milligram of ascorbic acid per 100 g of strawberry) was determined by the colorimetric method, based on the reduction of 2,6-dichlorophenolindophenol-sodium standardized with ascorbic acid (Horwitz, 2000).

Data on the agronomic and postharvest variables were subjected to the analysis of variance, and means were compared by Tukey's test, at 5%, probability, using the GENES software (Cruz, 2013).

Results and Discussion

Of all cultivars, San Andreas showed the highest number of total and commercial fruits, total and commercial yield per plant, and total and commercial yield. The total fruit mass of the San Andreas cultivar was greater than that of Aromas, Festival, and Oso Grande; however, commercial fruit mass did not differ between cultivars. Fruit length and diameter were also greater in cultivar San Andreas, when compared with Merced, Festival, and Oso Grande (Table 2).

The better performance of the San Andreas cultivar is attributed to its greater adaptability to photoperiod

Table 2. Agronomic variables evaluated in a strawberry (*Fragaria* x *ananassa*) crop in a semi-hydroponic cultivation system[(1)].

Parameter[(2)]	Cultivar					
	Aromas	Camarosa	Festival	Merced	Oso Grande	San Andreas
NTF (fruits per plant)	25.65ab (3.07)	20.48b (4.19)	16.99b (4.34)	12.77b (1.17)	21.68ab (4.46)	39.55a (6.77)
NCF (fruits per plant)	13.10b (1.32)	11.90b (2.79)	8.65b (2.18)	7.75b (0.80)	9.83b (2.22)	27.20a (4.80)
TYP (g per plant)	301.47b (32.34)	265.10b (61.37)	200.57b (50.19)	170.51b (12.86)	225.02b (48.44)	581.53a (95.35)
CYP (g per plant)	253.04b (43.10)	201.83b (48.94)	141.31b (36.23)	134.90b (10.85)	150.11b (33.92)	494.26a (81.91)
TY (Mg ha^{-1})	26.44b (2.84)	23.25b (5.38)	17.59b (4.40)	14.96b (1.13)	19.74b (4.25)	51.01a (8.36)
CY (Mg ha^{-1})	22.20b (3.78)	17.70b (4.29)	12.40b (3.18)	11.83b (0.95)	13.17b (2.98)	43.36a (7.19)
TFM (g per fruit)	11.82bc (0.21)	12.85ab (1.22)	11.93bc (0.61)	13.93ab (0.22)	10.29c (0.21)	14.91a (0.35)
TCF (g per fruit)	19.26a (2.61)	16.72a (0.76)	16.62a (0.25)	18.27a (0.46)	15.21a (0.44)	18.45a (0.46)
Fruit length (mm)	30.60ab (1.70)	32.10ab (2.00)	23.55b (3.21)	25.95b (1.44)	27.68b (1.94)	39.05a (1.56)
Fruit diameter (mm)	26.31ab (1.34)	24.88ab (1.83)	20.02b (2.66)	21.34b (1.07)	21.06b (1.52)	29.96a (1.24)

[(1)]Means followed by equal lowercase letters, in the lines, do not differ by Tukeys test, at 5% probability. Values in parentheses are the standard error of the mean. [(2)]NTF, number of total fruits; NCF, number of commercial fruits; TYP, total yield per plant; CYP, commercial yield per plant; TY, total yield; CY, commercial yield; TFM, average total fruit mass; and TCF, average commercial fruit mass.

and climatic conditions, such as temperature (Castro et al., 2017), as well as to its robustness as a day-neutral cultivar. Day-neutral cultivars, due to their genetic characteristics, show a better yield of fruits, which are characterized by a large size and good firmness (Ruan et al., 2013), and can flower in any photoperiod condition as long as the temperature is below 30/26°C day/night (Castro et al., 2015). However, high temperatures can decrease the percentage of pollen germination, inhibit plant growth and yield, and reduce the quality of strawberry fruits (Cui et al., 2021).

The commercial fruit yield of the San Andreas cultivar was the highest in October, November, and December. However, in December, cultivar Aromas did not differ significantly from San Andreas (Table 3). The highest yield of these two day-neutral cultivars may be associated with their lower sensitivity to climate variations (Scott et al., 2021), as they are more tolerant to heat and have prolonged harvest periods (Zeist & Resende, 2019). Therefore, day-neutral strawberry cultivars can produce fruit continuously throughout summer and autumn under favorable conditions (Castro et al., 2015).

Fruit moisture content, firmness, pH, TA, and total reducing sugars were similar between cultivars, with values ranging from 88.67 to 90.19 for Oso Grande and Aromas, 5.27 to 8.67 for Festival and Merced, 3.20 to 3.53 for San Andreas and Aromas, 0.75 to 0.88 for Camarosa, Festival, and Oso Grande, and 2.07 to 4.22 for Merced, Festival, and San Andreas (Table 4). These similar values may be associated with the used cultivation system, in which the availability and absorption of nutrients by the plant increase the quality parameters of the fruits in comparison with the conventional system, in which there are greater losses of nutrients to the soil (Shirko et al., 2018). In this sense, Bidaki et al. (2019) added that consumers prefer fruits with a better flavor and firmness. Moreover, in the semi-hydroponic system, there is a greater uniformity of the plant roots submerged in water or in

Table 3. Commercial fruit yield by harvest period of six strawberry (*Fragaria* x *ananassa*) cultivars in a semi-hydroponic cultivation system[(1)].

Period	Aromas	Camarosa	Festival	Merced	Oso Grande	San Andreas
August	2.80Aba (0.56)	2.43Aba (1.12)	2.48Aa (0.73)	0.40Aa (0.20)	1.46Aa (0.25)	3.27CDa (0.83)
September	1.90Bab (0.53)	1.54ABab (0.43)	0.88Aab (0.52)	1.38Aab (0.65)	0.37Ab (0.20)	5.05BCa (0.43)
October	3.43ABb (0.65)	4.89Ab (2.04)	2.15Ab (1.32)	1.24Ab (1.20)	2.70Ab (0.72)	12.37Aa (2.51)
November	3.33ABb (0.78)	3.53ABb (1.04)	2.90Ab (0.94)	1.82Ab (0.46)	3.06Ab (0.88)	8.06Ba (1.53)
December	6.57Aab (2.99)	2.57Abbc (0.85)	1.75Ac (0.49)	1.78Ac (0.64)	3.16Abc (1.22)	8.41Ba (2.24)
January	3.88Aa (1.06)	2.38Aba (0.75)	2.20Aa (0.81)	2.40Aa (1.06)	2.24Aa (0.81)	5.79BCa (1.31)

[(1)]Means followed by the equal letters, uppercase in the columns and lowercase in the rows, do not differ by Tukey's test, at 5% probability. Values in parentheses are the standard error of the mean.

Table 4. Values for postharvest variables of strawberry (*Fragaria* x *ananassa*) cultivars evaluated in a semi-hydroponic system[(1)].

Variable[(2)]	Cultivar					
	Aromas	Camarosa	Festival	Merced	Oso Grande	San Andreas
Moisture	90.19a (1.16)	89.82a (0.65)	88.70a (0.37)	89.29a (1.30)	88.67a (1.14)	89.50a (0.76)
Firmness	6.13a (1.49)	8.34a (1.37)	5.27a (1.03)	8.67a (2.55)	6.62a (1.23)	7.91a (1.40)
pH	3.53a (0.35)	3.26a (0.04)	3.29a (0.07)	3.24a (0.06)	3.21a (0.08)	3.20a (0.05)
TA(	0.82a (0.06)	0.75a (0.01)	0.75a (0.06)	0.68a (0.07)	0.88a (0.06)	0.87a (0.02)
RS	3.99a (0.45)	3. 29a (0.60)	2.07a (0.42)	2.07a (0.35)	3.27a (0.69)	4.22a (0.56)
SS (°Brix)	6.25b (0.67)	7.93ab (0.19)	7.65ab (0.70)	8.78a (0.17)	8.20ab (0.39)	7.58ab (0.17)
SS/TA	7.60b (0.40)	10.58ab (0.26)	10.28ab (0.97)	13.06a (1.33)	9.41b (0.54)	8.69b (0.06)
Vitamin C	73.53a (1.72)	65.13ab (2.72)	60.16ab (2.97)	58.51ab (2.12)	54.16b (3.85)	52.13b (4.57)

[(1)]Means followed by equal lowercase letters, in the lines, do not differ by Tukey's test, at 5% probability. Values in parentheses are the standard error of the mean. [(2)]TA, tritable acidity, expressed in gram of citric acid per 100 g strawberry; RS, reducing sugars, expressed as g 100 g^{-1} sample; and vitamin C, expressed as milligram ascorbic acid per 100 g fruit.

solution with nutrients, keeping the root zone hydrated and nourished (Diel et al., 2017; Sharma et al., 2018).

The SS content of the cultivars ranged from 6.25 to 8.78, with a higher value for Merced and a lower one for Aromas (Table 4). Consequently, the SS/TA ratio of cultivar Merced was higher than that of Aromas, Oso Grande, and San Andreas. The higher SS content and SS/TA ratio observed for Merced may be related to the lower total fruits of this strawberry cultivar, considering that fruits act as drains that reduce the accumulation of photoassimilates (Correia et al., 2011). In this line, Bertin et al. (1998) observed that an increase in the number of tomatoes (*Solanum lycopersicum* L.) decreased the individual weight and the total SS content in the pulp of each fruit. Although variations in the SS content between cultivars can be explained by genetic factors, fruit quality is also affected by environmental conditions, including climate, water management, and other cultivation practices (Cao et al., 2015). In the example of tomato, the genetic basis of its cultivars increases the potential for high levels of SS, but pre- and postharvest factors can reduce this parameter (Beckles, 2012). However, according to Shirko et al. (2018), the relationship between SS/TA is more important than each of these parameters individually, because the balance between sweet and acid, used in the evaluation of fruit flavour, is higher. This means that higher values for the SS/TA ratio are associated with the flavor preferred by consumers (Gude et al., 2021).

Vitamin C content was higher in cultivar Aromas than in Oso Grande and San Andreas (Table 4), a result related to the genotype, as the different parents that are used to develop the cultivars determine their nutritional quality (Olsson et al., 2004; Capocasa et al., 2008; Rocha et al., 2008). In addition, the vitamin C content of vegetable fruits can be increased or decreased by pre- and postharvest factors, such as climatic conditions, cultural practices, and maturation at harvest, as well as by relative humidity and storage temperature (Lee & Kader, 2000). Strawberry has been reported to be one of the richest fruits in vitamin C, with an average of 80 mg 100 g^{-1} fruit (Franke et al., 2004). For cultivar Aromas, Rocha et al. (2008) found a similar value of 81.14 mg 100 g^{-1}.

Among the evaluated cultivars, San Andreas is the most promising for cultivation in a semi-hydroponic system, as it presents the best results for the studied agronomic and postharvest variables, showing a high yield in the period between winter and spring.

Conclusion

In a semi-hydroponic system, the San Andreas cultivar presents the best results in terms of agronomic variables for fruit production, with the highest yield in October and November.

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