SCIENTIA PLENA VOL. 20, NUM. 04 2024
www.scientiaplena.org.br doi: 10.14808/sci.plena.2024.040206

Agronomic potential of nine strawberry cultivars for two consecutive cycles in a greenhouse

Potencial agronômico de nove cultivares de morangueiro por dois ciclos consecutivos em estufa

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(Recebido em 03 de dezembro de 2023; aceito em 11 de abril de 2024)

The lack of information about strawberry cultivation for more than one production cycle ends up generating high costs for producers to acquire daughter plants to reestablish their crops. Therefore, aiming at technical alternatives for a transition to more sustainable crops, the objective of this work was to investigate whether strawberry cultivars grown in a greenhouse for two cycles differ in terms of yield potential and fruit chemical quality. The treatments were nine strawberry cultivars (‘Albion’, ‘Aromas’, ‘Camarosa’, ‘Camino Real’, ‘Fronteras’, ‘Merced’, ‘Monterey’, ‘Portola’, and ‘San Andreas’) and two production cycles (2019/2020 and 2020/2021), arranged in a randomized block design with six replications. The results showed that in the second cycle the ‘Aromas’, ‘Camarosa’, ‘Camino Real’, ‘Merced’, and ‘Monterey’ cultivars stood out in terms of the highest number of fruits produced. ‘Fronteras’ and ‘Merced’ had the highest total production of strawberries in the second cycle. ‘Merced’ and ‘Monterey’ produced the highest fruits in the first cycle and ‘Fronteras’ produced strawberries with the highest average fresh fruit mass in the second cycle. ‘Albion’ and ‘Camarosa’ stood out for the higher sugar content in the fruits produced. The least acidic and most flavorful strawberries were produced in the first cycle. In conclusion, strawberry cultivars grown in greenhouses for two cycles differ in terms of yield potential and chemical fruit quality. This study indicates that the nine cultivars can be grown for two consecutive cycles without compromising berry production.
Keywords: *Fragaria* X *ananassa* Duch., agroecosystem, fruit production.

A falta de informações sobre o cultivo do morangueiro por mais de um ciclo produtivo acaba gerando aos produtores elevados custos para a aquisição de mudas para reestabelecer suas lavouras. Por isso, visando alternativas técnicas para uma transição para cultivos mais sustentáveis, o objetivo do trabalho foi investigar se cultivares de morangueiro conduzidas em ambiente protegido por duas safras diferem quanto ao potencial produtivo e a qualidade química de frutos. Os tratamentos foram nove cultivares de morangueiro (‘Albion’, ‘Aromas’, ‘Camarosa’, ‘Camino Real’, ‘Fronteras’, ‘Merced’, ‘Monterey’, ‘Portola’ e ‘San Andreas’) e dois ciclos de produção (2019/2020 e 2020/2021), dispostos em delineamento de blocos casualizados com seis repetições. Os resultados mostraram que na segunda safra as cultivares ‘Aromas’, ‘Camarosa’, ‘Camino Real’, ‘Merced’ e ‘Monterey’ destacaram-se quanto ao maior número de frutos produzidos. ‘Fronteras’ e ‘Merced’ tiveram a maior produção total de morangos na segunda safra. ‘Merced’ e ‘Monterey’ produziram os maiores frutos na primeira safra e ‘Fronteras’ produziu morangos com a maior massa fresca média de frutos na segunda safra. ‘Albion’ e ‘Camarosa’ destacaram-se pelo maior teor de açúcar nos frutos produzidos. Os morangos menos ácidos e mais saborosos foram produzidos na primeira safra. Em conclusão, cultivares de morangueiro conduzidas em estufa por duas safras diferem quanto ao potencial produtivo e a qualidade química de frutos. Este estudo indica que as nove cultivares podem ser conduzidas por dois ciclos consecutivos sem comprometer a produção de bagas.
Palavras-chave: *Fragaria* X *ananassa* Duch., agroecossistema, produção de frutos.

1. INTRODUCTION

The cultivated strawberry (*Fragaria* X *ananassa* Duch.) is increasingly reaching new agricultural frontiers because this small fruit is appreciated for its juicy texture, nutritional value, sweetness and unmistakable aroma [1]. This horticultural crop is a species belonging to the Rosaceae family, which includes many crops that produce fruits of estimated value for human consumption, such as apples, peaches, raspberries, and blackberries, in addition to roses with multiple uses. Still, the strawberry plant stands out due to the high production of berries in small areas and for generating a high economic return for producers [2].

Brazil occupies the 17th position among the largest strawberry producers, with a cultivated area of 5,279 hectares (ha) and a production of 218,881 tons (t), which represents an average yield of approximately 41.5 t ha^{-1} [3]. In the country, the conventional system (soil planting) is still the main form of cultivation. This is due to the reduction of costs with the acquisition of inputs (substrates), labor, and infrastructure [4]. Furthermore, the increase in demand for fruits, combined with the need to produce all year round, highlights cultivation in a greenhouse as a good alternative [5], in addition to providing the producer with the possibility of keeping the same plants for more than one production cycle. The inclusion of strawberries in this system, for example, increases productivity due to better use of photosynthetically active radiation by the plants and protects the crop from bad weather, pests, and diseases [1].

Strawberry producers aim to increase the productivity of their crops to ensure economic profitability. This is possible through the improvement of cultivation techniques and processes, through phytotechnical management. Among these management techniques, daily cleaning pruning, and squad renewal stand out. The pruning aims to keep the same plants for more than one production cycle in line with the reduction of costs with the acquisition of daughter plants. Most producers replace plants annually due to the incidence of diseases and reduced production. However, when cleaning pruning is used, combined with renewal pruning, plant growth, and development are stimulated, the occurrence of diseases/pests is reduced and this improves crop health [6]. Furthermore, if the production system is more sustainable (organic or with less soluble inputs) the incidence of diseases should be lower and, consequently, the need or intensity of these renewal pruning's will be lower.

However, the lack of information on strawberry cultivation for more than one production cycle ends up generating high costs for producers to purchase daughter plants to reestablish their crops [7]. Studies show that in soil cultivation, annual expenses with the acquisition of daughter plants for the renewal of the stock represent 40% of the production costs [4]. Thus, an alternative to reduce these costs is to keep the same plants for two or more consecutive cycles as long as adequate management is carried out for the plants, without compromising fruit production. However, the productive potential and the postharvest of the strawberry cultivars fruits conducted for more than one consecutive cycle are still not fully understood.

Thus, our study will generate information about the productive potential and the postharvest of strawberry cultivars fruits conducted in a greenhouse for two consecutive cycles. The results obtained can reduce the high cost of acquiring daughter plants by maintaining the same plants for two or more consecutive cycles. In addition, in more sustainable production systems, genetic diversity (use of several genotypes) adapted, and resilient to the system worked is valued. Still, this information can support the choice of cultivars by producers, who can choose materials that present, in their second cultivation cycle, horticultural potential equal to or greater than the first cycle.

Therefore, aiming at technical alternatives for a transition to more sustainable strawberry crops, the objective of this work was to investigate whether strawberry cultivars grown in a greenhouse for two production cycles differ in terms of yield potential and fruit chemical quality.

2. MATERIAL AND METHODS

2.1 Plant material

We use bare-root strawberry daughter plants from the Llahuén/Chilean Patagonia nursery (33º 50' 15.41" S; 70º 40' 03.06" W). The study was carried out in the municipality of Passo Fundo (28º 15' 41" S; 52º 24' 45" W), Rio Grande do Sul (RS), Brazil, from May (autumn) 2019 to December (summer) 2020, in a 510 m^2 greenhouse, with a semicircular roof, installed in a northwest-southeast direction. The galvanized steel structure is covered with a low-density polyethylene film, with an anti-ultraviolet additive and with a thickness of 150 microns.

2.2 Experimental design

We studied nine strawberry cultivars (‘Albion’, ‘Aromas’, ‘Camarosa’, ‘Camino Real’, ‘Fronteras’, ‘Merced’, ‘Monterey’, ‘Portola’, and ‘San Andreas’) and two production cycles (2019/2020 and 2020/2021), in a randomized block design, with six replications. Each plot consisted of seven plants (7 plants per plot x 6 replications = 42 plants per treatment).

In relation to flowering, ‘Albion’, ‘Aromas’, ‘Monterey’, ‘Portola’, and ‘San Andreas’ cultivars are classified as neutral-day (ND) and ‘Camarosa’, ‘Camino Real’, ‘Fronteras’, and ‘Merced’ cultivars are classified as short-day (SD).

2.3 Cultivation procedures

The daughter plants were transplanted directly into the soil, classified as humic dystrophic Red Latosol [8], from May to June (winter) 2019, in beds covered by mulching (polyethylene with a thickness of 30 microns) and with dimensions of 15 m long x 1.0 m wide. The plants were distributed at a spacing of 0.30 x 0.30 m, with two rows of plants per bed. The soil’s chemical characterization is presented in Table 1.

Table 1: Chemical properties of cultivated soil.

Clay	pH	SMP	P	K	OM	Al	Ca	Mg	H+Al	CEC	Saturation (%)		
%	H_2O^1	index	mg dm^{-3}		%	$cmol_c$ dm^{-3}					Bases	Al	K
42	6.5	6.8	63.4	330	4.8	0.0	9.8	4.4	1.7	16.8	90	0.0	5.0
	Sulfur		Boron			Manganese			Zinc			Copper	
						mg dm^{-3}							
	8.0		0.6			5.1			10.6			1.7	

[1]pH H_2O = hydrogen potential in water; SMP index = Shoemaker-Mac’Lean-Pratt index; P = phosphorus; K = potassium; OM = organic matter; Al = aluminum; Ca = calcium; Mg = magnesium; H+Al = potential acidity; CEC = cation exchange capacity.

In the experiment, localized irrigation was used, using drip tapes, with a flow rate of 1.2 L h^{-1} per unit. The moisture content in the soil was monitored by tensiometers at a depth of 20 cm and irrigation was activated when the content was less than -20 kPa. The fertilization (via fertirrigation) provided to the plants was due to the crop’s need, following the recommendations of the fertilization and liming manual for the Brazilian states of Rio Grande do Sul and Santa Catarina [9].

A meteorological station monitored the air temperature inside the greenhouse (Figure 1). At the end of the first production cycle, in February (summer) 2020, we carried out renewal pruning on the plants (intensity of 70%), aiming to maintain them for the second production cycle. Pruning consisted of keeping approximately seven young central leaves on the plant and eliminating the old and dry leaves.

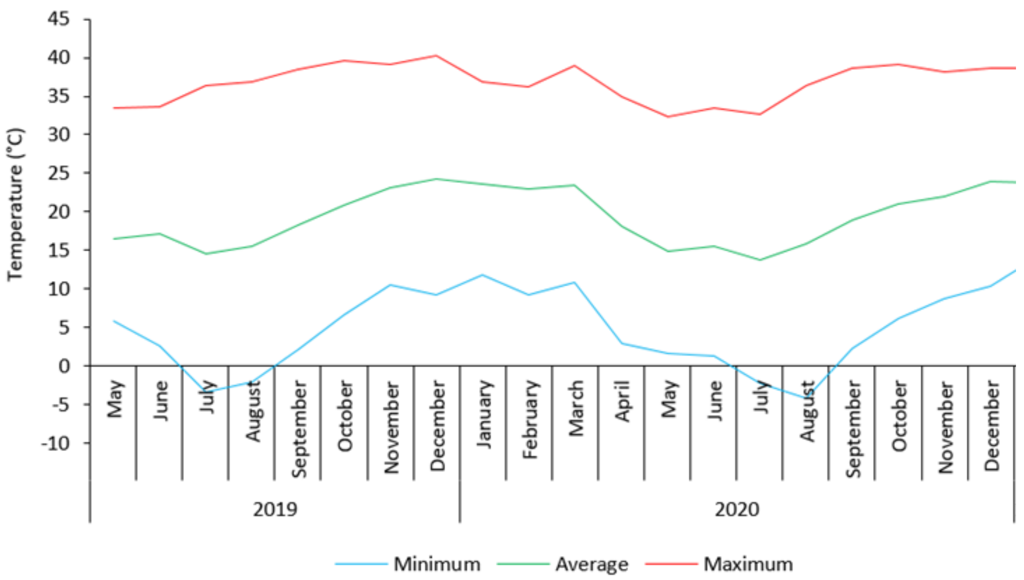

Figure 1: Temperatures recorded in the cultivation environment during the experiment (May 2019 to December 2020).

2.4 Fruit production

From fruiting, in August (winter) 2019 (first production cycle) and April (autumn) 2020 (second production cycle), the total number of fruits per plant (TNF, number per plant) and the total production of fruits per plant (TP, grams per plant), harvested when they are from ¾ to fully ripe. The fruits were weighed on an electronic digital scale. In addition, the average fresh fruit mass (AFFM, grams) was determined by dividing TP by TNF.

2.5 Fruit quality

Fruit quality analysis was carried out in November (spring) of 2019 (first cycle) and 2020 (second cycle). We evaluated the total soluble solids content (TSS, %) and total titratable acidity (TTA, % of citric acid), from 20 fruits of each treatment for each repetition. The TSS content was determined in an analog refractometer and the TTA was performed according to the rules of the Instituto Adolfo Lutz [10]. To evaluate the fruits flavor, we determined the TSS/TTA ratio.

2.6 Data analysis

The data obtained were subjected to analysis of variance (Anova) and, when there was significance, the treatments' means were compared by Tukey's test, at 5% probability of error, with the aid of the Sisvar® software [11].

3. RESULTS

3.1 Fruit production

There was an interactive effect among cycles and cultivars for all evaluated attributes. Considering the absolute values obtained for the strawberry production, in all cultivars we observed that TNF and TP increased from the first to the second cycle (Table 2). Even though with a higher TP, there was a reduction in AFFM in the second cycle due to the higher TNF (Table 2).

Table 2: Association among strawberry cultivars and cycles in relation to fruit production.

Cultivars	TNF (number per plant)[1]	
	Cycles	
	First	Second
'Albion'	31.00±1.14 Ab	36.74±1.04 Ac
'Aromas'	41.47±2.01 Bab	79.54±3.74 Aa
'Camarosa'	41.67±1.99 Bab	70.19±3.09 Aa
'Camino Real'	29.73±0.98 Bb	66.14±2.87 Aa
'Fronteras'	33.78±1.03 Bb	62.42±1.96 Aab
'Merced'	36.28±1.05 Bb	73.61±2.45 Aa
'Monterey'	35.92±0.99 Bb	67.14±1.98 Aa
'Portola'	51.07±2.98 Ba	63.69±2.81 Aab
'San Andreas'	37.50±0.87 Bb	45.42±1.97 Abc
Mean	50.18	
CV (%)[2]	17.41	
Cultivars	TP (grams per plant)	
	Cycles	
	First	Second
'Albion'	369.91±22.14 Aab	369.99±23.15 Abc
'Aromas'	319.52±21.19 Bb	587.79±39.12 Aabc
'Camarosa'	478.04±29.17 Aab	524.19±31.96 Aabc
'Camino Real'	402.39±45.15 Aab	617.27±40.09 Aabc
'Fronteras'	447.35±39.07 Bab	722.59±47.09 Aa
'Merced'	515.62±36.17 Ba	714.42±52.13 Aa
'Monterey'	504.17±30.19 Aa	634.84±45.91 Aab
'Portola'	530.36±34.75 Aa	625.03±48.19 Aab
'San Andreas'	357.99±22.98 Aab	420.65±30.12 Abc
Mean	507.90	
CV (%)	22.88	
Cultivars	AFFM (grams)	
	Cycles	
	First	Second
'Albion'	11.87±0.10 Abcde	09.79±0.05 Bab
'Aromas'	07.67±0.04 Af	07.34±0.03 Ac
'Camarosa'	11.37±0.09 Acde	07.34±0.03 Bc
'Camino Real'	13.44±0.12 Aabc	09.14±0.06 Bbc
'Fronteras'	13.33±0.14 Aabcd	11.50±0.09 Ba
'Merced'	14.15±0.17 Aab	09.67±0.07 Bab
'Monterey'	14.17±0.18 Aa	09.36±0.08 Bb
'Portola'	10.30±0.09 Ae	09.70±0.07 Aab
'San Andreas'	11.14±0.18 Ade	07.84±0.04 Bbc
Mean	10.51	
CV (%)	10.63	

Data presented as mean ± standard deviation. Means followed by the same uppercase letter in the row and lowercase in the column do not differ by Tukey's test ($p \leq 0.05$). [1]TNF = total number of fruits; TP = total production; AFFM = average fresh fruit mass; [2]CV = coefficient of variation experimental.

In the second year of cultivation, 'Aromas', 'Camarosa', 'Camino Real', 'Merced', and 'Monterey' produced the highest number of fruits (Table 2). In the same cycle, 'Albion' and 'San Andreas' had the lowest TNF (Table 2). 'Fronteras' and 'Merced' had the highest TP of strawberries in the second cycle (more than 700 grams), while 'Albion' and 'San Andreas' produced less fruit mass (Table 2), below 420 grams.

'Merced' and 'Monterey' produced the biggest fruits in the first cycle and 'Fronteras' produced strawberries with the highest AFFM in the second cycle (Table 2). 'Aromas' and

'Portola' maintained small fruits, similar in both seasons. There was an average reduction of 24% in fruit size from the first to the second cycle.

In the first cycle, we verified that the production peaks were dependent on the cultivar and occurred in October ('Camarosa', 'Camino Real', 'Merced', and 'Monterey') and November ('Albion', 'Aromas', 'Fronteras', 'Portola', and 'San Andreas') (Figure 2A). In the second cycle, the production peak of all cultivars occurred simultaneously, in October (Figure 2B). We observed that there was an early harvest of the second cycle, with strawberry fruits available in June (beginning of winter), and with prolonged production, maintaining the same average production until December.

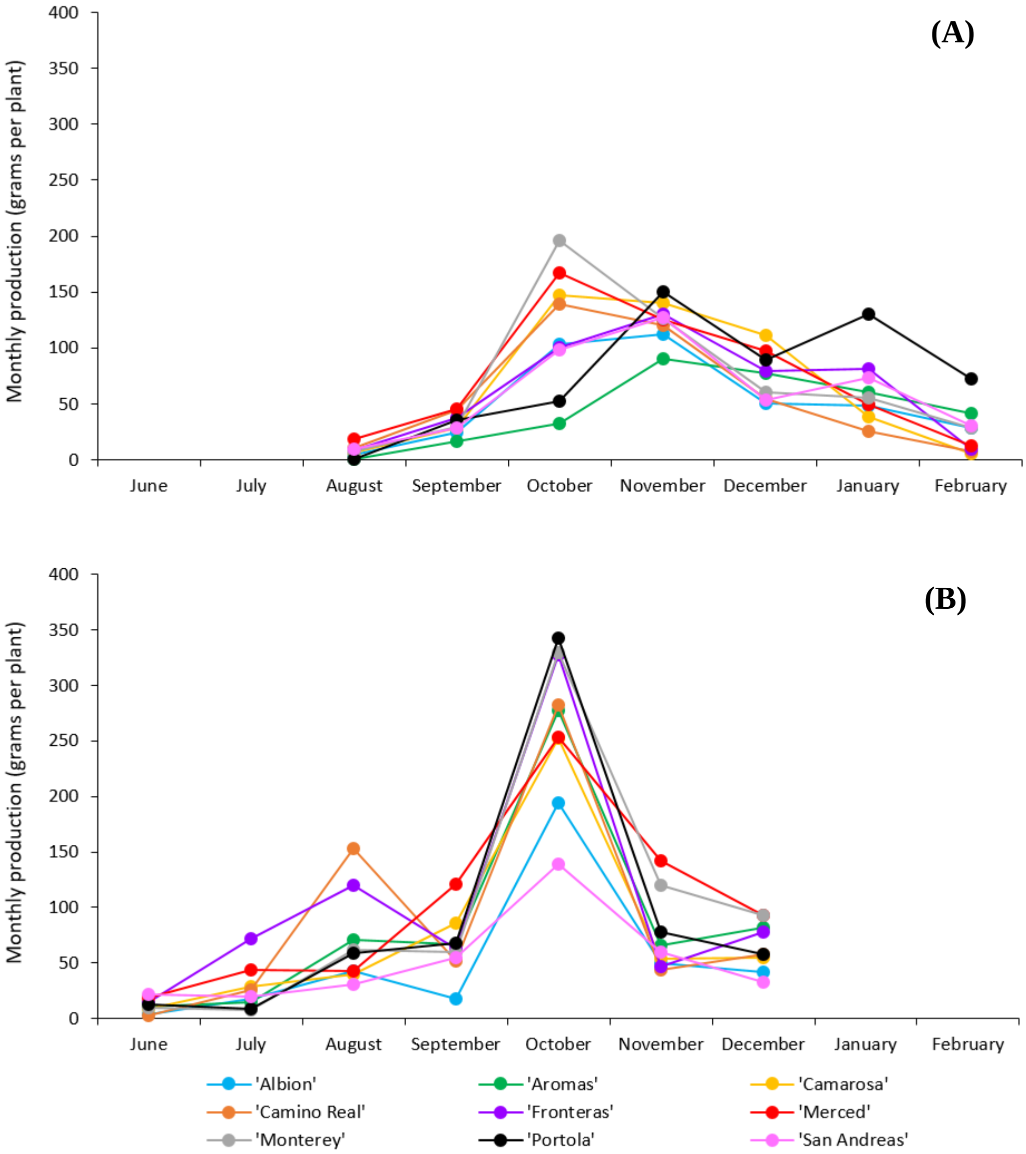

Figure 2: Monthly production of nine strawberry cultivars in two subsequent cycles in southern Brazil, cultivated in a greenhouse. (A) First crop (2019/2020). (B) Second crop (2020).

3.2 Fruit quality

There was a significant effect of the cultivar factor for TSS and the cycle factor for TTA and TSS/TTA. Strawberry cultivars were grouped into three extracts for TSS (Table 3). 'Albion' and 'Camarosa' stood out for the highest sugar content in the fruits produced, followed by 'Aromas', 'Camino Real', 'Fronteras', 'Merced', 'Monterey', and 'San Andreas' and, as the last extract, 'Portola' (Table 3). Less acidic and more flavorful strawberries were produced in the first cycle (Table 3), but those from the second cycle are also within the desirable range.

Table 3: Effect of cultivars and crops on the chemical quality of strawberries.

Cultivars	TSS (%)[1]	TTA (%)	TSS/TTA
'Albion'	8.75±0.09 a	0.77±0.01 ns	11.78±0.99 ns
'Aromas'	7.25±0.06 ab	0.73±0.01	10.22±0.98
'Camarosa'	8.75±0.07 a	0.71±0.01	12.65±1.01
'Camino Real'	7.66±0.06 ab	0.63±0.01	12.46±1.06
'Fronteras'	7.10±0.07 ab	0.65±0.01	11.20±1.04
'Merced'	7.34±0.06 ab	0.75±0.02	10.22±1.07
'Monterey'	7.29±0.08 ab	0.72±0.01	10.62±0.99
'Portola'	6.41±0.05 b	0.68±0.01	09.93±0.89
'San Andreas'	7.83±0.08 ab	0.78±0.02	10.76±0.99
Cycles			
First	7.48±0.06 ns	0.63±0.01 b	12.13±1.03 a
Second	7.71±0.07	0.79±0.02 a	10.06±1.00 b
Mean	7.60	0.71	11.09
CV (%)[2]	22.30	17.46	20.35

Data presented as mean ± standard deviation. Means followed by the same letter in the column do not differ by Tukey's test ($p \leq 0.05$). ns = Not significant ($p \geq 0.05$). [1]TSS = total soluble solids; TTA = total titratable acidity; TSS/TTA = fruit flavor; [2]CV = coefficient of variation experimental.

4. DISCUSSION

This study showed that strawberry cultivars, grown in a greenhouse for two cycles, differed in their productive performance. 'Fronteras' and 'Merced' had the highest total strawberry production in the second cycle, while 'Albion' and 'San Andreas' produced the lowest amount of fruits. In the first cycle, with production starting in August, we observed that the production peaks were dependent on the cultivar and occurred in October and November 2019. In the second cycle, however, there was an early production, which started in June and the peak production of all cultivars occurred simultaneously in October 2020.

The cultivars used in the Southern Hemisphere are mainly those classified as SD and ND in relation to flowering. Temperature and photoperiod are the two main environmental signals that regulate flower ontogeny [12] of these cultivars. These environmental interactions are complex and challenge general strawberry classifications based on daytime response, because temperatures alter typical photoperiod responses [13]. The production of fruits per plant in the second cycle, in relation to the first, was higher for all cultivars, with emphasis on 'Fronteras' and 'Merced' (Table 2). Therefore, all cultivars can be used by growers who aim to keep the same plants for more than one consecutive cycle. Another strategy that contributes to improving the yield and supply of strawberries to the consumer market corresponds to the diversification of cultivars with transplantation of daughter plants at different times [4]. For example, in the southern hemisphere this phytotechnical management allows fruit production in the off-season (May/June), as long as the daughter plants are transplanted in March/April.

The literature reports that the development of the entire plant aerial part influences the number of flower buds and, consequently, the number of fruits formed. We also emphasize that a long photoperiod and high temperatures stimulate the appearance and growth of new leaves in the plant [14]. Thus, the removal of dry, old, and diseased leaves, which have already exercised their biological function in the plant, must be carried out through phytotechnical management related to plant maintenance pruning [15]. Thus, in the second cycle, 'Aromas', 'Camarosa', 'Camino Real', 'Merced', and 'Monterey' cultivars produced a greater number of fruits, which can be explained by the performance of cultural treatments, such as renewal pruning, aiming at the beginning of this second production cycle. We highlight that all management procedures from the first cycle were repeated in the second production cycle, such as irrigation, fertilization, pest and disease control (when necessary) and cleaning pruning of plants (removal of dry and/or diseased leaves). Generally, the plants crowns are thicker in the second year of production and this allows for the development of more floral and vegetative buds. These gems can allow the production of daughter plants in a more sustainable and organic cultivation system [16].

Unlike our results (Table 2), Cipriani et al. (2023) [17] demonstrated that yield reduced from the first to the second cycle for ‘Albion’, ‘Aromas’, ‘Camarosa’, ‘Monterey’, ‘Portola’, and ‘San Andreas’. These contrasts in terms of cultivar performance indicate that microclimatic factors and phytotechnical management can alter genotype responses in relation to fruit yield. In the growing conditions of the Brazilian subtropics, SD cultivars (‘Camarosa’, ‘Camino Real’, ‘Fronteras’, and ‘Merced’) are induced to flower in a photoperiod of less than 14 hours and temperatures below 15ºC [18], which was confirmed in this study (Figure 1). However, in these same growing regions, ND cultivars (‘Albion’, ‘Aromas’, ‘Monterey’, ‘Portola’, and ‘San Andreas’) are induced to flower by the main effect of temperature [19]. Thus, they are qualitative long-day (LD) plants at high temperatures (27ºC), quantitative LD plants at intermediate temperatures (between 10 and 27ºC) and ND plants at temperatures below 10ºC [20]. Furthermore, at intermediate latitudes (25 to 33º), ND plants have a quantitative LD response. Therefore, these cultivars do not differ from the behavior of a SD cultivar under conditions of mild temperatures (15ºC) and short photoperiod (<13 hours), when differentiation of floral buds occurs for both types of cultivars [4].

Strawberries are appreciated for their nutritional value and antioxidant activity that contributes to the preventive health of consumers. This large-scale demand causes producers to use strategies to supply more fruit to distribution centers. In general, the fruits produced in the first cycle are visually more attractive and larger [21], as verified in this study (Table 2). This higher AFFM can be attributed to the greater number and size of leaves, which characterizes the source and drain dynamics between vegetative growth and fruit production [22]. In this phase, a translocation of nutrients may also occur for the formation of new daughter plants, the stolons.

After transplanting bare-root daughter plants, they direct their photoassimilates to emit leaves [4]. This greater quantity of leaves allows, through photosynthesis, a greater production of photoassimilates by plants, which are converted, through photomorphogenesis, into fruits [23]. Due to the management of removing old and diseased leaves throughout the first cycle and at the time of plant renewal, fruit size reduced in the second cycle (Table 2). Partial leaf removal modifies strawberry yield components because it reduces the photoassimilates production. Thus, it is possible to enhance the management of pruning, making it less severe, to maximize the results of the plant’s vegetative growth.

The main attribute that has been used as an indicator of fruit quality is the TSS content. It is noteworthy that the sour or acidic flavor of the fruits is determined by the TTA. The relationship between the TSS content and the TTA is the most important attribute with regard to the palatability of fruits, so that this relationship gives the fruits a better balance between sweet and acidic and thus generates a more pleasant and attractive flavor [24]. The values of this ratio considered ideal are between 8.5 and 14 [25]. In this study, the mean value obtained for the TSS/TTA ratio was 11.09 (Table 3), indicating that the fruits produced, regardless of the cultivar, were suitable for consumption. This genetic diversity allows commercialization alternatives to the farmer. For example, sweeter and smaller fruits (‘Albion’) may have a different fate than small and more acidic fruits (‘Portola’). However, the best commercial value is added to larger fruits (‘Fronteras’, in both cycles) or the sweetest ones (‘Camarosa’).

By studying the chemical quality and yield components, we were able to know and understand the performance of nine strawberry cultivars kept in cultivation for two consecutive cycles. As there is difficulty in acquiring daughter plants, in more sustainable crops it is important to also consider these factors when choosing genotypes (and not just the ease of daughter plants production; there is a large supply of ‘San Andreas’, for example, but it does not reach the best results). These results suggest that producers should choose materials with different aptitudes (production and fruit quality) according to their production system and the demands of the consumer market. Knowledge of this horticultural variability can be useful for selecting more productive and/or qualitative materials [25].

5. CONCLUSION

Strawberry cultivars grown in a greenhouse for two cycles differ in terms of yield potential and fruit chemical quality. These nine materials can be driven for two consecutive cycles without compromising berry production. All cultivars produce a greater number and total fresh fruit mass in the second cycle, with emphasis on 'Merced' and 'Fronteras'. 'Albion' and 'San Andreas' have lower yield potential in the second cycle. 'Albion' and 'Camarosa' produce strawberries with higher sugar content. Less acidic and tastier fruits are produced in the first harvest. Our findings help strawberry growers to choose cultivars with greater productive and qualitative potential, when inserted in a greenhouse, for two consecutive cycles. This can improve the financial sustainability of producers and enhance the strawberry production chain.

6. ACKNOWLEDGMENTS

To Bioagro Comercial Agropecuária Ltda., for the supply of the strawberry daughter plants.

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