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Research Article

Multivariate Contrasts of Seven Strawberry Cultivars in Soilless Cultivation and Greenhouse in Southern Brazil

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Abstract: Understanding the performance of strawberry cultivars in response to the evolving environment and growth medium is a key factor in choosing materials with the aptitude to serve the consumer market. Here, we investigated whether strawberry cultivars in soilless cultivation and greenhouse differ in their agronomic potential. We have studied seven cultivars in an experiment designed in randomized blocks, with four replications. We used analysis of variance and multivariate to examine production attributes, the chemical quality of fruits, and their phytochemical profile. Among the seven cultivars, three heterogeneous groups were formed, gathering the materials mainly due to the similarity in terms of the content of total polyphenols (TPO) and average fresh fruit mass (AFFM). 'Aromas' produced the greatest number of strawberries. 'Fronteras' and 'Monterey', in turn, were the most productive cultivars, and 'Albion' and 'Fronteras' produced the largest fruits. 'Albion' produced the sweetest and tastiest fruits, with an adequate relationship between sugar and acidity. 'Camino Real' produced fruits with higher phytochemical content. We conclude that the seven strawberry cultivars in soilless cultivation and greenhouse have contrasting agronomic potential, which indicates that the producers can establish their crops with different materials. We suggest the use of 'Fronteras' to obtain greater yield and fruit size, 'Albion' to producers looking to grow sweeter and tastier fruits, and 'Camino Real' to obtain strawberries rich in secondary metabolites.

***Keywords*: *Fragaria* × *ananassa Duch*., yield, secondary metabolites, substrate**

1. Introduction

Establishing a sustainable agri-food system is one of the requirements to enable the development of horticultural agriculture that is ecologically correct, socially just, technologically adequate, economically viable, and culturally accepted. Among the agricultural practices that contribute to the sustainability of horticultural systems are the application of bioinputs to control pests and diseases [1], biotechnologies that improve plant growth and development [2], in greenhouses [3], and soilless cultivation using substrates [4].

The literature reports several examples of successful substrate cultivation in horticulture [5, 6]. For example, this

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soilless system optimizes labor [7], provides protection against soil phytopathogens [8], reduces the use of conventional chemical inputs [5], provides adequate water and nutrients, which reduces their waste [9], and increases the yield and quality of horticultural crops. Farming agroecosystems are sustainable when these aspects are taken into account.

Among the vegetable crops that are grown in the substrate is the strawberry (*Fragaria* × *ananassa* Duch.), recognized as a healthy food [10]. These berries have anticarcinogenic action, improve cardiovascular health and maintain a healthy immune system [11, 12]. Among the small fruits, strawberries have the highest concentrations of antioxidants [13] and their productive potential varies from 0.37 to 2.1 kg per plant [14]. The evolving environment, production systems, and genotypes influence both berry production and quality [15].

Strawberry cultivation in Brazil, inserted in different environments and growth media, is distributed in a cultivated area of 5,279 hectares (ha) and has a production of more than 218,881 tons (t), with a productivity of approximately 41.5 t ha^{-1}. These data have placed Brazil in the seventeenth position among the largest producers of strawberries [16] and highlighted the country's challenge in boosting the production of this berry. As an initiative, Brazilian producers in Brazilian subtropics are migrating from soil to substrate cultivation in a greenhouse. In addition, scientists can focus their research on the horticultural potential of cultivars to support the growers' choice of materials [17].

However, if an option to improve the production and quality of strawberries is to implement crops in substrate cultivation in greenhouses, why does only a portion of Brazilian strawberry growers adopt soilless cultivation? What management strategies are needed to increase the yield and quality of strawberries in this system? What eco-physiological and geoclimatic factors need to be understood to support the choice of cultivars with the potential for insertion in the substrate and in a greenhouse? What are the dynamics among cultivars and subtropical agroecosystems?

Having stated that, the objective is to discover the answers to these research questions. Beforehand, the literature indicates that the dynamics between temperature and photoperiod interfere with the adaptability of strawberry cultivars in agroecosystems because both factors control plant development and regulate its transition to the reproductive phase [18, 19]. However, the information scarcity on the agronomic potential of strawberry cultivars in response to the cultivation system and the production environment micrometeorological conditions restricts the choice of cultivars by producers, who may choose materials with less productive input and low fruit quality [17].

Therefore, based on the hypothesis that berry yield and quality are heterogeneous among cultivars, the aim of the study was to investigate whether strawberry cultivars in soilless cultivation change their agronomic potential. Our findings will allow us to provide producers with a portfolio of cultivars aimed at the implementation of commercial strawberry crops in the substrate with the staggering of materials. This will fill the fruit production and quality gap through cultivar diversification that can be established in commercial crops.

2. Materials and methods

2.1 *Plant material and experimental design*

The plant material consisted of bare-rooted strawberry daughter plants imported from the Llahuén nursery, Chile. Seven strawberry cultivars (Table 1) were used in the experiment.

Table 1. Main characteristics of the seven strawberry cultivars

Cultivars	Classification of flowering[1]	Growth habit[2]	Color of fruit[2]	Shape of fruit[2]	Main uses
'Albion'	ND	Semi-upright	Dark red	Conical	Industrialization
'Aromas'	ND	Semi-upright	Medium red	Cordate	*In natura* market
'Camino Real'	SD	Semi-upright	Dark red	Rhomboid	*In natura* market and industrialization
'Fronteras'	SD	Semi-upright	Dark red	Conical	*In natura* market
'Monterey'	ND	Upright	Dark red	Conical	*In natura* market and industrialization
'Portola'	ND	Spreading	Orange red	Conical	Industrialization
'San Andreas'	ND	Semi-upright	Medium red	Cylindrical	*In natura* market and industrialization

Note: [1]ND: neutral-day; SD: short-day
[2]Characteristics according to the morphological descriptors of the culture presented in International Union for the Protection of New Varieties of Plants, UPOV (https://www.upov.int/edocs/tgdocs/en/tg022.pdf)

Seven strawberry cultivars were studied ('Albion', 'Aromas', 'Camino Real', 'Fronteras', 'Monterey', 'Portola' and 'San Andreas'). The experiment was arranged in a randomized block, with four replications. Six plants formed each experimental plot. The experiment had 28 plots and 168 plants. These cultivars were used because they represent the genetic material used by producers, mostly, to establish commercial strawberry crops in southern Brazil.

2.2 *Cultivation environment and plant management*

The study was conducted in the municipality of Passo Fundo (28° 15' 41" S; 52° 24' 45" W), Rio Grande do Sul (RS), Brazil, from May (autumn) 2021 to January (summer) 2022, in a greenhouse (430 m^2) with a semi-circular roof, covered with a low-density polyethylene film, installed in a northwest-southeast direction. The greenhouse was not heated. Ventilation control was performed manually by opening and/or closing the side plastic (curtains). In addition, at each front end, the structure contained two zenith windows for internal air renewal.

The daughter plants were transplanted from May to July (winter) 2021 in containers (1 m long and 0.5 m wide) containing the Dallemole® substrate, composed of pine bark, rice husk, rice ash, and organic compost class A. Daughter plants were spaced 0.17 m apart and arranged in a planting row. Physical [20] and chemical [21] characterization of the substrate is shown in Table 2.

Table 2. Chemical and physical properties of Dallemole®

Physical properties[1]							
Substrate	D		TP	AE	RAW	BW	RW
	(kg m^{-3})				(m^3 m^{-3})		
Dallemole®	212		0.885	0.502	0.144	0.017	0.222
Chemical properties[2]							
Substrate	N	P_2O_5	K_2O	OC	pH	EC	C/N ratio
		% (m m^{-1})				mS cm^{-1}	
Dallemole®	0.82	0.58	<0.25	26.10	7.6	1.05	33.42

Note: [1]D: density; TP: total porosity; AE: aeration space; RAW: easily available water; BW: buffer water; RW: remaining water
[2]N: nitrogen; P_2O_5: phosphorus pentoxide; K_2O: potassium oxide; OC: organic carbon; pH: hydrogen potential; EC: electric conductivity; C/N ratio: relationship between carbon and nitrogen.

Using localized irrigation (1.41 L h^{-1} per dripper), the irrigation regime consisted of activating the system seven times a day. We provided nutrient solutions to the plants weekly [22]. Conjointly with the nutrient solution, we used the fertilizer Vit-Org® (80 mL L^{-1} H_2O), a product based on plant extracts, formulated with humic substances, amino acids, and glycine-betaine (quaternary ammonium compound). With a mini meteorological station, the air temperature was monitored (Figure 1).

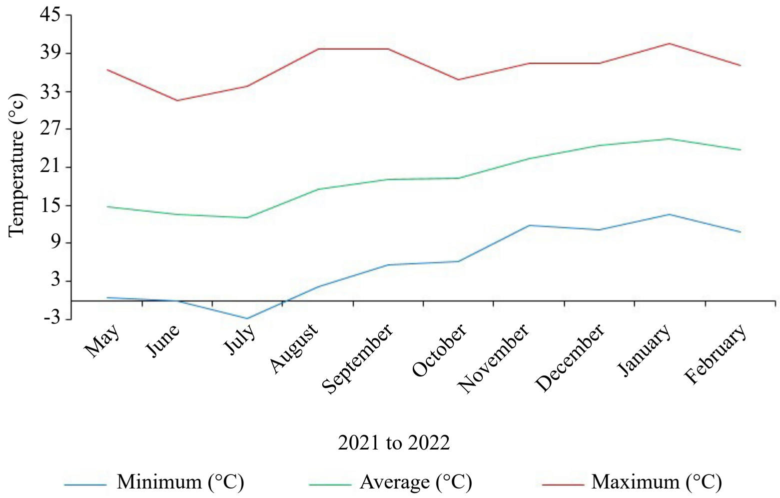

Figure 1. Climate characterization in the greenhouse during the experiment

2.3 *Strawberry productive potential*

From September (spring) 2021 to January 2022, with approximately two weekly harvests, we evaluated the total number of fruits per plant (TNF, number per plant) and the total production of fruits per plant (TP, g per plant), harvested when they were fully mature. We determined the average fresh fruit mass (AFFM, g) by the ratio between TP and TNF.

2.4 *Berry quality*

The analysis of fruit quality was carried out in October (spring) 2021. From 20 fruits of each cultivar for each repetition, we evaluated the total soluble solids (TSS, %) and the total titratable acidity (TTA, % citric acid) according to the norms of the Adolfo Lutz Institute [23]. To evaluate fruit flavor, the TSS/TTA ratio was determined.

We also studied the fruits' phytochemical profiles. For that, the harvested strawberries (100 g) were submitted to the secondary metabolite extraction procedure [24]. Afterward, we quantified the levels of total anthocyanins (TA), total flavonoids (TF), and total polyphenols (TPO) using spectrophotometry (PerkinElmer Lambda 20 spectrophotometer, Perkin Elmer®).

TA content was determined by the differential pH method [25, 26] and the results were expressed in milligrams of pelargonidin-3-*O*-glycoside (PE) equivalent per 100 grams of fresh fruit (mg PE.100 g FF^{-1}). TF content [27] was expressed in milligrams of rutin per 100 grams of fresh fruit (mg rutin.100 g FF^{-1}). TPO content was determined by the Folin-Ciocalteu method [28] and the results were expressed in milligrams of gallic acid equivalent per 100 grams of fresh fruit (mg GAE.100 g FF^{-1}).

2.5 *Statistical analysis*

The data was submitted to analyze the variance and means of the cultivars. They were later compared using Tukey's test, at a 5% error probability, using the Costat® program [29]. Furthermore, to classify the seven strawberry cultivars into groups according to yield and fruit quality, we used principal component analysis (PCA) and hierarchical cluster analysis. Both were performed after the standardization of the attributes, in which each one had a mean of 0 and a variance of 1.

We performed the PCA to condense the amount of information [30] of the nine attributes investigated in our study. We disregarded eigenvalues below 1 from the analysis, as they did not have relevant information. We ran the PCA with the 'factoextra' package in R, a software environment for statistical computing [31].

The means of the attributes were normalized. The Euclidian distance was then calculated as a measure of dissimilarity among strawberry cultivars. Distinct techniques of hierarchical cluster analysis were tested, and the choice was based on the highest cophenetic correlation coefficient. Heatmaps were then generated to visualize the results from the cluster analysis with all variables with the package *'pheatmap'* [31].

3. Results

3.1 *Strawberry productive potential*

'Aromas' produced 38% more fruit than 'San Andreas', which was the cultivar that produced fewer berries (Table 3). The other five cultivars produced average amounts of fruit, ranging from approximately 24 ('Camino Real') to 31 ('Monterey') fruits per plant (Table 3).

'Fronteras' and 'Monterey' were the most productive cultivars, both with an average yield 27% higher when compared to 'San Andreas', which had the lowest yield potential among the seven cultivars studied (Table 3).

'Albion' and 'Fronteras' originated fruits with the highest AFFM (Table 3). On average, this effect was 63% higher than 'Aromas' which, despite producing the highest number of berries, had the lowest AFFM (Table 3). These results show the effect of greater or lesser competition for photoassimilates and reserves among berries.

Table 3. Fruit production of seven strawberry cultivars

Cultivars	TNF[1] (number per plant)	TP (grams per plant)	AFFM (grams)
'Albion'	25.33 ± 3.72 bc	265.78 ± 24.19 ab	10.56 ± 0.78 a
'Aromas'	36.79 ± 2.74 a	303.73 ± 16.16 ab	08.26 ± 0.19 c
'Camino Real'	24.87 ± 3.75 bc	253.68 ± 28.32 ab	10.25 ± 0.79 ab
Fronteras'	27.16 ± 3.34 bc	318.96 ± 49.74 a	11.70 ± 0.53 a
'Monterey'	31.20 ± 2.10 ab	325.37 ± 16.39 a	10.44 ± 0.71 ab
'Portola'	29.62 ± 3.90 abc	288.58 ± 56.52 ab	09.86 ± 0.76 bc
'San Andreas'	22.79 ± 1.85 c	234.08 ± 17.34 b	10.33 ± 1.10 ab
Mean	28.25	284.31	10.18
CV[2] (%)	11.48	12.08	7.79

Note: Data was presented as mean ± standard deviation. Means followed by the same letter in the column do not differ from each other 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

It was observed that the productivity peaks were dependent on the cultivar and occurred in the months of December ('Aromas', 'Camino Real' and 'Fronteras') and January ('Albion', 'Monterey', 'Portola' and 'San Andreas') (Figure 2). Even having reduced its yield from December, 'Fronteras' had the highest accumulated production. This occurred because the cultivar stood out from the others due to its higher yield potential in September.

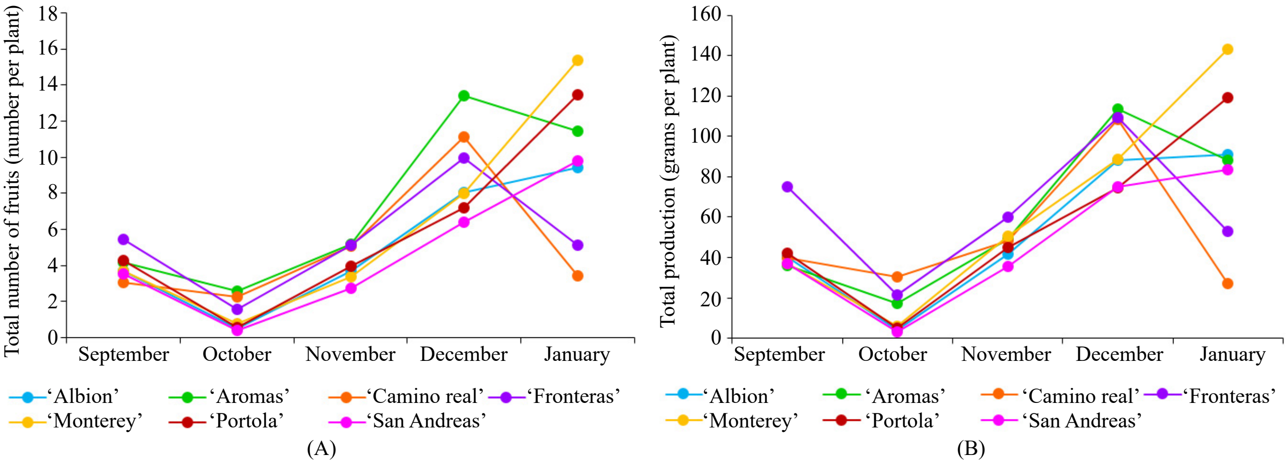

Figure 2. Number of fruits (A) and production (B) per month (from 2021 to 2022) of seven strawberry cultivars in southern Brazil, grown in a greenhouse

3.2 *Berry quality*

We did not observe any effect on TTA content (average of 1.09%). However, 'Albion' produced the fruits with the highest levels of TSS and with an adequate relationship between sugar and acidity (Table 4).

'Albion', 'Aromas' and 'Camino Real' produced strawberries with higher TA content. This effect was 59% higher than 'San Andreas' (Figure 3A).

'Camino Real' produced berries with TF contents 35% higher than 'Portola', which was the cultivar that produced fruits with the lowest TF content (Figure 3B).

Strawberry cultivars 'Camino Real' and 'Fronteras' have the highest TPO content. This was 29% and 21% higher compared to 'Albion' and 'Portola', respectively (Figure 3C).

Table 4. Chemical quality of fruits of seven strawberry cultivars

Cultivars	TSS[1] (%)	TTA (%)	TSS/TTA
'Albion'	8.47 ± 0.61 a	0.86 ± 0.13[ns]	10.01 ± 1.74 a
'Aromas'	5.72 ± 1.25 bc	1.10 ± 0.14	05.27 ± 1.60 b
'Camino Real'	5.75 ± 1.26 bc	1.26 ± 0.13	04.55 ± 1.04 b
'Fronteras'	6.00 ± 0.51 bc	1.24 ± 0.31	05.12 ± 1.55 b
'Monterey'	6.32 ± 1.16 ab	1.14 ± 0.20	05.62 ± 1.31 b
'Portola'	3.85 ± 0.17 c	0.87 ± 0.23	04.72 ± 1.46 b
'San Andreas'	5.32 ± 0.46 bc	1.19 ± 0.16	04.53 ± 0.69 b
Mean	5.92	1.09	5.69
CV[2] (%)	15.84	16.97	14.88

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

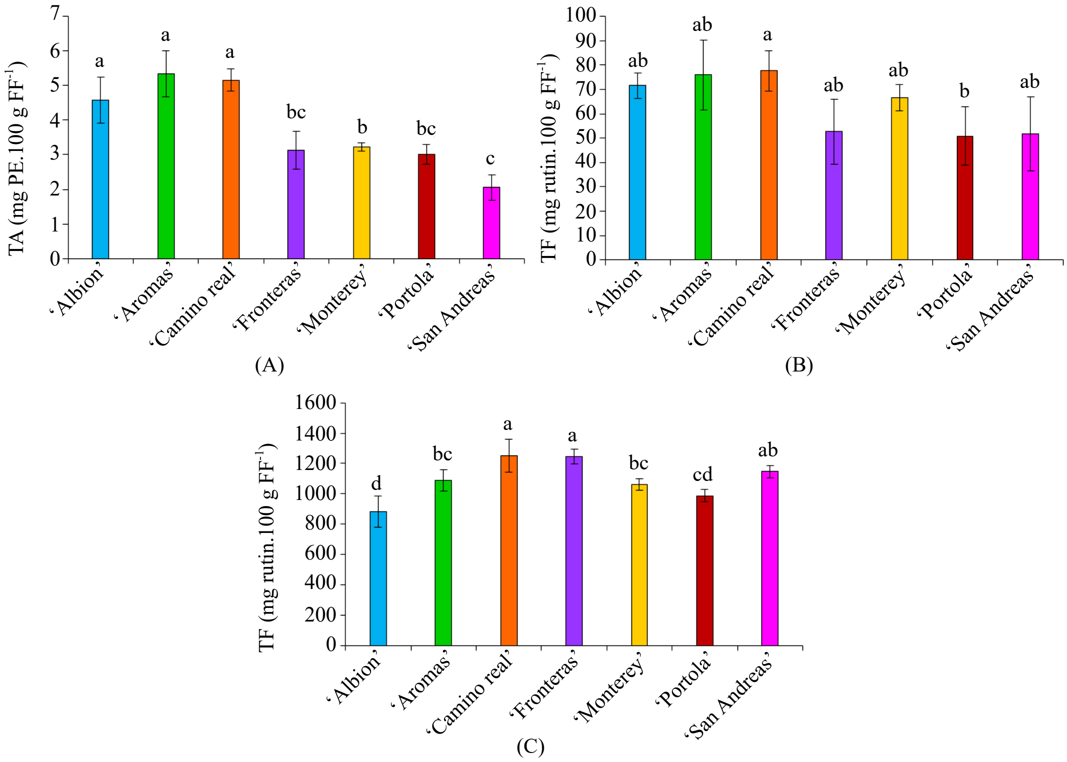

Figure 3. Phytochemical composition of fruits. (A) Total anthocyanins (mg PE.100 g FF^{-1}). (B) Total flavonoids (mg rutin.100 g FF^{-1}). (C) Total polyphenols (mg GAE.100 g FF^{-1}).

Note: Data presented as mean ± standard deviation. Different letters on the columns indicate differences by the Tukey's test ($p \leq 0.05$)

3.3 *Multivariate contrasts among cultivars*

Through multivariate analysis, we observed that the first four principal components (PC) had eigenvalues (λi) greater than 1. The first two PC had accumulated a proportion of variance of 54.72% and, of these, the first PC explained 30.41% of the total variance and the second PC explained 24.30% (Figure 4). By the contribution of the analyzed attributes (Figure 4), we observed that the relationship between TSS/TTA (fruit flavor) and TNF had the greatest contribution to PC 1 and PC 2, respectively.

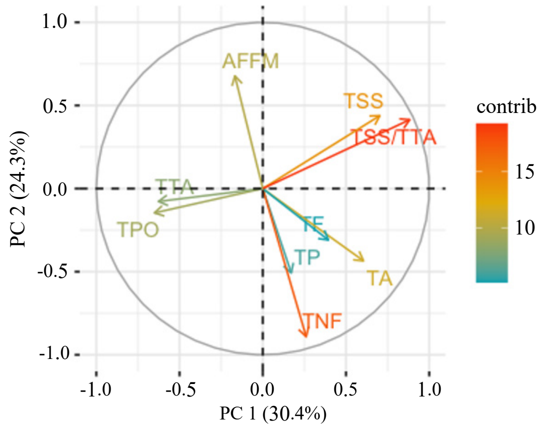

Figure 4. Principal component analysis.

Note: TP: total fruit production per plant (grams per plant); TNF: total number of fruits per plant (number per plant); AFFM: average fresh fruit mass (grams per fruit); TA: total anthocyanins (mg PE.100 g FF^{-1}); TF: total flavonoids (mg rutin.100 g FF^{-1}); TPO: total polyphenols (mg GAE.100 g FF^{-1}); TSS: total soluble solids (%); TTA: total titratable acidity (% citric acid); TSS/TTA: fruit flavor

PC analysis evidenced the dissimilarity among the seven cultivars regarding the attributes studied through the formation of three groups (Figure 5). Group 1 gathered five strawberry cultivars. This group had similar performance in relation to the attributes AFFM (Table 3) and TPO (Figure 3C). Group 2 was formed by 'Albion' and group 3 by 'Aromas' (Figure 5). The heterogeneity between groups 2 and 3 was attributed to fruit production, especially AFFM (Table 3).

The group formed by 'Albion' stood out for the chemical quality of fruit attributes, represented by TSS and TSS/TTA (Figure 5). This result confirmed what was obtained through univariate analysis (Table 4). In addition, the group composed of 'Aromas' showed the greatest contribution of the attributes TNF and TA (Figure 5), which we also demonstrated in the univariate analysis (Table 3 and Figure 3A).

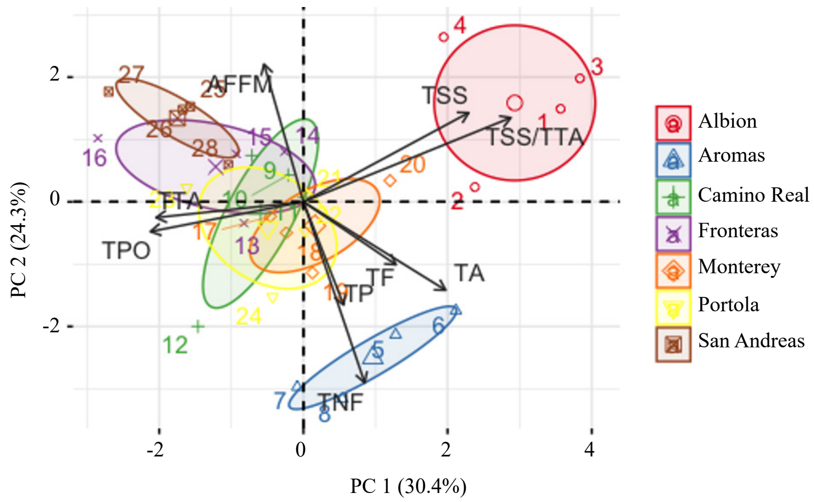

Figure 5. Clustering relationship, through PCA, among seven strawberry cultivars and fruit yield and quality attributes.
Note: TP: total fruit production per plant (grams per plant); TNF: total number of fruits per plant (number per plant); AFFM: average fresh fruit mass (grams per fruit); TA: total anthocyanins (mg PE.100 g FF^{-1}); TF: total flavonoids (mg rutin.100 g FF^{-1}); TPO: total polyphenols (mg GAE.100 g FF^{-1}); TSS: total soluble solids (%); TTA: total titratable acidity (% citric acid); TSS/TTA: fruit flavor

The dendrogram obtained through a heatmap with hierarchical grouping and its relationship among cultivars and attributes studied (Figure 6) generated the same three groups of cultivars in relation to the grouping originated by the method of PC (Figure 6).

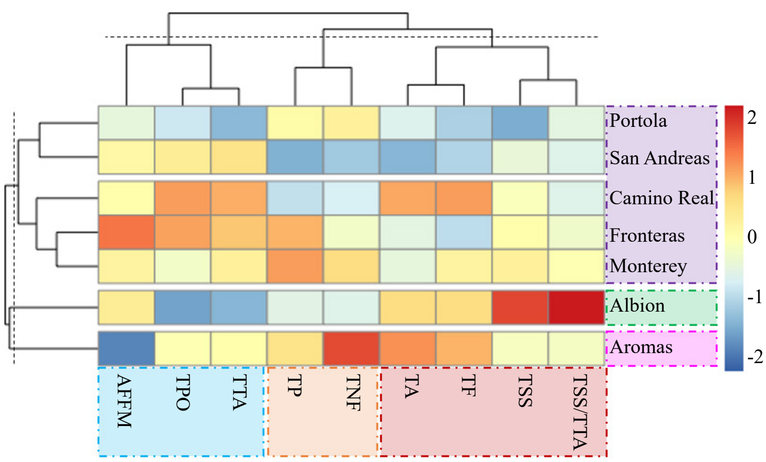

Figure 6. Dendrographic relationship, obtained from a heatmap with hierarchical grouping, among seven strawberry cultivars and fruit yield and quality attributes.
Note: TP: total fruit production per plant (grams per plant); TNF: total number of fruits per plant (number per plant); AFFM: average fresh fruit mass (grams per fruit); TA: total anthocyanins (mg PE.100 g FF^{-1}); TF: total flavonoids (mg rutin.100 g FF^{-1}); TPO: total polyphenols (mg GAE.100 g FF^{-1}); TSS: total soluble solids (%); TTA: total titratable acidity (% citric acid); TSS/TTA: fruit flavor

Still, there was the formation of three groups when we analyzed the production and quality of fruits (Figure 6). In this case, group 1 was formed only by berry quality attributes (TSS/TTA, TSS, TF, and TA). The cultivars that contributed the most to the dissimilarity of this group were 'Albion', 'Portola', and 'San Andreas' (Figure 6). Group 2 gathered only fruit production attributes (TNF and TP). 'Aromas' and 'San Andreas' were the contrasting cultivars of this group (Figure 6). Finally, group 3 was composed of the attributes of TTA, TPO, and AFFM, with 'Aromas' and 'Fronteras' as the most dissimilar cultivars in the group (Figure 6).

Through the correlation matrix among the attributes studied, we observed negative associations between TNF-AFFM, TA-AFFM, TSS/TTA-TPO, and TSS/TTA-TTA (Figure 7). We also observed positive correlations between TA-TF, TSS/TTA-TSS, TP-TNF, and TPO-TTA (Figure 7). These correlations reinforced the results already reported by univariate (Table 3, Table 4, and Figure 3) and multivariate (Figure 4 and Figure 5) analyses.

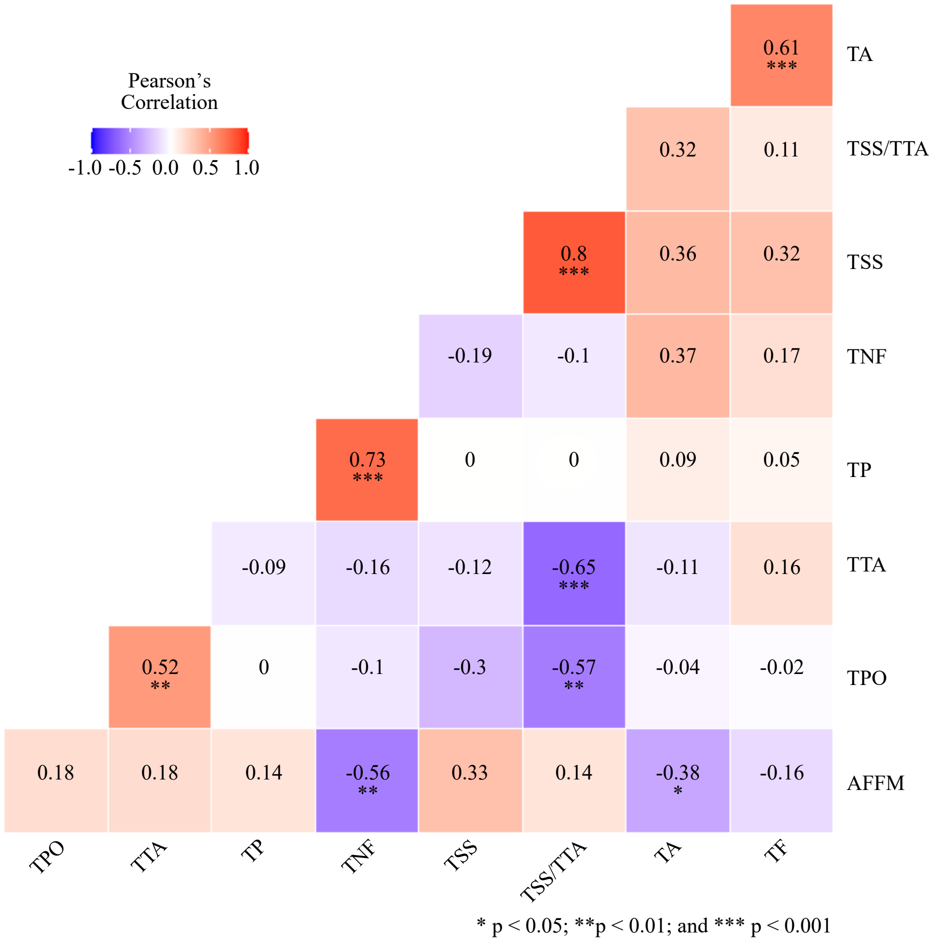

Figure 7. Pearson's correlation.

Note: TP: total fruit production per plant (grams per plant); TNF: total number of fruits per plant (number per plant); AFFM: average fresh fruit mass (grams per fruit); TA: total anthocyanins (mg PE.100 g FF^{-1}); TF: total flavonoids (mg rutin.100 g FF-1); TPO: total polyphenols (mg GAE.100 g FF^{-1}); TSS: total soluble solids (%); TTA: total titratable acidity (% citric acid); TSS/TTA: fruit flavor

4. Discussion

By studying the performance of strawberry cultivars in soilless cultivation and greenhouse, we showed that these seven materials have contrasting agronomic potential. This indicates that the staging of cultivars can be a strategic tool during the planning of strawberry crops. The multivariate clustering methods (PC and heatmap) have formed the same three groups of cultivars, which were combined, mainly due to the content of TPO and AFFM.

The productive potential of ‘Albion’, ‘Aromas’, ‘Camino Real’, ‘Monterey’, ‘Portola’ and ‘San Andreas’, in soilless cultivation, is already known [32, 33]. However, we did not find reports on the productive performance of ‘Fronteras’ inserted in soilless cultivation. Thus, the total number of fruits, total fruit production, and average fresh mass of ‘Fronteras’ berries are documented for the first time in literature.

In Brazil, regardless of the cultivation system adopted, strawberry production is concentrated in ‘Albion’ and ‘San Andreas’, which together represent approximately 65% of the total cultivated area [17, 34]. However, here we found that ‘Fronteras’ and ‘Monterey’ obtained the highest fruit yield (Table 3). ‘San Andreas’ was the least productive among the seven cultivars studied (Table 3). This points to the need for strategic planning, on the part of producers, regarding the establishment of strawberry crops. Hence, our findings will assist growers in selecting more productive cultivars suited to growing regions in southern Brazil.

After structuring our results and verifying the contrasts between the most productive cultivars and the cultivars that are actually used in commercial crops, we wonder why this happens. Despite the better phytosanitary quality and robustness of ‘Albion’ and ‘San Andreas’ against biotic stresses [35], factors that explain the diffusion of both materials, we believe that the lack of information on the productive potential of new strawberry cultivars is still the main reason for this scenario. Here comes the inseparable role of scientists and extension workers, who must deliver research-based information to producers, in order to substantially contribute to agricultural development at local, regional, and global scales.

The literature shows different productive performances of strawberry cultivars. In a soilless culture study, Cecatto et al. [32] found that the production of marketable fruits (grams per plant) was 350, 346, 310, 280, 266, 245 and 205 for the cultivars ‘Florida Festival’, ‘Camino Real’, ‘Portola’, ‘Ventana’, ‘San Andreas’, ‘Camarosa’ and ‘Monterey’, respectively. In an organic production system, for example, production (grams per plant) was 744, 732, 518 and 368 for ‘Camino Real’, ‘Portola’, ‘Aromas’ and ‘Albion’, respectively [36]. In our study, the low production of some cultivars, such as ‘Camino Real’, ‘Albion’ and ‘San Andreas’ (Table 3), may be related to the inadaptability of these materials to the environment where the plants were inserted. These cultivar performance discrepancies among the literature and our results (Table 3) suggest that the productivity of materials varies as a function of the biogeographic factors in the producing region [37], edaphoclimatic conditions of the crop agroecosystem [38] and the ecophysiology of this horticultural crop [39, 40].

Soilless strawberry cultivation provides higher plant survival rates, less water and less biocides are used [2, 33]. Due to the environmental benefits, producers who adhere to soilless cultivation obtain greater profits resulting from the reduced use of resources (water, biocides, labor). Furthermore, compared to soil cultivation of this horticultural crop, soilless cultivation improves the quality of strawberries [32].

In Brazil, the cultivars used in commercial crops come from genetic breeding programs in the United States of America. This is because there are no cultivars adapted to the soil and climate conditions in Brazil [41]. However, there are research groups that focus on the development of materials more adapted to tropical and subtropical growing conditions in Brazil [34, 42, 43].

In regard to flowering, strawberry cultivars used in the southern hemisphere are classified as short-day (SD) and neutral-day (ND) [17]. The literature reports that the use of ND cultivars makes it possible to shorten the off-season and add value to marketed fruits because these materials have a longer production period and produce strawberries during summer and autumn [39]. Traditionally, SD cultivars produce for a shorter period of time (from May to December), which creates a gap in the supply of strawberries to the consumer market. However, our findings showed that the SD cultivars used produced strawberries until January of the following year in relation to the establishment of the crop, with ‘Fronteras’ standing out for the higher fruit production (Table 3).

At intermediate latitudes (25° to 33°) ND cultivars do not differ from the performance of an SD cultivar in conditions of mild temperatures (15 °C) and short photoperiod (<14 hours) [38] and this makes it possible to synchronize the period of fruit production of these materials in the Brazilian subtropics. In this context, producers can establish their crops with ‘Fronteras’ (SD cultivar) and ‘Monterey’ (ND cultivar) to obtain greater fruit production (Table 3). Complex environmental interactions challenge strawberry classification for flowering because temperatures alter typical photoperiod responses [44]. Thus, regardless of the flowering classification, the similarity of cultivars (Figure 5) occurred in terms of the content of total polyphenols (Figure 3C) and average fresh fruit mass (Table 3).

For producers to achieve financial sustainability with their crops, it is not enough to focus on strategies that only boost the production of strawberries. Thus, from here, our research discusses the quality of fruits as a key factor to meet an increasingly demanding consumer market, especially regarding the acquisition of fruits with the potential to promote health benefits. We want our discoveries to enable producers to become more competitive in the market by choosing cultivars with better fruit quality.

The typical strawberry aroma, which influences its consumer acceptability, is attributed to volatile compounds such as furaneol, γ-decalactone, mesifuran, linalool, and (E)-nerolidol [45, 46]. Furaneol and mesifuran are the most important flavor constituents of strawberry aroma [46]. Strawberry flavor comes from the biosynthesis of phytochemicals, including acids, sugars, and volatile compounds [47], but is also determined by the acids and sugars ratio [45]. Producers who want to obtain tastier fruits should opt for 'Albion', which had a better TSS/TTA ratio (Table 4), which suggests that this material, in soilless cultivation, can have a balanced taste between sweet and acid. According to the literature, the balanced taste between sweet and acid can be explained by the higher presence of myrcene, limonene, linalool, and (E)-nerolidol in fruits produced by 'Albion' [48].

Several other factors that affect the flavor of strawberries, including secondary metabolites, are associated with a peach flavor, attributed to γ-decalactone [49], and a burnt caramel flavor, provided by mesifuran [50]. Due to the beneficial effects on consumers' health attributed to the phytochemicals present in strawberries, to supply a demanding consumer market that prefers fruits with health-promoting activity, producers should prioritize the cultivation of 'Camino Real' (Figure 3). In general, the contents of secondary metabolites were different among the seven cultivars (Figure 3).

Despite the extensive improvement of strawberries in recent years, there is still a large variation in fruit quality, both within and among cultivars, due to the influence of environmental factors and adopted production systems [51, 52]. Prat et al. [46] reported improvements in the organoleptic quality of fruits in soilless cropping systems. Several studies have indicated that the effect of genotype on the phytochemical profile of strawberries is stronger than environmental factors [53, 54]. Strawberry consumption reduces the risk of cardiovascular disease [55], cancer [56] and memory loss [57]. Thus, our findings may make consumers, producers, breeders and industries more interested in health-beneficial secondary metabolites present in strawberries for their nutraceutical properties.

In this study, no strawberry cultivar had the desired combination of high yield, high concentrations of phytochemicals, high concentrations of sugar and low concentrations of citric acid. This suggests that growers should strategically scale their commercial crops with more than one cultivar to serve different purposes. We suggest the use of 'Fronteras' and 'Monterey' to improve fruit production (Table 3), 'Albion' to obtain tastier strawberries (Table 4), and 'Camino Real' to produce fruits rich in secondary metabolites (Figure 3). These cultivars have been shown to adapt to soilless cultivation and greenhouse in southern Brazil.

The knowledge of this dissimilarity of the seven materials studied can be useful to guide professionals who work in strawberry genetic breeding programs. Breeding programs for nutrient-rich and better-tasting cultivars can be successful if there is variability and diversity of bioactive compounds [58]. This will enable consumers who are demanding in terms of quality, who seek functional foods, and who are willing to pay a higher price for it, even when cheaper options are available.

5. Conclusion

The seven strawberry cultivars in soilless cultivation and greenhouse have contrasting agronomic potential, which indicates that producers can establish their crops with different materials. We suggest the use of 'Fronteras' to obtain greater production and fruit size, 'Albion' for producers looking to grow sweeter and tastier fruits, and recommend 'Camino Real' to obtain strawberries rich in secondary metabolites. Our findings can help producers in choosing the best cultivars to meet consumers' increasing demands for both quantity and quality. Thus, genetic management, which is always welcome in horticulture, could enhance the strawberry production chain around the world.

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Conflict of interest

There is no conflict of interest for this study.

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