



Morpho-phenological and agronomic performance of strawberry cultivars with different photoperiodic flowering responses

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ABSTRACT. The adaptability of the strawberry is known; however, little is known about the morphological and agronomic performance of these runner plants when transplanted in the Southern Hemisphere. The objective of this study was to evaluate whether strawberry cultivars classified according to their flowering differ in morpho-phenology and agronomic performance. Six cultivars of strawberry were used, two of which were Short Day (SD), Camarosa and Camino Real, and four of which were Neutral Day (ND), Aromas, Albion, Monterey, and San Andreas. The cultivars were arranged in a randomized complete block design with four blocks. The research developed in two parts: one part as descriptive research (morphological performance and phenology) and the other part as explanatory research (morphology of the root system and the agronomic performance). In the descriptive research, the data about the strawberry cultivars were presented in a descriptive way. The data on morpho-agronomic performance (explanatory research) were submitted to analysis of variance and Tukey's test at a 5% probability of error. It is inferred that there is variability among cultivars regardless of their classification in terms of flowering. In all cultivars, we observed a botanical structure called a hypsophyll that is not included in the morphological descriptors of the species.

Keywords: precocity; descriptors; photoperiodic classification; hypsophyll; short days; neutral days.

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Introduction

Brazil is the second-largest producer of strawberries (*Fragaria ananassa*) in the world, and the main region where they are produced in the country is the south of Minas Gerais, where 90% of the production in that state is concentrated, with an annual production close to 85 thousand tons (Curi, Peche, Pio, Caproni, & Oliveira, 2016).

The runner plants used by the producers in the Brazilian subtropics are mainly developed in the Argentinean and Chilean Patagonia. This makes availability low at the time indicated for planting (beginning of autumn) and conditions the transplant timing on the delivery of the runner plants.

It has been observed that due to this irregularity, there are alterations in the culture cycle. These changes may be related to the development of the molt, which requires cold hours for the accumulation of carbon in the crown and for phase change (Tazzo, Fagherazzi, Lerin, Kretschmar, & Rufato, 2015).

The characteristic high concentration of these reserves in the crown is directly related to the capacity of the vegetative buds to differentiate from reproductive buds. This is related to the specific genotype of the cultivars used, since those cultivated in the Southern Hemisphere are mainly those classified as Short Day (SD) and Neutral Day (ND). In the case of SD, they flower in a photoperiod of less than 14 hours of light (Shalit et al., 2009), while those of ND begin to differentiate floral buds from the intrinsic stimulus of the cultivar (autonomous flowering route) or when several cycles of temperatures occur below 10°C (Coubesier & Coupland, 2005; Heide, Stavang, & Sønsteby, 2013).

Understanding these factors is extremely important in determining the time of planting, flowering and beginning of harvest. This information is directly linked to the morpho-physiology of the species and may

show the plant's adaptability to developmental conditions. Many authors have described the strawberry plant, but few of these descriptions were based on the crop descriptors and when they were, the descriptions were in other contexts (Massetani, Gangatharan, & Neri, 2011). To understand how this species grows and develops, it is important to know its morphology in its cultivation habitat, since it is known for its great adaptability to the growing environment and growing conditions (Akhatou, González-Domínguez, & Fernández-Recamales, 2016). These data allow adjustment of crop management in relation to the system and the cropping site.

Based on this, the natural adaptability of the species is known, but little is known about the morpho-phenology and agronomic performance of these runner plants when transplanted at different times in the Southern Hemisphere.

Based on the above, it is necessary to clarify whether there is variability between strawberry cultivars classified on the basis of flowering regarding morpho-phenology and morpho-agronomic performance.

The hypothesis of the research is that strawberry cultivars with different paths to flowering are distinct in morpho-phenology and morpho-agronomic performance.

The objective of this research was to evaluate whether strawberry cultivars classified according to their flowering differ in their morpho-phenology and morpho-agronomic performance.

Material and methods

Material and location of the experiment

Six strawberry cultivars were used, two Short Day (SD), Camarosa and Camino Real and four Neutral Day (ND), Aromas, Albion, Monterey, and San Andreas. The runner plants were obtained from the Llahuen Nursery, located in Chilean Patagonia (33°50'15.41" S and 70°40'03.06" W).

The experiment was carried out in a greenhouse of 510 m² under a conventional cultivation system (soil) in Rio Grande do Sul, Brazil (28°15'39" S, 52° 24'33" W).

Treatments and experimental design

The cultivars consisted of the treatments, which were arranged in a randomized complete block design, with four replications. Each plot consisted of eight plants, totalling 32 plants per treatment.

Procedures

The experiment was conducted from May to October 2016. The cultivars were transplanted according to the availability of the nursery. Thus, there were three transplant dates: May 12th, 2016 Camarosa and Camino Real; July 6th, 2016 Monterey and Albion and June 21st, 2016 Aromas and San Andreas.

Soil samples were collected and chemical analysis was performed (Table 1).

Table 1. Result of soil chemical analysis.

Clay (%)	pH H ₂ O	Ind SMP	P	K	OM (%)	Al	Ca	Mg	H+Al	CTC	Saturation				
			mg dm ⁻³			cmol _c dm ⁻³			Bases		Al	K			
													%		
42	6.5	6.8	63.4	330	4.8	0	9.8	4.4	1.7	16.8	90	0.0	5.0		
													Micronutrients		
													mg dm ⁻³		
			Sulfur	Boron	Manganese			Zinc					Copper		
			8.0	0.6	5.1			10.6					1.7		

The flowerbeds were approximately 15 m long by 1.0 m wide. Mulch was placed on the flowerbeds. The drop irrigation system was spaced every 0.30 m. After being received, the runner plants were submitted to measurement of the crown diameter to standardize them. Those that had diameters greater than 8 mm were considered for planting (Figure 1).

After standardization, the runner plants were transplanted at a spacing of 0.30 x 0.30 m. The fertigation solutions used were administered according to the needs of the crop and the phenological stage of the plants (Table 2).

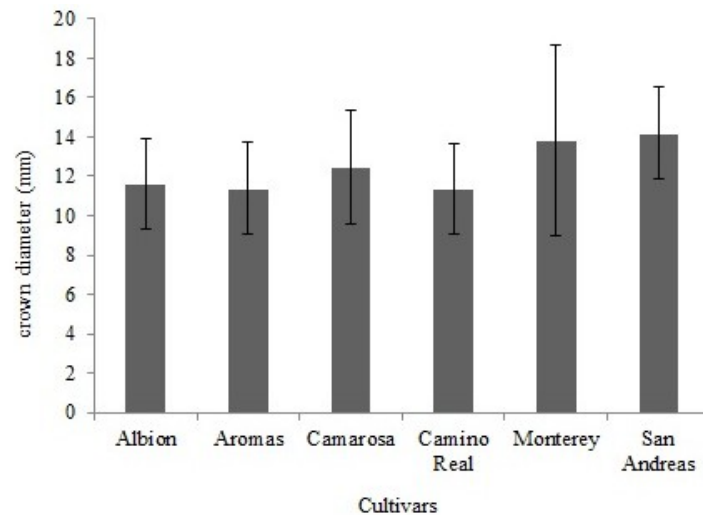


Figure 1. Mean diameter of the crown of runner plants of strawberry cultivars.

Table 2. Concentration of macronutrients administered in the fertigation during the vegetative and fruiting phase of the strawberry.

Authors	Concentration (mmol L ⁻¹)						
	NO ₃ ⁻	NH ₄ ⁻	K ⁺	H ₂ PO ₄	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻
Furlani and Fernandes Júnior (2004) ¹	8.3	0.8	3.8	1.6	2.6	1.5	1.5
Furlani and Fernandes Júnior (2004) ²	8.3	----	4.6	1.6	2.6	1.5	1.5

¹Vegetative phase; ²Fruiting phase.

Assessments

The study developed in two parts: one as descriptive research (performance of morpho-phenology) and another as explanatory research (morpho-agronomic performance).

Morpho-phenology Performance

To evaluate the aerial part morphology, the following characteristics were used, based on the morphological descriptors of the strawberry (UPOV, 2012) for the analysis of the cultivars tested (Table 3).

Table 3. Characteristics of the strawberry cultivars according to the morphological descriptors (UPOV, 2012).

Characteristics	Description
Plant	
Growth habit	erect; semi-erect; open
Density of leaves	scarce; average; dense
Position of inflorescence in relation to leaves	under; in the same height; above
Leaf	
Petiole colour	yellowish green; light green; medium green; dark green; bluish green
Leaf colour	yellowish green; light green; medium green; dark green; bluish green
Brightness	absent or weak; medium; strong
Edge of terminal leaflet	serrated; serrated to trimmed; trimmed
Anthocyanin pigmentation of stipules	absent or very weak; weak; average; strong; very strong
Convexity	absent or weak; medium; strong
Inflorescence	
Number of flowers	low; medium; high
Fruit	
Size	very small; small; medium; large; very large
Form	reniform; conical; cordiform; ovoid; cylindrical; rhomboid; obloid; globular; cuneiform
Colour	whitish yellow; light orange; medium orange; orange red; medium red; dark red; blackish red
Brightness	weak; medium; strong
Position of the achenes	below the surface; at the same height as the surface; on top of the surface
Pulp colour	whitish; light pink; orange red; light red; red medium; dark red
“Heart” colour	white; light red; medium red
Cavity	absent or small; medium; large

In relation to the phenology, the evaluations consisted of observations and weekly records of the different stages of development between the stages that determine the first expanded leaf (E11) and most of the fruit with red coloration (E87), according to the BBCH coding (Biologische Bundesanstalt, Bundessortenamt and Chemical Industry) of the strawberry development phenological stages described by Meier (1994).

During the experimental period, we determined the thermal sum. For this, a meteorological mini-station located inside the agricultural greenhouse was used from which average air temperature data were extracted. The daily thermal time (DTT) was calculated according to Arnold (1960) using the following equation:

$$DTT = (ADT - BT) [^{\circ}\text{day}^{-1}] \quad (1)$$

where: ADT = average daily temperature and BT = base temperature.

The BT used was 7°C (Antunes et al., 2006). The DTT was accumulated from the transplant of the runner plants, resulting in the accumulated thermal time (ATT), that is,

$$ATT = \sum DTT \quad (2)$$

Morpho-agronomic performance

To evaluate the morphology of the root system, plant roots were collected at the end of the experiment for analysis using images from WinRHIZO® software coupled to a scanner. The readings were performed on four plants from each treatment. The evaluations included total root length (cm), surface area (cm²) and root volume (cm³). The roots were grouped by software in different diameter classes in relation to their total extension: very fine roots (VFR), with a diameter of 0.00 to 0.5 mm; fine roots (FR), with a diameter of 0.5 to 2 mm; and thick roots (TR), with a diameter greater than 2 mm (Böhm, 1979).

To determine the fruit yield of the first flowering, fruits were harvested when ¾ of their epidermis was red (maturation), and the total fresh mass of the fruits (g) was evaluated.

Data analysis

The morpho-phenology data (descriptive research) on the aerial part of the strawberry cultivars were presented in a descriptive way. Data on morpho-agronomic performance (explanatory research) were submitted to analysis of variance, and the means were compared by the Tukey test at 5% error probability.

Results

Morpho-phenologic performance

For this study, we considered 18 morphological characteristics present in the descriptors of the species (Table 4). The cultivars classified as SD (Camarosa and Camino Real) presented only 5 common characteristics among them. For leaves, considering the edge of the terminal leaflet, both are crenate. Their bulging is classified as strong. When evaluating the fruits, the characteristic size was classified as large and the brightness was classified as strong. The colour of the pulp was classified as dark red for the two cultivars.

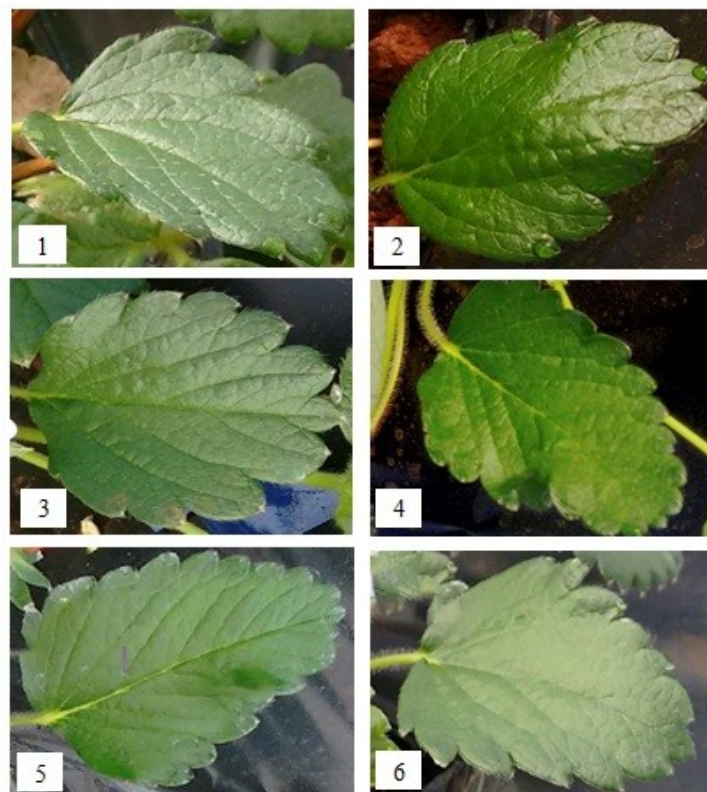
The cultivars of ND presented 3 common characteristics. The leaf stem colour was described as light green. For the fruit, the position of the achenes is located below the surface. All fruits present absent or small cavities.

In general, great variability was observed among all cultivars regardless of their photoperiodic classification.

In all cultivars studied, the presence of a botanical structure called a hypsophyll (Figure 2) was observed, which is not included in the morphological descriptors for this species.

Table 4. Characterization of strawberry cultivars according to the morphological descriptors.

Characteristics	Morphological Description					
	Albion	Aromas	Camarosa	Camino Real	Monterey	San Andreas
	Plant					
Growth habit	Semi-erect	Semi-erect	Open	Semi erect	Erect	Semi-erect
Density of leaves	Spaced	Average	Dense	Average	Spaced	Dense
Position of inflorescence in relation to leaves	Above	Under	Under	Above	Under	Above
	Leaf					
Petiole colour	Light green	Light green	Light green	Yellowish green	Light green	Light green
Leaf colour	Dark green	Light green	Light green	Dark green	Dark green	Dark green
Brightness	Absent or weak	Absent or weak	Absent or weak	Medium	Medium	Absent or weak
Edge of terminal leaflet	Crenate	Crenate	Crenate	Crenate	Serrated-Crenate	Crenate
Anthocyanin pigmentation of stipules	Weak	Weak	Absent or very Weak	Average	Strong	Weak
Convexity	Weak	Strong	Strong	Strong	Strong	Medium
	Inflorescence					
Number of flowers	Medium	Medium	High	Medium	Medium	Many
	Fruit					
Size	Medium	Medium	Large	Large	Medium	Small
Form	Conic	Cordiform	Cordiform	Rhomboid	Conic	Cylindrical
Colour	Dark red	Medium red	Medium red	Dark red	Dark red	Medium red
Brightness	Strong	Medium	Strong	Strong	Strong	Strong
Position of the achenes	Below the surface	Below the surface	Below the surface	At the same height as the surface	Below the surface	Below the surface
Pulp colour	Medium red	Light red	Dark red	Dark red	Dark red	Light red
“Heart” colour	Reddish	White	Light red	White	Whitish	Pinkish
Cavity	Absent or small	Absent or small	Absent or small	Large	Absent or small	Absent or small

**Figure 2.** Morphological aspect of the hypsophyll of strawberry cultivars studied. Cultivars: Albion (1), Aromas (2), Camarosa (3), Camino Real (4), Monterey (5), and San Andreas (6).

Because the hypsophyll does not appear in the descriptors and is not an official parameter, six characteristics of descriptors used to describe leaves were used for the characterization of the hypsophyll (Table 5), since the structure resembles a leaflet.

Table 5. Description of the hypsophyll in six strawberry cultivars.

Descriptors	Morphological Description					
	Albion	Aromas	Camarosa	Camino Real	Monterey	San Andreas
Hypsophyll						
Petiole colour	Light green	Light green	Light green	Medium green	Light green	Light green
Brightness	Weak	Weak	Weak	Weak	Medium	Weak
Hypsophyll colour	Light green	Light green	Medium green	Dark green	Dark green	Light green
Hypsophyll Edge	Serrated-Crenate	Serrated-Crenate	Crenate	Serrated-Crenate	Serrated	Crenate
Anthocyanin pigmentation of stipules	Average	Weak	Average	Average	Weak	Average
Width of the hypsophyll in relation to the length	Symmetrical	Longer length	Symmetrical	Longer length	Longer length	Longer length

The new structure described presented great variability among the cultivars independent of the photoperiodic classification of the studied cultivars. Those classified as ND had a single common characteristic, stem colour, all of which were classified as light green. The SD cultivars presented two common characteristics. For brightness, they were classified as weak, and for the anthocyanin pigmentation of stipules, classification was described as the mean.

Considering the phenology data, strawberry cultivars classified as ND, in general, were earlier to initiate flowering (mean of 48 days) (Figure 3).

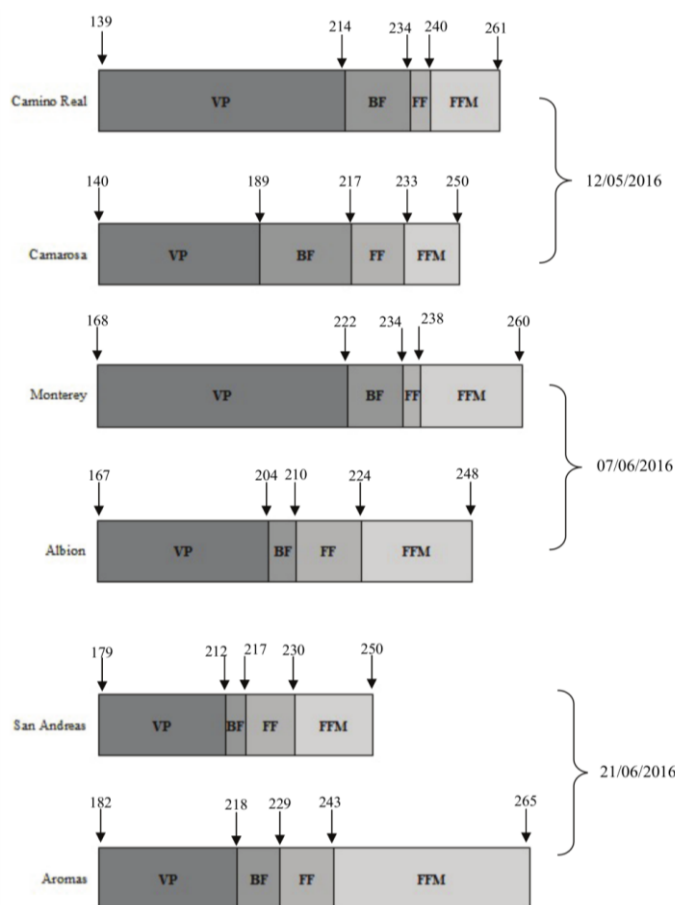


Figure 3. Vegetative and reproductive cycle, according to the strawberry phenological stages scale, represented by Julian days according to the transplant dates of the runner plants. V.P. = Vegetative Phase, B.F. = Beginning Flowering, F.F. = Full Flowering, F./F.M. = Fruit Formation and Maturation.

The cultivars identified as the earliest of all studied were San Andreas (ND) and Camarosa (SD). Both required approximately 327.0°C day⁻¹ (Figure 4) to start flowering. However, the cultivar San Andreas was transplanted 40 days after Camarosa, achieving the mentioned thermal sum in only 39 days. Camarosa took 55 days. Thus, San Andreas took less time to accumulate the same physiological time (degree days⁻¹) than Camarosa.

Among the ND cultivars, the latest to start flowering was Monterey (63 days), with a longer vegetative phase (54 days) among the cultivars tested. Between the SD cultivars, the later was Camino Real (81 days). As a consequence of the precocity of its flowering, San Andreas began the process of fruit maturation in advance in comparison to the other cultivars (57 days after transplant), independent of the photoperiodic classification.

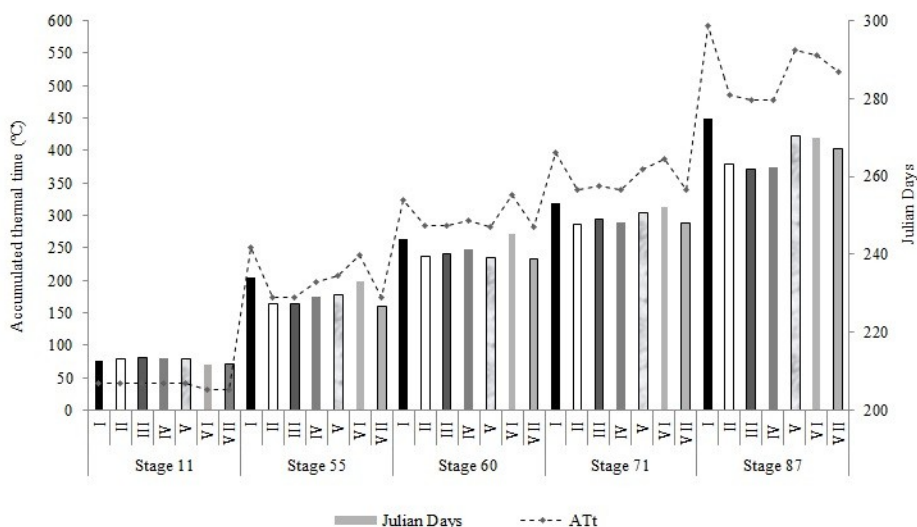


Figure 4. Cumulative thermal time and Julian days in the main vegetative and reproductive stages of strawberry. E11: first expanded sheet; E55: Early floral beginnings appear at the base of the rosette; E60: first open flower; E71: receptacle protruding from the crown of sepals; E87: most of the fruit with red coloration. Cultivars: Albion (1), Aromas (2), Camarosa (3), Camino Real (4), Monterey (5), and San Andreas (6).

Morpho-agronomic performance

In the deployment of fruit yield interaction (Figure 5), considering the strawberry cultivars within each harvest season, those that stood out were Camarosa (August, September and October) and Camino Real (October). However, for the harvesting periods of each cultivar, in general, it was observed that September and October were the months that recorded the best results of total fresh fruit mass in the present study. In August, at the start of production, lower values were recorded for most of the cultivars.

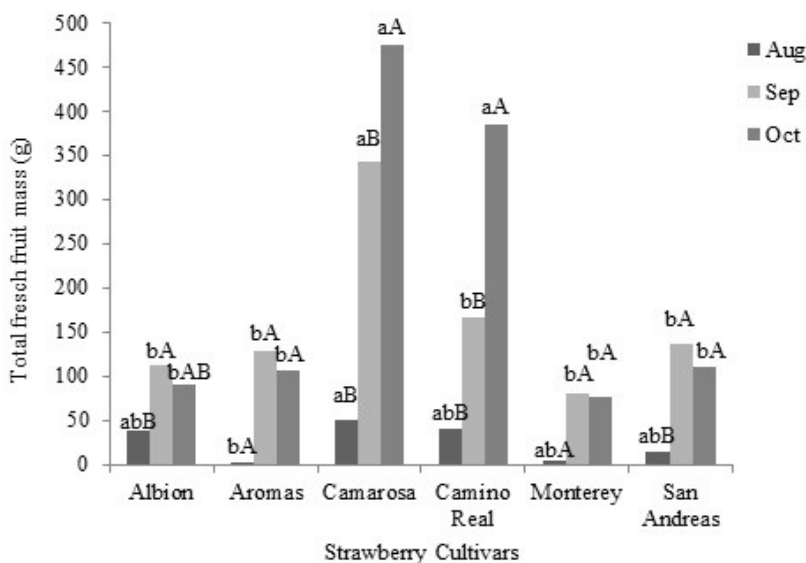


Figure 5. Interaction for strawberry fruit yield. Different letters on the columns, lowercase for month and uppercase for cultivar, differ statistically by the Tukey test at 5% probability of error.

The agronomic performance of fruits is directly related to the accumulated thermal sum (Figure 6). The SD cultivars Camarosa and Camino Real, although belonging to the same photoperiodic classification, showed different performance mainly in relation to the vegetative phase. Camino Real started flowering later requiring accumulation of a greater thermal sum to reach the beginning of flowering.

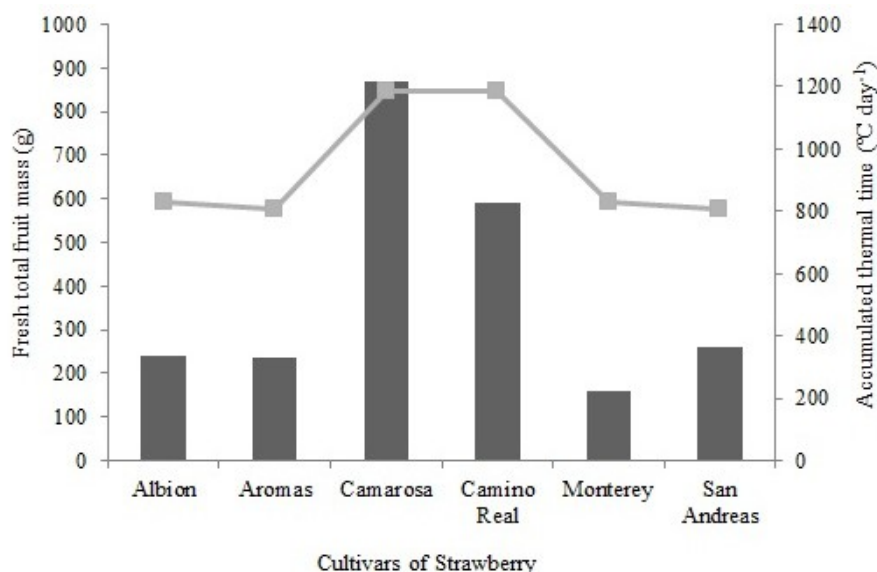


Figure 6. Relation between the total fresh fruit mass (g) of the first inflorescence accumulated in three months of cultivation and the accumulated thermal sum.

Discussion

Morpho-phenologic performance

The cultivars of strawberry, classified on the basis of their flowering, presented differences in morpho-phenology and agronomic performance. This indicates that even in cultivars with the same photoperiodic classification, there is variability among cultivars regardless of their classification.

The morphological distinctions between cultivars with the same photoperiodic classification in their morphological descriptors (Stewart & Folta, 2010; Durner, 2015) showed the close relationship between the genotypes of each cultivar, as each cultivar has a genetically heterogeneous structure, resulting in high genetic variability among different cultivars (Conti, Minami, & Tavares, 2002).

The structure observed and described for the first time in the strawberry plant has already been called a bract by some authors (Aguiar, 2013), but it is denominated botanically as a hypsophyll, a foliaceous organ located in the terminal portion of the stem floral zone and distinguished from normal leaves by colour, size, shape and other features (Castroviejo, Talavera, Aedo, Zarco, & Salgueiro, 1999). We emphasize that our research group has already developed research identifying and describing the hypsophyll for the strawberry cultivars Albion (ND) and Camarosa (SD) (article in process in scientific journal). However, these cultivars were maintained in this study because other evaluations were performed due to the research objective. In addition, for the other cultivars (Aromas, Camino Real, Monterey, San Andreas), the identification and description of the hypsophyll are unpublished.

The correct designation and inclusion of this structure in the morphological descriptors of the strawberry plant is suggested because its presence is confirmed in all cultivars used in the study, due to the structure's variability among the studied cultivars and due to its possible importance in the protection of flower buds and inflorescences (Ferri, 1999), which is the function assigned to this structure in the other species that present this structure. The function may be the same for the strawberry plant, as it was observed that a hypsophyll was present for each developed inflorescence.

In strawberry phenology, the explanation for the fact that the ND cultivars fruited earlier was the availability of the runner plants, since the ND cultivars were supplied later by the nursery. The runner plants of these cultivars had more time to accumulate reserves in the crown when they were still in the nursery and, soon after transplant, these reserves were quickly mobilized for leaf growth since these

cultivars bloom autonomously, necessitating a certain number of leaves for the liberation of florigen (a flowering hormone) in the phloem, which is transported to the regions of the stem apex and which determines the differentiation of the vegetative buds from the flower buds (Heide et al., 2013, Taiz, Zeiger, Moller, & Murphy, 2017). It should be noted that for these cultivars (ND), larger crown diameters (12.75 mm) were observed (Figure 1) when the runner plants were received. This indicates that the larger the diameter of the crown of the plants, the greater the amount of reserves are accumulated, allowing early development (Costa et al., 2018) and greater efficiency in the initial emission of leaves (Costa et al., 2018).

Under the conditions of the Southern Hemisphere, with a subtropical climate, the ND cultivars are rarely stimulated to bloom through temperature conditions, as they require several cycles (14 to 21) with temperatures below 10°C (Sønsteby & Heide, 2007). Thus, the stimulus route to flowering under these conditions was autonomous (Heide et al., 2013; Taiz et al., 2017), unlike in SD cultivars, which flower based on the photoperiod.

The Monterey cultivar, which also had a large crown diameter, began flowering after the San Andreas cultivar, again evidencing the genotypic influence within cultivars of the same photoperiodic classification (Conti, 2002).

The Camarosa cultivar started flowering later. This was mainly due to the lower accumulation of reserves in the crown of the runner plants at the time of its supply (month of May) and due to the average temperature recorded from its transplant until the beginning of flowering, which was 12°C. It should be noted that during this period, 10 days occurred with average temperatures below 7°C. For the San Andreas cultivar, the average temperature from the time of transplant to the beginning of flowering was 15°C. Beyond the effect of temperature, this once again reinforces the stimulus carried out from reserves stored in the crown of the plant (Costa et al., 2018).

Morpho-agronomic performance

Regarding the morphology of the root system, there was no distinction among cultivars. The result found in the present study may be related to the analyses that were performed in the month of October, at which time the roots would still be growing. Data different from those of the present study were found for agronomic performance in cultivars Camarosa and Camino Real, with peak production in November and December (Carvalho et al., 2013). In August, at the start of production, lower values were recorded for most cultivars. This result was also confirmed in another study (Antunes, Ristow, Krolow, Carpenedo, & Reisser Júnior, 2010).

Agronomic performance was associated with the accumulated thermal sum. It is worth mentioning that this condition is linked to the beginning of production. Camino Real was late to start flowering in relation to Camarosa under the same conditions of accumulation of thermal sum. This shows different responses among the cultivars, even those that belong to the same photoperiodic classification. Camino Real showed lower production. The ND cultivars showed a more balanced production potential among them because, under the conditions of cultivation in the Southern Hemisphere, the beginning of flowering is an intrinsic factor to the cultivar. More specifically, ND cultivars are insensitive to photoperiod and the microclimatic conditions do not provide several cycles with temperatures below 10°C, which would trigger expression of the ND genotype (Sønsteby & Heide, 2007). In this case, the intrinsic factor is the determining factor for the emission of leaves because, in these cultivars, the emission of leaves is responsible for the signalling (liberation of florigen) for the beginning of the differentiation of the vegetative meristem in flower buds (Heide et al., 2013, Taiz et al., 2017). If this process starts early, early flowering is the consequence.

Conclusion

There is variability among cultivars independent of their flowering classification. Albion, Camarosa and San Andreas are more precocious and have greater production potential. Camino Real, Monterey, and Aromas are cultivars suitable for regions with a tropical climate with higher average temperatures, which will benefit the shortening of the vegetative period. In all cultivars, a botanical structure called a hypsophyll is observed that is not included in the morphological descriptors of the species. It is inferred that this structure in the strawberry plant protects floral buds, as in other species.

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