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PHYLLOCHRON, AND ROOT SYSTEM DEVELOPMENT OF SIX STRAWBERRY CULTIVARS WITH DIFFERENT PHOTOPERIODIC FLOWERING RESPONSES

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ABSTRACT - Bare-root strawberry plants produced in Patagonia accumulate more reserves in the main crown, which allows their immediate development after transplantation. Due to the dependence on these bare-root plants, Brazilian producers use early cultivars, which start the leaves emission and the flower buds differentiation in advance, since these bare-root plants do not always arrive within the estimated time for planting in southern Brazil. The objective of the work was to investigate whether six strawberry cultivars, produced in a greenhouse, differ in their phyllochron, and root system development. Six cultivars were tested, arranged in a randomized block design, with four replications. Bare-root plants were cultivated in soil in a greenhouse. The phyllochron was evaluated by counting the number of leaves, weekly, from the beginning of leaf emission (from the main crown) until the appearance of the first fruit. The roots were digitized by a scanner and the images analyzed by the WinRHIZO® software. 'Camarosa' cultivar was considered the earliest to start fruiting, as it had the lowest phyllochron value (69.93ºC day^{-1} leaf^{-1}), while the cultivar 'San Andreas' was the latest (166.67ºC day^{-1} leaf^{-1}). 'Albion' and 'Aromas' presented the highest total root length in relation to the other cultivars. In conclusion, the six strawberry cultivars analyzed in this study, with different photoperiodic classifications regarding flowering, differ in relation to their morphophenological performance. In the growing conditions of southern Brazil, phyllochron study indicates that 'Camarosa' cultivar is the earliest and 'San Andreas' cultivar is the latest. 'Albion' and 'Aromas' cultivars are more compact plants, with greater potential for the development of the root system.
Keywords: *Fragaria* x *ananassa* Duch., precocity, short days, neutral days, WinRHIZO®.

FILOCRONO E DESENVOLVIMENTO DO SISTEMA RADICIAL DE SEIS CULTIVARES DE MORANGUEIRO COM DIFERENTES RESPOSTAS FOTOPERIÓDICAS AO FLORESCIMENTO

RESUMO - Mudas de morangueiro de raiz nua produzidas na Patagônia acumulam mais reservas na coroa principal, o que permite seu desenvolvimento imediato após o transplante. Devido à dependência dessas mudas, os produtores brasileiros usam cultivares precoces, que iniciam a emissão de folhas e diferenciação de gemas floríferas antecipadamente, já que nem sempre as mudas chegam no prazo estimado para o plantio no sul do Brasil. O objetivo do trabalho foi investigar se seis cultivares de morangueiro, produzidas em estufa, diferem quanto ao seu filocrono e desenvolvimento do sistema radicial. Foram testadas seis cultivares, dispostas no delineamento de blocos casualizados, com quatro repetições. As mudas de raiz nua foram cultivadas no solo em uma estufa. O filocrono foi avaliado por meio da contagem do número de folhas, semanalmente, desde o início da emissão de folhas (da coroa principal) até o surgimento do primeiro fruto. As raízes foram digitalizadas por um scanner e as imagens analisadas pelo software WinRHIZO®. A cultivar Camarosa foi considerada a mais precoce para iniciar a frutificação, pois apresentou o menor valor de filocrono (69.93ºC dia^{-1} folha^{-1}), enquanto a cultivar San Andreas mostrou-se a mais tardia (166.67ºC dia^{-1} folha^{-1}). Albion e Aromas apresentaram o maior comprimento total de raízes em relação às demais cultivares. Conclui-se que as seis cultivares de morangueiro analisadas neste estudo, com distintas classificações fotoperiódicas quanto ao florescimento, diferem em relação ao seu desempenho morfofenológico. Nas condições de cultivo do sul do Brasil, o estudo do filocrono indica que a cultivar Camarosa é a mais precoce e a cultivar San Andreas é a mais tardia. As cultivares Albion e Aromas são plantas mais compactas, com maior potencial de desenvolvimento do sistema radicial.
Palavras-chave: *Fragaria* x *ananassa* Duch., precocidade, dias curtos, dias neutros, WinRHIZO®.

INTRODUCTION

As one of the horticultural crops with the greatest economic value, the strawberry (*Fragaria* x *ananassa* Duch.) is reaching new agricultural frontiers on a world scale. The Brazilian production of strawberries (150 thousand tons) is still concentrated in the conventional

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cultivation system (in the soil and in an open field), with yield of 35.7 t ha^{-1} (CHIOMENTO et al., 2021). Due to the growing demand for fruit, most producers in southern Brazil have migrated from traditional open-field cultivation to greenhouses (COSTA et al., 2016); in addition, they choose to purchase quality bare-root strawberry plants imported from Argentina and/or Chile (COSTA et al., 2014).

In Argentine and Chilean nurseries, these bare-root plants have a greater accumulation of cold hours in the main crown, which guarantees them more reserves to enhance their development immediately after transplantation (COSTA et al., 2017). However, due to the dependence on the supply of bare-root plants, Brazilian producers opt for early cultivars, that is, that start the leaves emission and the flower buds differentiation in advance, since these bare-root plants do not always arrive within the estimated time for planting in southern Brazil, which compromises the beginning of the strawberry cycle (COSTA et al., 2018).

In the last decade, in addition to production systems, new strawberry cultivars are being adapted to the edaphoclimatic conditions of the producing regions. The growth and development of strawberry cultivars are controlled by complex environmental interactions, which include the photoperiod and temperature (SØNSTEBY; HEIDE, 2017). Thus, morphophenology studies are important for strawberry cultivation due to the plant physiology being influenced by environmental factors, which directly interfere in the crop photoperiodic responses, indicating the plant adaptability in relation to the development conditions (COSTA et al., 2021). This information is relevant to the establishment of cultural management in relation to the cultivation system.

An attribute used to describe the vegetative development of agricultural crops is the number of leaves accumulated on the main stem, which results from the integration of leaf appearance rate (LAR) over time (STRECK et al., 2003). One way to estimate LAR is through the phyllochron, defined as the time interval between the appearance of two successive leaves on the main crown (KLEPPER et al., 1982). The time unit used for the phyllochron includes the thermal sum (ºC day^{-1}), which considers the effect of temperature on plant development. Through this thermal time approach, the phyllochron is expressed in ºC day leaf^{-1} (XUE et al., 2004).

The knowledge about the phyllochron of strawberry cultivars is important to determine the precocity of cultivars with different photoperiodic classifications regarding flowering, when inserted in the Brazilian subtropic (where the climatic conditions differ from the place of origin of the bare-root plants). The answers obtained with this research will make it possible to make a portfolio of cultivars available to producers, which can be used to establish commercial strawberry crops allowing the staggering of cultivars based on their precocity.

The hypothesis of the study is that strawberry cultivars grown in southern Brazil have distinct morphophenological development, according to their photoperiodic classifications regarding flowering. Therefore, the objective of the work was to investigate whether six strawberry cultivars, produced in a greenhouse, differ in their phyllochron, and root system development.

MATERIAL AND METHODS

In this study, bare-root strawberry plants were used from the Llahuén/Chilean Patagonia nursery (33º 50' 15.41" S; 70º 40' 03.06" W), which constituted the plant material for the experiment. The research was carried out at the University of Passo Fundo (28º 15' 46" S; 52º 24' 24" W), Rio Grande do Sul (RS), Brazil, in a greenhouse from May (autumn) to October (spring) of 2016.

The treatments were six strawberry cultivars ('Albion', 'Aromas', 'Camarosa', 'Camino Real', 'Monterey' and 'San Andreas'), arranged in a randomized block design with four replications. Each experimental plot consisted of eight plants (8 plants per plot x 4 replicates = 32 plants per treatment). 'Camarosa' and 'Camino Real' are classified as short day (SD) cultivars, whereas 'Albion', 'Aromas', 'Monterey' and 'San Andreas' are classified as neutral day (ND) cultivars.

Strawberry plants were cultivated in soil in a 510 m^2 greenhouse with a semicircular roof installed in the northwest-southeast direction. The galvanized steel structure is covered with low-density polyethylene film with anti-UV additive and thickness of 150 µ. Prior to establishment of the experiment, we performed soil sampling to obtain its chemical characterization. We collected twelve soil subsamples within the greenhouse at random. The distance between subsamples was 5 meters. Sampling was performed with the aid of a shovel at a depth of 10 cm. All subsamples were placed in a container and homogenized. Then, approximately 500 g of soil were used for chemical analysis (Table 1).

TABLE 1 - Chemical properties of cultivated soil.

Clay (%)	pH H_2O	SMP Index	P	K	OM	Al	Ca	Mg	H+Al	CEC	Saturation		
			(mg dm^{-3})		%	(cmol$_c$ dm^{-3})					Bases	Al	K
											%		
40	6.2	6.6	62.7	323	4.1	0.0	8.9	3.8	1.3	15.7	89	0.0	4.7

S	B	Mn	Zn	Cu
mg dm^{-3}				
7.0	0.4	4.8	10.2	1.2

In May 2016, the bare-root strawberry plants were transplanted into beds covered by mulching (thickness of 30 microns), with dimensions of 15 m long x 1.0 m wide. The plants were spaced 0.30 m x 0.30 m, with two rows of plants per bed. At the time of transplantation, bare-root plants have been harvested in Chilean Patagonia 25 days ago.

Localized irrigation was through drip tapes with a flow rate of 1.2 L h^{-1} per experimental unit. Soil moisture content was monitored by tensiometers at 20 cm depth, and irrigation was performed when soil moisture content was lower than -20 kPa. According to the chemical analysis of soil (Table 1), liming was not necessary. Fertilization was carried out based on soil analysis. Nitrogen, phosphorus and potassium were applied using urea, monoammonium phosphate and potassium nitrate, respectively (CQFS - RS/SC, 2016).

During the execution of the experiment, through a meteorological mini-station (WatchDog®), the air temperature (minimum, average and maximum) inside the greenhouse was monitored. According to the microclimate characterization of the cultivation environment (Figure 1), minimum and maximum absolute temperatures of -4.8ºC (May 12th) and 39.7ºC (July 13th), respectively, were recorded. The general average temperature was 17.3ºC. During the period of conducting the experiment, 60 days were recorded with temperatures below 7.0ºC.

The evaluations were initiated after the leaves emission of the plants. The phyllochron and the root system morphology of the six strawberry cultivars were evaluated. The phyllochron was evaluated by counting the number of leaves, weekly, from the beginning of leaf emission (from the main crown) until the appearance of the first fruit. A new leaf was emitted when visible, approximately 1 cm long.

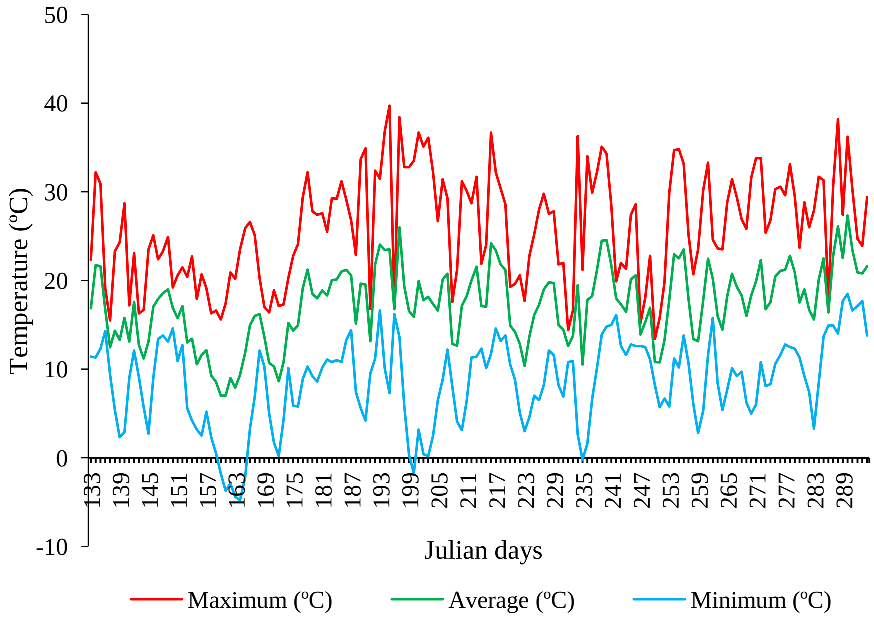

FIGURE 1 - Absolute temperatures recorded in the cultivation environment during the conduct of the experiment (May to October 2016).

For this, the average daily temperature (ADT) was evaluated according to the following equation, which calculates the arithmetic mean of the temperatures recorded by the meteorological mini-station every hour (Equation 1). Then, the daily thermal sum (DTS) was calculated according to Gilmore Junior and Rogers (1958) and Arnold (1960) (Equation 2)

$$\text{ADT (ºC)} = \frac{(t0 + t1 + t2 + \ldots + t23)}{24} \qquad \text{(Equation 1)}$$

$$\text{DTS (ºC day}^{-1}\text{)} = \text{ADT - BT} \qquad \text{(Equation 2)}$$

The base temperature (BT) is defined as the minimum temperature below which no leaves appear. The BT for strawberry cultivation was considered as 7.0ºC (COSTA et al., 2014). DTS has been accumulated since the transplant of bare-root plants, resulting in the accumulated thermal sum (ATS), that is, ATS (ºC day^{-1}) = Σ DTS. Finally, a regression analysis was performed between the number of leaves and the ATS. The angular coefficient of the linear regression is considered the LAR (leaves $ºC^{-1}$ day^{-1}) and the phyllochron (ºC day^{-1} $leaf^{-1}$) was estimated by the inverse of the angular coefficient of the linear regression (KLEPPER et al., 1982).

Regarding the root system morphology, at the end of the experiment (October 2016) the roots were collected and washed in water to eliminate soil fragments. Then, the roots were digitized by a scanner and the images analyzed by the WinRHIZO® software. The evaluated attributes were the total root length (TRL, cm), surface area (SA, cm^2) and root volume (RV, cm^3). The roots were grouped by the software in different diameter classes in relation to their total length (BÖHM, 1979): very thin roots (VTR, cm: Ø <0.5 mm), fine roots (FR, cm: Ø from 0.5 to 2.0 mm) and thick roots (TR, cm: Ø> 2.0 mm).

To estimate the phyllochron, linear regression was performed between the number of leaves and the ATS. The phyllochron was estimated as the inverse of the angular coefficient of the linear regression. The other data obtained were subjected to analysis of variance and the treatment means were compared using the Tukey test, at 5% probability of error, with Costat® program.

RESULTS AND DISCUSSION

Among the ecophysiological factors that condition the adaptability of strawberry cultivars to cultivation agroecosystems are the photoperiod and temperature (SØNSTEBY; HEIDE, 2017). Both factors are the main environmental signs that regulate the ontogeny of strawberry flowers (DURNER, 2016). Temperature can impair various physiological processes in strawberry plants such as chilling requirement, onset of flowering and time of ripening (KRUGER et al., 2012).

Phenology consists of the study of recurrent biological events over time (DENNY et al., 2014). Since temperature is the primary factor determining plant phenology, phenological series are often indexed by thermal time cumulative above a threshold (TSIMBA et al., 2013). The relationship between the accumulated thermal sum and the emission of leaves represents the phyllochron, which is used in ecophysiological studies to understand the development of plants and improve production efficiency (LONGHI et al., 2019).

In decreasing order, the LAR was 0.0143, 0.0090, 0.0077, 0.0067, 0.0063 and 0.0060 accumulated leaves every °C day^{-1} for the cultivars ‘Camarosa’, ‘Monterey’, ‘Aromas’, ‘Albion’, ‘Camino Real’ and ‘San Andreas’, respectively (Figure 2), with phyllochron of 69.93, 111.12, 129.87, 149.25, 158.73 and 166.67 °C day^{-1} leaf^{-1}, in the same order of cultivars, to emit two consecutive leaves (Figure 2). Thus, ‘Camarosa’ cultivar was considered the earliest to start fruiting, as it had the lowest phyllochron value (69.93 °C day^{-1} leaf^{-1}), while ‘San Andreas’ cultivar was the latest, as it had the highest phyllochron value (166.67 °C day^{-1} leaf^{-1}). As strawberry plants have productive peaks, followed by a decrease in production, these results allow to develop a portfolio of cultivars so that producers in southern Brazil can carry out a planting schedule with different materials and have fruit supply for a longer period.

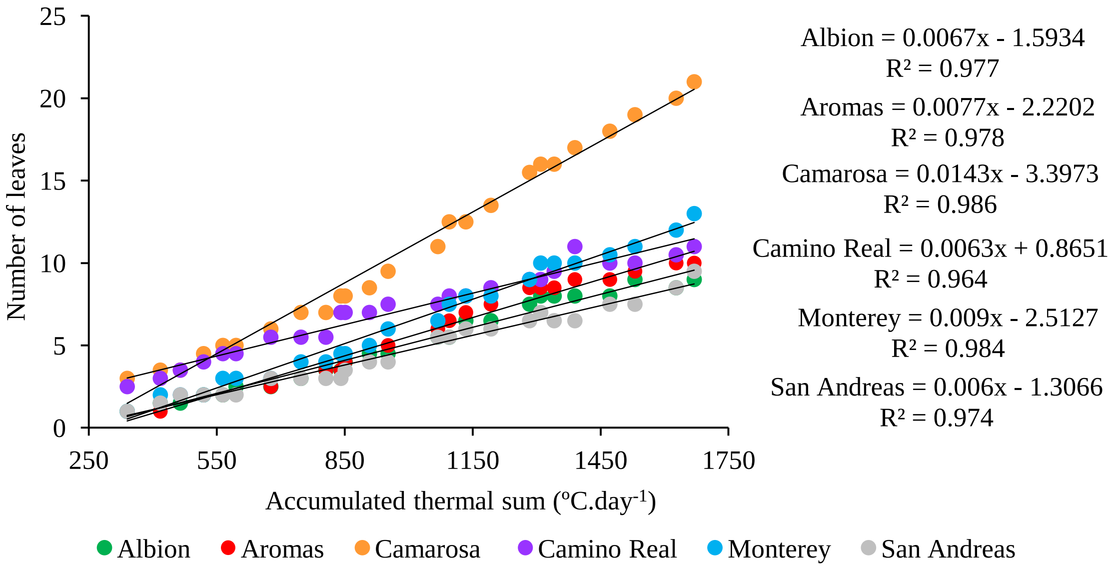

FIGURE 2 - Estimated phyllochron, calculated from the accumulated thermal sum and the number of leaves (of the main crown) of six strawberry cultivars.

Literature reports different values of phyllochron (°C day^{-1} leaf^{-1}) for ‘Camarosa’ cultivar, ranging from 90.33 (MENDONÇA et al., 2012) to 120.48 (COSTA et al., 2019), values higher than those obtained in the present work (Figure 2). High phyllochron values in the plants indicate that LAR is lower, as the plant requires a greater number of °C day^{-1} between the appearance of two successive leaves. However, it is important that LAR is higher (consequently, lower phyllochron) during the vegetative stage in order to increase the number of leaves before flowering, ensuring a greater number of fruits (ROSA et al., 2011).

In this study, the interval of days for emission of new leaf ranged from 7.3 (‘Camarosa’) to 17.5 (‘San Andreas’). The period between the emission of one leaf and another for strawberry cultivation varies from 8 to 12 days, with temperature being the main factor that affects this physiological process (GALLETTA; HIMELRICK, 1990). The linear relationships observed in the present study, with high coefficients of determinations (R^2) between the number of leaves and ATS (Figure 2), indicated that temperature was one of the decisive factors for leaves emission in the analyzed strawberry cultivars. When the crop cycle occurs at the recommended time for cultivation, the response of leaves emission in relation to air temperature is generally linear (STRECK et al., 2003), which was confirmed in this work.

Regarding to the root system morphology, the six strawberry cultivars showed similar performance for the SA (mean ± standard deviation = 412.37±92.68 cm^2), RV (10.15±3.19 cm^3), VTR (992.57±126.38 cm), FR (323.27±63.68 cm) and TR (107.65±54.72 cm) attributes. However, there was a significant effect on the TRL attribute, with emphasis on ‘Albion’ and ‘Aromas’ cultivars. Both cultivars presented, on average, a TRL higher by 30% when compared to the other cultivars (Figure 3).

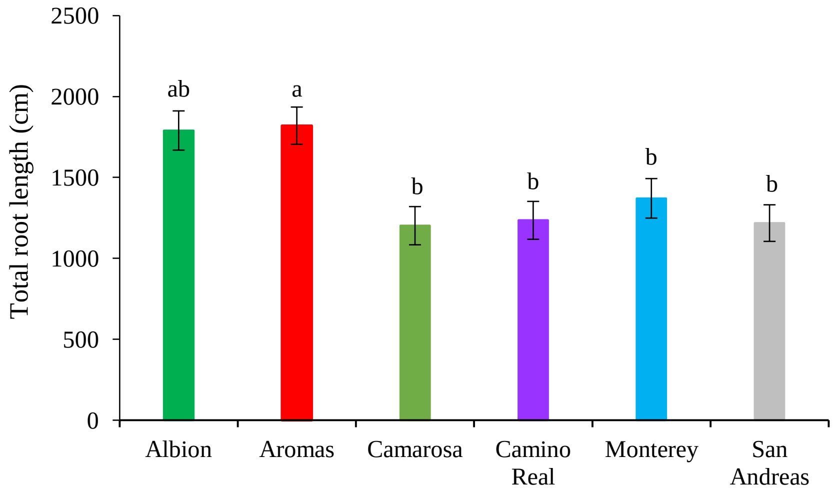

FIGURE 3 - Total root length of six strawberry cultivars. Data presented as mean ± standard deviation. Different letters on the columns indicate difference by the Tukey’s test ($p \leq 0.05$).

The root length is one of the most important parameters that measure the functionality of a plant’s root system (MATTNER et al., 2018). Kumar and Dey (2011) showed that the root length was positively correlated with the acquisition of nitrogen, phosphorus and potassium, with the efficiency of water use and with the fruit yield in strawberry plants grown under different mulch treatments and irrigation. This indicates that ‘Albion’ and ‘Aromas’ cultivars are the most efficient in the acquisition and use of resources available in the growth medium.

The greater number of leaves (Figure 2) confirmed the potential of vegetative development of ‘Camarosa’ cultivar. However, this did not occur regarding the root system development (Figure 3). ‘Aromas’ and ‘Albion’ are plants with a more compact aerial part and with greater capacity to develop the root system, which has already been confirmed in other research (COSTA et al., 2019). Strawberry growth and development are regulated by the interaction of a complex set of factors, such as temperature, photoperiod and light intensity. In addition, the distribution of roots is coordinated by the cultivar of the species and is also influenced by other factors, such as the fertility of the growth medium (YADAV et al., 2015) and the density of plants.

This study could help producers to select strawberry cultivars that start production in advance, giving them greater profitability. In addition, studies in different producing regions around the world are recommended to investigate the horticultural potential of strawberry cultivars. This allows for a positive impact on the producers’ income and enhances the strawberry production chain.

CONCLUSIONS

The six strawberry cultivars analyzed in this study, with different photoperiodic classifications regarding flowering, differ in relation to their morphophenological performance.

In the growing conditions of southern Brazil, the phyllochron study indicates that ‘Camarosa’ cultivar is the earliest and ‘San Andreas’ cultivar is the latest. This knowledge allows producers to schedule the planting of cultivars and thus have a supply of fruits for a longer period.

‘Albion’ and ‘Aromas’ cultivars are more compact plants, with greater potential for the development of the root system. Thus, both cultivars exploit more the growth medium in which they are inserted and this can improve the acquisition and use of water and nutrients.

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