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Carpochron: a concept for the time interval between the appearance of fruits in consecutive harvests

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Abstract

The aim of this research was to estimate the base temperature for the appearance of fruits at harvest point in the strawberry and to propose a concept to represent the time required for the appearance of fruits in consecutive harvests. The experiment was conducted in 2021 in four seedling transplanting seasons: May (season 1), June (season 2), July (season 3) and August (season 4) of two cultivars: Fronteras and Merced. Twenty-four consecutive fruit harvests were carried out from September 9, 2021, to December 1, 2021, when the number, length (cm), diameter (mm), and fresh weight of the fruits (g) were evaluated. The base temperature for the fruit emission of the strawberry was calculated using the method of the smallest mean square error. Carpochron was estimated at each season and for each cultivar, obtaining a simple linear regression between the number of fruits and the accumulated thermal sum (°C day) and the number of days after transplanting (DAT), using as base temperature the one estimated in this work. The base temperature for the appearance of consecutive fruits at the harvest point in the strawberry is 11°C. Carpochron increases with the delay of the transplanting season and the values ranged from 81.97°C fruit day to 144.93°C fruit day for cultivars Merced and Fronteras.

Keywords: development, *Fragaria x ananassa*, management techniques phenology

Introduction

Food quality associated with practices to improve the well-being and health of the population is an important factor that must be taken into account in food production chains, as well as environmental sustainability in the most diverse production systems. The strawberry (*Fragaria x ananassa* Duch.) belongs to the Rosaceae family and is a species with economic and social importance, mainly because it is an alternative for cultivation on family farms and for the possibility of destining the production for the fresh trade and for industrialization (Antunes et al., 2016).

World production and the demand for strawberries are on the rise, with an increase of 46% between 2013 and 2019 and exceeding the production of 12 million tons in an area of 522,527 hectares. In this scenario, Brazil ranks 17th position among the largest producers with a cropped area of 4,500 ha and annual production of approximately 165,000 tons, out of which 90% of the domestic production is sold in the domestic market, in its fresh form. Thus, management techniques such as the establishment of the harvest time and the interval between consecutive harvests are important to offer a quality product to the final consumer, avoiding deterioration as the Brazilian average productivity is approximately 38 tons per hectare (Antunes & Bonow, 2021).

For the improvement of harvesting techniques and their planning to avoid production losses, it is necessary to know the time between the consecutive harvest of fruits per plant. Hence, the concept of carpochron is being proposed, which is related to the time interval between the appearance of consecutive fruits at the point of harvest, which can be estimated in days fruit^{-1} or °C day fruit^{-1}. However, to estimate carpochron considering the thermal sum (°C day) it is necessary to estimate the base temperature for fruit emission in the

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strawberry, considering that the base temperature is the one below at which development does not occur or is not significant (Arnold, 1960) and possibly differs from the base temperature for leaf emission.

Concepts that determine the time interval for the appearance of leaves (phyllochron), nodes (plastochron), and consecutive flowers (anthochron) have been described in the literature. However, a term that determines the time interval for the consecutive appearance of fruits, as an example, for fruits at harvest point in species that present multiple harvests was not found. This new concept can help improve management techniques to increase productivity and also improve the quality of post-harvest practices, mainly by reducing waste. The objective of this experiment was to estimate the base temperature for the appearance of fruits at harvest point in the strawberry and to propose a concept to represent the time required for the appearance of fruits in consecutive harvests and its application in the strawberry crop.

Material and Methods

Seedlings of strawberry were produced from stolons from stock plants of two cultivars: Fronteras and Merced, both classified as short-day plants, that is, flowering is induced when the day length is shorter than the cultivars' critical photoperiod. The stolons were planted in 72-cell expanded polystyrene trays filled with commercial substrate and the seedlings were kept in these containers with no additional fertilization until transplanting. During this period, the seedlings remained in an agricultural greenhouse with a plastic cover, and irrigation was performed through sprinkling.

The experiment was conducted in 2021 in four seedling transplanting seasons, which occurred in the third ten-day period of May (season 1), June (season 2), July (season 3) and August (season 4), except for cultivar Fronteras in which transplanting occurred only in the first two seasons due to the smaller number of seedlings produced. The experiment was carried out in the soil, inside an agricultural greenhouse without plastic cover and with screened sides. Inside the greenhouse, four beds were made with approximate dimensions of 1.2 m in width, 12 m in length, and 0.2 cm in height, in which each bed housed a period of transplanting seedlings. The seedlings were transplanted when they had 4 to 6 leaves in unfertilized furrows approximately 15 cm deep and the spacing was 0.3 m between plants and between rows. Each experimental unit consisted of nine plants with three replications in each season and the circulation area was 0.5 m between beds.

Irrigation was performed using drip hoses on the ground with a distance of between the emitters of 0.2 m. weeds were controlled weekly with manual weeding in the rows and between the rows of cultivation and the control of insects (ants) was carried out in a preventive way with applications of baits around the greenhouse.

Twenty-four consecutive fruit harvests were carried out from September 9, 2021, to December 1, 2021, when the number, length (cm), diameter (mm), and fresh weight of the fruits (g) were evaluated. The length was obtained with a graduated ruler, the diameter with a digital caliper, and the fresh mass with the use of a digital scale. The harvest point was set as the one when the fruits achieved 75% or more of the mature color. The evaluations were carried out on all plants of each experimental unit with fruits ready for harvest at the time of the evaluations.

Air temperatures were collected in the experimental area using an Onset® data logger where the daily minimum and maximum temperatures were obtained. With the temperature data, the average air temperatures (Tmed) were calculated. The method used to determine the daily thermal sum was: TSd = (Tmean – Tb). One day, if Tmean < Tb then Tmean = Tb, where: Tmean is the daily average temperature and Tb is the base temperature (Arnold, 1960). The accumulated thermal sum (TSa) was calculated by adding the TSd values.

The base temperature for the fruit emission of the strawberry was calculated in the four transplanting periods using the method of the smallest mean square error (MSE) of the linear regression between the number of fruits and the accumulated thermal sum. Thus, simple linear regression equations were estimated between the values of the number of fruits in each transplanting season and in each harvest, which occurred for the cultivar Merced: from September 3 to October 12 (season 1), September 6 to October 8 (season 2), September 10 to October 8 (season 3), September 16 to October 14 (season 4) and for the cultivar Fronteras from September 3 to October 18 (season 1). The accumulated thermal sum was calculated using the base temperature values ranging from zero to 21°C with an increment of 1°C and the base temperature value was the one that presented the smallest mean square error (Sinclair et al., 2004). Harvests were limited until October 18 at this stage because they were carried out at milder temperatures, therefore, close to the base temperature.

The term carpochron was created through the derivation of the Greek radicals: Carpo (Karpós = fruit) and Chrono (Cronos = time), that is, the carpochron represents the time or the speed for the appearance of consecutive fruits per plant, in which the time is represented in the conventional unit (day^{-1}) or thermal unit (°C day^{-1}). Carpochron was estimated at each season and for each cultivar, obtaining a simple linear regression between the number of fruits and the accumulated thermal sum (°C day) and the number of days after transplanting (DAT), using as base temperature the one estimated in this work. This concept is being proposed to represent the time required for the appearance of consecutive fruits at the point of harvest, with application in this research in the strawberry crop, and was estimated as the inverse of the angular coefficient of linear regression, a methodology traditionally used to estimate the phyllochron (Schmidt et al., 2018), plastochron (Valera et al., 2022) and anthochron (Schwab et al., 2017).

Strawberry yield data were tabulated and the mean of all variables was calculated for the comparison of cultivars in the transplanting seasons of May and June (seasons 1 and 2) with harvests in the interval from October 4 to December 1. Means were compared using the t-test for independent samples, with a 5% error probability. The analyses were performed using Bioestat 5.0 and Microsoft Excel software.

Results and Discussion

The minimum and maximum temperatures over the experimental period were in absolute values -3.3°C and 35.8°C, with an overall mean of 16.88°C (**Figure 1**). Considering only the minimum daily temperatures in the experimental period, it ranged from -3.3°C to 20.9°C, which indicates that the cultivars at different transplanting times were subjected to mild and low temperatures during the cycle and fruit production. In this context, after the beginning of the harvest on September 3, 2021, the minimum temperatures ranged from 6.4 to 20.9°C, so this was the interval between the minimum temperatures in the reproductive period. This information regarding the variation of minimum temperatures is important in experiments to determine the base temperature for the emission of leaves or nodes in the vegetative phase and also in the appearance of fruits in consecutive harvests in the reproductive phase, as in this work.

A statistically significant difference was observed for the length, diameter, and fresh mass of fruits, except for the diameter in the second transplanting season, which was in June (**Table 1**). In both transplanting seasons, the cultivar Fronteras presented fruits with greater length, diameter, and fresh mass. These results may be related to the genetic/productive characteristics of the cultivars

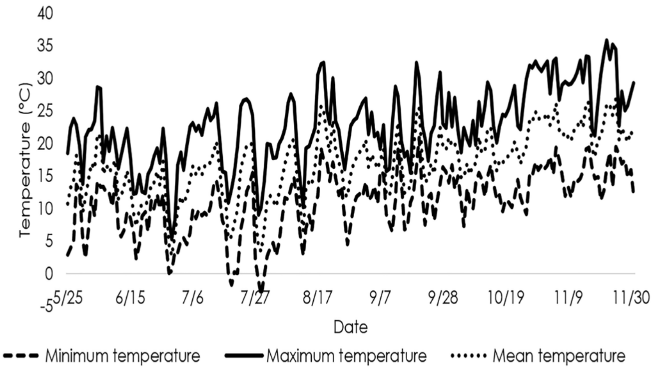

Figure 1. Minimum, mean, maximum temperatures during the experiment.

Table 1. Length, diameter and fresh mass of fruits of cultivars Merced and Fronteras in two transplanting seasons

May (season 1)			
Cultivar	Lenght (cm)	Diameter(mm)	Fresh mass (g fruit)
Merced	2.72 b	24.07 b	10.39 b
Fronteras	3.89 a	29.11 a	17.55 a
June (season 2)			
Cultivar	Lenght (cm)	Diameter(mm)	Fresh mass (g fruit)
Merced	2.58 b	24.66 a	9.97 b
Fronteras	3.38 a	24.42 a	12.21 a

*Means followed by different letters differ by the t-test for independent samples at 0.05 probability ($P<0.05$).

and suggest that for fresh fruit commercialization, the Fronteras cultivar may be more attractive to the final consumer and generate greater added value for the producer. It is important to point out that both cultivars are short-day, that is, their flowering and production are restricted by environmental conditions (photoperiod) during the year and the knowledge of this productive seasonality is extremely important for the destination of the production, either for the commerce of fresh fruits or industrialization.

The dimensions of strawberry fruits vary among cultivars, as well as the number of fruits, which is mainly influenced by photoperiod sensitivity so short-day cultivars have a smaller production period compared to neutral-day cultivars. On the other hand, the variations that occur among cultivars with dimensional characteristics, such as length, diameter, and mass, are influenced by genetic, environmental, physiological, and nutritional factors (Antunes et al., 2016).

Strawberries can be grown in different production systems. Also, according to (Richter et al., 2018), soil cultivation showed higher fruit production (g plant^{-1}) compared to the semihydroponic system using day-neutral cultivars (Albion, San Andreas, and Capitola). The difference between the systems was 47% and was attributed to the arrangement of plants and the oscillations of the fertigation system. However, production in a semihydroponic system showed a higher fruit quality.

The production system chosen, as well as the cultivars, must take into account the destination of production, place of cultivation, and the technological level available on the farm, thus seeking to maximize the quantity and quality of fruits produced per unit of the area regardless of the production system.

For the cultivar Merced, the base temperature was estimated for the four transplanting seasons. On the other hand, for the cultivar Fronteras, in the second transplanting season, the base temperature could not have been estimated because the method used did not converge to the smallest mean square error. In all combinations between transplanting seasons and cultivars in which it was possible to estimate the base temperature, the 88 linear equations between the number of fruits and the thermal sum accumulated with an initial temperature of 0°C to a temperature of 21°C showed a coefficient of determination greater than 0.895 until at a temperature of 16°C (**Figure 2**).

Above this temperature, a sharp drop was found in the coefficient of determination. In the first transplanting season, higher coefficients of determination were observed for the two cultivars, which were higher than 0.971 and 0.982 for the cultivars Merced and Fronteras, respectively, up to the estimated temperature of 16°C.

A variation was observed in the estimated base temperatures for the cultivars and transplanting times and this variation occurred in the interval between 10°C and 12°C. Although small in absolute values, this variation is expected from a biological point of view and occurred in experiments with different crops, such as for estimating the base temperature for emitting nodes in chia (Koefender et al., 2021) and for opening florets in gladiolus (Schwab et al., 2017). Thus, the base temperature for the appearance of consecutive fruits at harvest point in the strawberry was determined as the average of the values observed in all seasons and cultivars, that is 11.2 = 11°C.

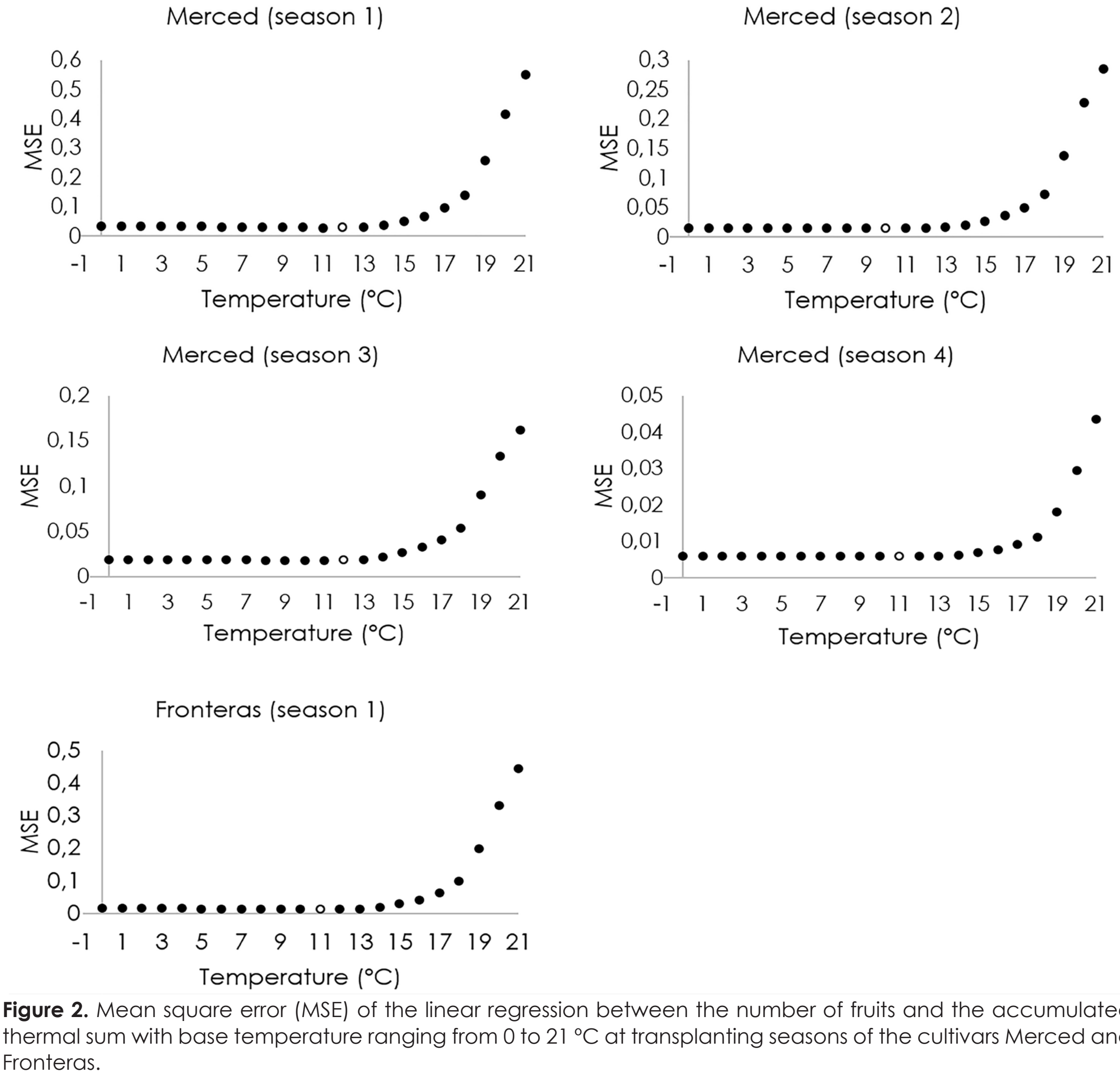

Figure 2. Mean square error (MSE) of the linear regression between the number of fruits and the accumulated thermal sum with base temperature ranging from 0 to 21 °C at transplanting seasons of the cultivars Merced and Fronteras.

At this temperature, for all seasons and cultivars, the coefficient of determination was greater than 0.92. This value was observed for the last transplanting season and in the other seasons, the value was between 0.956 and 0.991, which points to a high relationship between the appearance of fruits and the accumulated thermal sum, that is, the temperature had a predominant effect on the consecutive appearance of fruits at harvest point in the strawberry.

With the base temperature of 11°C obtained in this work, the daily and accumulated thermal sums were calculated, and later the values were used to estimate the carpochron (**Figure 3**). The values of carpochron (°C day) ranged from 82.64°C day to 144.93°C for the cultivar Merced. As for the cultivar Fronteras, the values ranged between 81.97°C day and 129.87°C day for the appearance of fruits at the harvest point. This shows that for the cultivar Merced, for example, between the first and the last transplanting season, the accumulation of heat units varied by f 62.29°C day for the emission and growth of fruits until reaching the Harvest point. This result demonstrates that the delay in the transplanting season of strawberry seedlings negatively affects productivity due to the longer time needed for the fruits to reach the point of harvest consecutively on the same plant. Characters that quantify plant development can be correlated with air temperature given the direct relationship of this meteorological variable with the physiology of plant development (Bahuguna & Jagadish, 2015), as observed in the present work with strawberries.

Linear regressions between the number of fruits and days after transplanting of cultivars Merced and Fronteras at the respective seasons showed a high coefficient of determination, which was greater than 0.87. However, it should be observed that for the cultivars in the first two transplanting seasons, the coefficient of determination was greater than 0.95 and this can be used as an indication that the methodology used for estimating carpochron was appropriate, as observed by Schwab et al. (2014) for the estimation of anthochron in gladiolus cultivars.

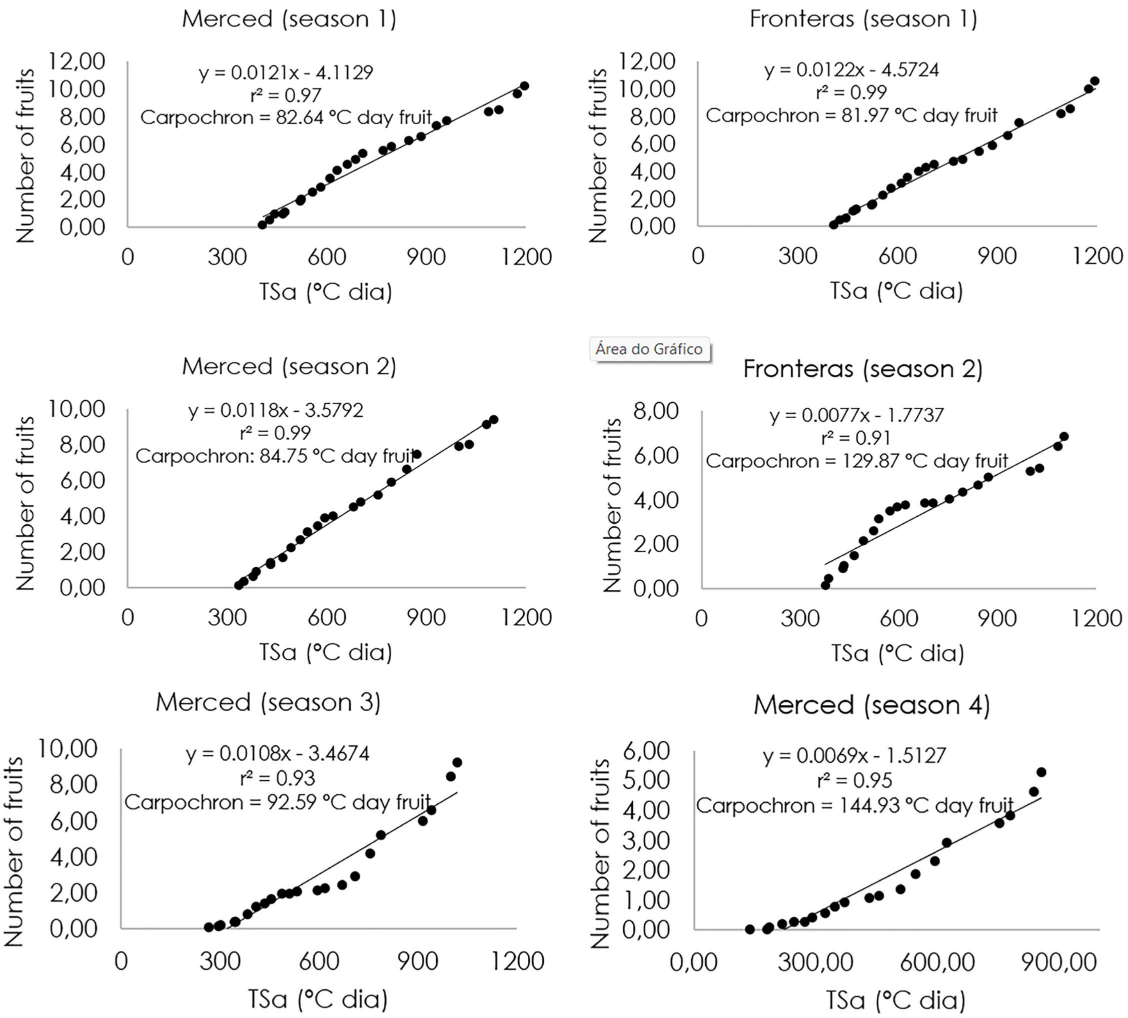

Figure 3. Carpochron (°C day fruit) for cultivars Merced and Fronteras at different seasons of seedling transplanting.

When the time length for the appearance of consecutive fruits was in days in the application of carpochron, at transplanting in May, the appearance of consecutive fruits at the harvest point occurred at intervals of 9.20 and 9.22 days for the cultivars Merced and Fronteras, while in the following month, the values were 9.33 days and 13.60 days for cultivars Merced and Fronteras, respectively (**Figure 4**). This result points to the definition of the transplanting time of seedlings for the production beds as important and, for these cultivars, the response concerning the delay of the transplanting time was different. Cultivar Merced showed greater stability in the emission of consecutive fruits in the first two transplanting seasons, while for the cultivar Fronteras an increase of 4.38 days was observed for the appearance of consecutive fruits at harvest point in the second transplanting season. This demonstrated that in addition to genetic traits, environmental interactions influence carpochron after the first fruit harvest.

This trend in increasing the interval between the harvest of consecutive fruits with the delay of the transplanting season was confirmed in the periods of July and August when the carpochron presented values of 10.28 and 15.70 days fruit^{-1}. This result corroborates what was observed in the production evolution over the experiment. According to Antunes et al. (2016), while seedlings are transplanted from February to March in the southeast region, in the South region it extends from April to June. In this context, late transplanting times should be avoided due to the long interval in fruit production and consequent lower productivity. In late transplants, vegetative development is reduced, which negatively affects the accumulation of reserves and productivity (Janisch et al., 2008).

Thus, the carpochron is an efficient time measure to represent the interval between the appearance of consecutive fruits in strawberry cultivars and provides important information on the productive behavior of cultivars at different transplanting seasons. The effect of transplanting date on carpochron is at least partially related to air temperature, since, for both cultivars, carpochron increased as the transplanting season was

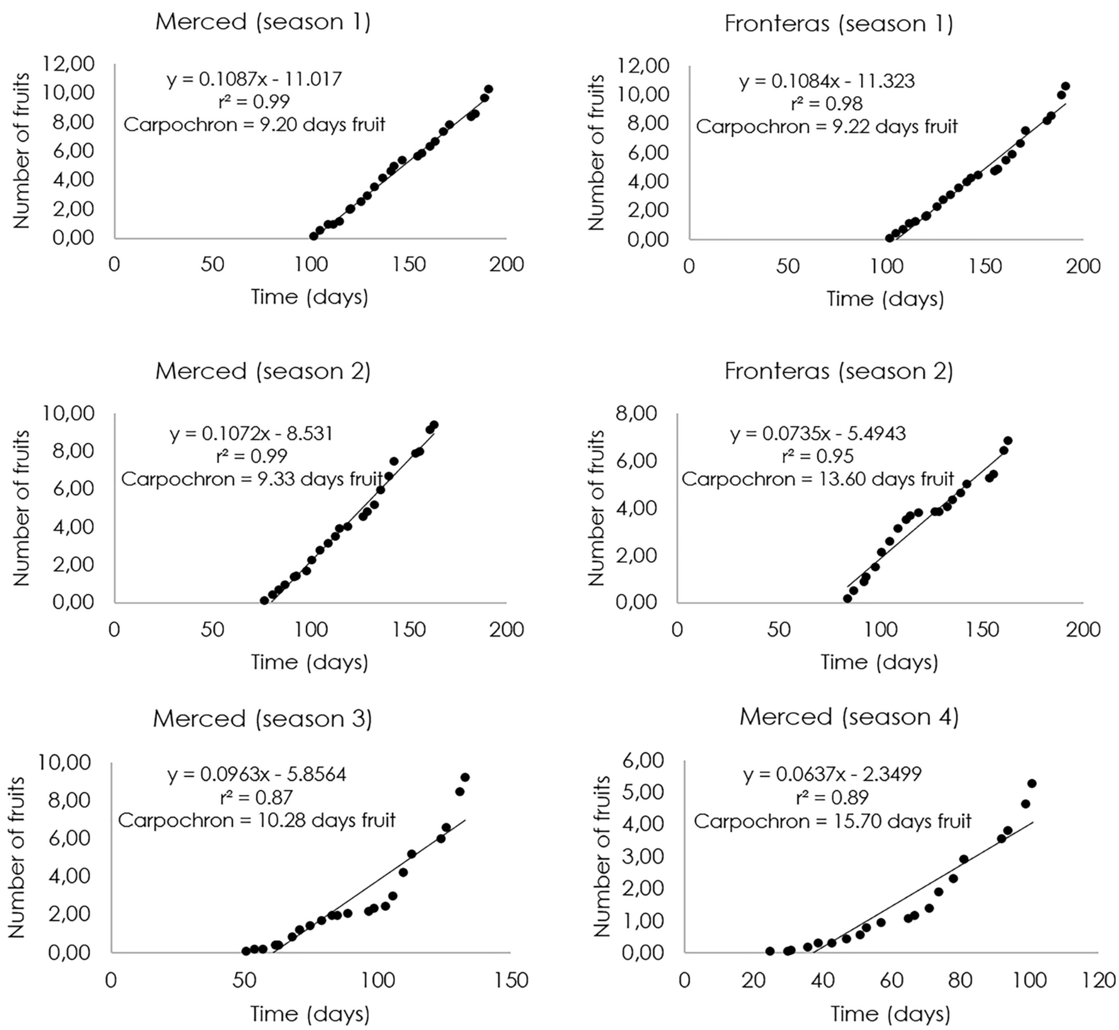

Figure 4. Carpochron (days fruit) for cultivars Merced and Fronteras at different seasons of seedling transplanting.

delayed, that is, the interval between the appearance of consecutive fruits increased.

The concept of carpochron was proposed to quantify the time between the appearance of fruits at the harvest point in the strawberry, in this experiment, short-day cultivars were used. However, it can be applied to day-neutral cultivars and also, possibly, to other vegetable species that need consecutive fruit harvests, such as zucchini (*Curcubita pepo*), varieties of tomato (*Solanum lycopersicum*) and pepper (*Capsicum annuum)*. So, it is suggested the need for further work with other species to evaluate the expansion of the applicability of carpochron.

Carpochron can be determined through linear regression analysis between the number of fruits and time, whether expressed in days or degree-days after sowing or seedling transplanting to the production beds, even allowing the measurement of the duration of the harvest period (from the first to the last harvest), being a function between the speed of appearance of consecutive fruits and the total number of fruits produced, similar to what was observed for the concepts of phyllochron (Streck et al., 2012) and anthochron (Schwab et al., 2014).

Conclusions

The base temperature for the appearance of consecutive fruits at the harvest point in the strawberry is 11°C.

Carpochron increases with the delay of the transplanting season and the values ranged from 81.97°C fruit day to 144.93°C fruit day for cultivars Merced and Fronteras.

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