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Phenology and yield of *Physalis peruviana* L. cultivated in open field in subtropical environment

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Abstract

Cape gooseberry (*Physalis peruviana* L.) is a plant that presents fruits with high aggregate value and expressive levels of beneficial components to the human health. However, the lack of knowledge of the phenological phases limits the expansion of the crop under subtropical conditions, especially in open field production, despite being a typical tropical plant. This research aimed to evaluate the phenological stages related the growth and the production of cape gooseberry cultivated under subtropical environment in an open field production system. The phenological stages were determined by the evaluations from the plant's emerging date until it is senescence. The cape gooseberry cycle comprised 254 days with a total of 3,843.6 °C day. Cape gooseberry reached a maximum of 173 leaves, 193 cm height, and 1.16 cm stem diameter. The plastochron at the vegetative phase was 15.7 °C day node^{-1} and at the reproductive phase 20.6 °C day node^{-1}. The fruit reached the harvest point with 3,045.3 °C day, corresponding to 179 days from the sowing or 100 days after transplantation, and the production period was extended for 60 days. Under the edaphoclimatic conditions (subtropical region), the production was 151.2 g per plant with estimated yield of 1,007.8 kg ha^{-1}.

Keywords: cape gooseberry, development, growth, small fruit

Introduction

The cultivation of fruit to supply certain niche markets has resulted in the expansion of the cultivation of small fruit, especially non-traditional (exotic). Among the various fruit that make up this group, cape gooseberry (*Physalis peruviana* L.), is relevant in the human diet with exotic organoleptic properties (Pereda et al., 2019). Besides, it is interesting for consumers, especially given the current market demand for healthier and more attractive products (Pérez-Herrera et al., 2020).

Several factors related to vegetative growth and development (phenology) and management systems, can limit the expansion of the production of this fruit tree. Furthermore, the cultivation of cape gooseberry depends on several factors related to quality and yield (Sandoval et al., 2018). Cultivation in climatic conditions other than the tropical region can change the cycle and cultural management. Thus, the lack of knowledge of the plants phenological phases, linked to that of cultivation practices are the main limitations in the production of cape gooseberry in regions with productive potential (Muniz et al., 2011) and, thus, the production expansion and the cultural practices optimization are dependent of this knowledge.

Phenology is designated by phases that mark the emission or senescence of vegetative and reproductive parameters (Rodrigues et al., 2018). The knowledge of the phenology of exotic species is generally based on observations of extremely visible stages of development, such as leaf development, flowering, and fruiting (Rodrigues et al., 2013). Therefore, studies that evaluate the response of growth and production in field are relevant because they allow observing the behavior of these genotypes in the face of the interaction of climatic factors, simultaneously (Medeiros et al., 2018). The knowledge of phenology represents an important tool

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for the insertion of cultures in areas that present different conditions from those required, with the aim of harvesting fruit at different times (Oliveira et al., 2015).

Although the cultivation of cape gooseberry occurs prominently in open fields (Lima et al., 2010; Muniz et al., 2011), with factors acting incisively and with limited control, the phenological studies are predominantly carried out in greenhouses (Rodrigues et al., 2018; Pedó et al., 2019). The results obtained by different studies cannot always be extrapolated from one region to another or from one cultivation system to another (Zeist et al., 2020), because essential aspects related to the fruit development are changed according to the cultivation conditions (Dias et al., 2015). Thus, the study of the phenological phases of cape gooseberry for regions with possible productive and cultivation potential appears as essential aspects for the management of the culture.

The aim of this research was to study the phenology related to the growth and the production, and physically evaluate the fruit of cape gooseberry cultivated in subtropical environment.

Material and Methods

The study was carried out in the experimental area of the Federal University of Pampa, Itaqui, Rio Grande do Sul (RS), Brazil (coordinates 29° 09' 21.68" S; 56° 33' 02.58" W, altitude 74 m). According to the Brazilian soil classification system, the soil was classified as Kandic Plinthaquults (Embrapa, 2018) and, according to the climatic classification of Köppen (1948), the climate of the region is of the Cfa type, subtropical with no defined dry season.

To produce the seedlings, seeds were acquired from a commercial seed seller Sambalina Sementes. Seeds were sown on October 24, 2017, in an expanded polystyrene trays, with 72 cells, with one seed per cell distributed at a depth of 0.4 cm. The trays were placed on iron benches, one meter high and kept in a greenhouse, covered with transparent 120-micron polyethylene.

In the planting area, pH correction was carried out according to the need for corrective material indicated by the soil analysis (Table 1). The basic fertilization consisted of 20 kg ha^{-1} of N, 230 kg ha^{-1} of P_2O_5, and 40 kg ha^{-1} of K_2O in the forms of urea (45% N), triple superphosphate (41% P_2O_5) and potassium chloride (58% K_2O), respectively. The cover fertilization consisted of 170 kg ha^{-1} of N and 230 kg ha^{-1} of K_2O, in the forms of urea and potassium chloride, respectively, being divided into five applications, the first performed 40 days after transplantation and the others performed every 20 days. The transplantation was performed 80 days after sowing, when the plants had approximately six expanded leaves and arranged in beds made in the north-south direction, with 3.0 m spacing between beds and 0.5 m between plants.

Table 1. Chemical composition of the soil for the cultivation of cape gooseberry. Itaqui, RS, 2017.

Clay	OM	V	pH	Index	P	K	Al	Ca	Mg	H+Al	CTC
.........%.........			water	SMP	...mg dm^{-3}...		.......cmol$_c$ dm^{-3}.........				pH7
18.0	1.4	73.0	5.4	6.4	4.1	30.0	0.1	5.6	2.2	2.9	10.8

Source: Authors.

The conduction system was an espalier type, using support poles with 2.3 m length with galvanized wire wires fixed at 0.5 and 1.7 m from the ground. The formation pruning was carried out 48 days after transplantation, maintaining six stems per plant and conducted with the aid of plastic tape supported by wire (Muniz et al., 2011). Maintenance pruning, with the removal of basal and axillary shoots, was carried out weekly, with no stem apex removal.

The experimental was designed in a completely randomized blocks, with four blocks, consisting of 15 plants each block. Field evaluations were performed after transplantation and consisted of determining plant height, stem diameter, number of nodes, number of leaves, flower buds, flowers in anthesis, and fruit per plant depending on the period of the crop cycle. Following the dates of the evaluations and days after the emergence of the phenological stages, the accumulated growing degree days (aGDD) were calculated to estimate the beginning of each phenological phase and the plastochron, considering 6.29 °C as the base temperature (Salazar et al., 2008). The aGDD needed to complete each phenological stage was calculated according to the equation:

$$aGDD = \sum_{i=1}^{n} (aDT - bT$$

Where, aGDD are accumulated in the period considered (°C day); aDT is the average daily temperature (°C); bT is the base temperature (°C); n is the number of days in the period considered.

The plastochron was defined by the inverse of the angular coefficient of the linear regression between the number of nodes on the main stem and the aGDD (°C day). To obtain reliable plastochron estimates, equations for the vegetative and reproductive phases were performed and defined according to Toebe et al. (2010), considering vegetative phase - from transplantation until the beginning of flowering, reproductive phase - from the beginning of flowering until the beginning of fruit maturation, and monophasic - from the transplantation until the beginning of fruit maturation.

The plant height was obtained by measuring between the base of the plant and the bud located at the end of the tallest branch, with the aid of a graduated ruler. The stem diameter was obtained by measuring the thickest stem at 10 cm from the ground, with the aid of a manual caliper. The number of leaves was quantified from the first leaf from the base to the apical meristem of the branches, in which only those that presented the fully expanded limbus were considered. The number of nodes, flower buds, flowers in anthesis and fruit were obtained by counting the total number of structures per plant.

Besides, laboratory evaluations were carried out at the time of harvest, which consisted of obtaining the vertical and horizontal diameter of the fruit, fresh weight of the fruit with calyx, and calyx fresh weight. Production and yield were also estimated. The harvest point was determined following the Colombian Technical Standard N° 4,580, 1999, of the Colombian Institute of Technical Standards, following the visual scale, when the calyxes of the fruit were in yellow-green, yellow, and brown-yellow colors. The vertical and horizontal diameter of the fruit were evaluated with the aid of a manual caliper. The fresh weight of the fruit with calyx and fresh weight of the calyx were obtained with the aid of a precision scales. Yield per hectare was being obtained by the following equation: yield = production per plant (kg) x 10,000 m^2 / area occupied by the plant.

The results were submitted to the analysis of normality, by the Shapiro-Wilk test, and homogeneity of variances by the Bartlett test, with subsequent regression, adjusting the equations to the data obtained, adopting the interaction by the F test significant to the model as a criterion for choosing the model ($p \leq 0.05$), through the Sisvar® statistical program (Ferreira, 2011). The results were subjected to analysis of the main components using the Past® program. Before the multivariate analysis, the data matrix was dimensioned for each variable to assume the same weight during the analysis (mean = 0 and variation = 1).

Results and Discussion

With the development of cape gooseberry, the dependent variables showed different behaviors, being emphasized through multivariate analysis (Figure 1). Together, the principal component one (PC I) (Figure 1a) and two (PC II) (Figure 1b), explained 83,09% of the total variation between the variables. While the PC I explain the occurrence of the vegetative and reproductive phases, PC II distinguishes the periods according to the rate of emission and senescence of the plant structures. From the evaluations performed, there is a gradual increase in the height and diameter of the stem, however, from the middle of the cycle, there is a reduction in the number of leaves, flower buds and flowers, and the number of fruit is related to the intermediate period of the cycle of culture.

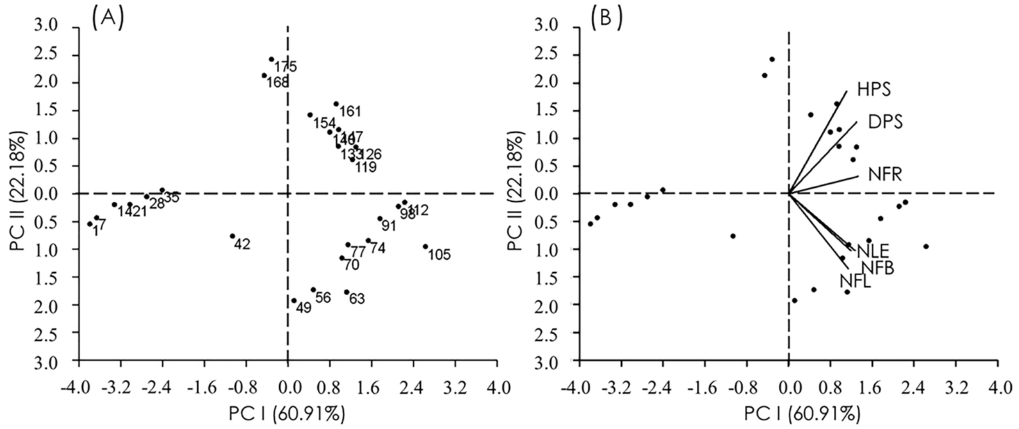

Figure 1. Analysis of the principal components between time (a) and the relationship with the dependent variables (b), regarding height (HPS), diameter of stem (DPS), number of leaves (NLE), number of flower buds (NFB), number of flowers (NFL) and number of fruit (NFR) at different stages on cape gooseberry development. Itaqui, RS, 2018.

The vegetative phase corresponds to the period of sowing until the emission of flower buds comprising a growing degree day of 2,032.7 °C day over a period of 121 days (Table 2). The reproductive phase was defined from the emission of flower buds until the senescence of the plant, comprising 1,810.9 °C day and 133 days. The fruit reached the harvest point with 3,045.3 °C day, corresponding to 100 days after transplantation (DAT), and the production period was extended for 60 days. The marked senescence of the leaves linked to the reduction in the emission rate of vegetative and reproductive structures occurred at 254 days after sowing with a total of 3,843.6 °C day (Table 2).

Table 2. Estimated duration of phenological stages, days after transplant (DAT), cycle, growing degree days (GDD) and accumulated growing degree days (aGDD) of the different development phases on cape gooseberry. Itaqui, RS, 2018.

Stage	Duration (days)	DAT (days)	Cycle (days)	GDD (°C day)	aGDD (°C day)
Sowing until the emergence	14	-	14	0	0
Emergence until the transplant	66	-	80	1,243.5	1,243.5
Transplant until the flower buds	41	-	121	789.2	2,032.7
Flower buds until the flowering	7	41	128	127.2	2,160.0
Flowering until the fruiting	7	49	135	130.9	2,290.8
Fruiting until the maturation	44	56	179	754.5	3,045.3
Maturation until the senescence	75	100	254	798.2	3,843.6

Source: Authors.

The results corroborate those obtained by Rodrigues et al. (2018), evaluating the phenology and yield of cape gooseberry grown in a greenhouse, who also observed that the reproductive phase had a longer duration in days when compared to the vegetative phase, however, the vegetative period proved to be more thermally demanding for the development of the culture. Aguilar-Carpio et al. (2018), evaluating the growth and yield of cape gooseberry cultivated with four stems in a greenhouse under different nutrient solutions, obtained different results, with the phenological stage of flowering being between 70 and 85 days after transplantation (DAT), and the maturation period of the initial fruit occurred between 110 and 125 DAT. Thus, the reproductive period remains superior to the vegetative period, regardless of the place of cultivation, however, the phenological phases are altered according to the biotic and abiotic factors acting. These authors observed a thermal sum of 1,370 to 1,527 °C day^{-1} for the different treatments of supplying nutrients from the transplantation phase until fruit maturation. Divergent results were observed in the conditions evaluated on this research, in which for the same period, 1,801 °C day were required (Table 2).

Results obtained by Betemps et al. (2014), in which they evaluated the effect of the sowing time on the growth of cape gooseberry, shown the need for greater accumulation of GDD from emergency until transplantation and, when the sowing occurred closer to the summer period, shorter were the duration in days of each phenological stage. Therefore, the period of seedling formation until the beginning of the reproductive stage is essential for the development of the root system, increase in the leaf area and accumulation of photosynthate for the emission of reproductive structures.

Cape gooseberry, due to the habit of indeterminate growth, is characterized by presenting, simultaneously, flower buds, flowers and fruit. From this perspective, it is noted that the period between the emission of flower buds and the maturation of the initial fruit lasted 58 days (Table 2). However, the duration of this period varies greatly according to the growing conditions (Betemps et al., 2014), varying between 30 and 73 days (Rodrigues et al., 2013; Rodrigues et al., 2018; Zeist et al., 2020).

The period required for these phases to occur may be related to the average temperature (21.7 °C) in the cultivation local (Figure 2). The cultivation of cape gooseberry in regions with temperatures above 30 °C tend to favor and stimulate vegetative growth, however, in mild climate conditions, below 14 °C, stimuli the emission of reproductive organs and the cultivation cycle may tends to be shorter (Lima et al., 2010). Thus, temperatures close to 20 °C as observed in this study, may favor the balanced development of plants.

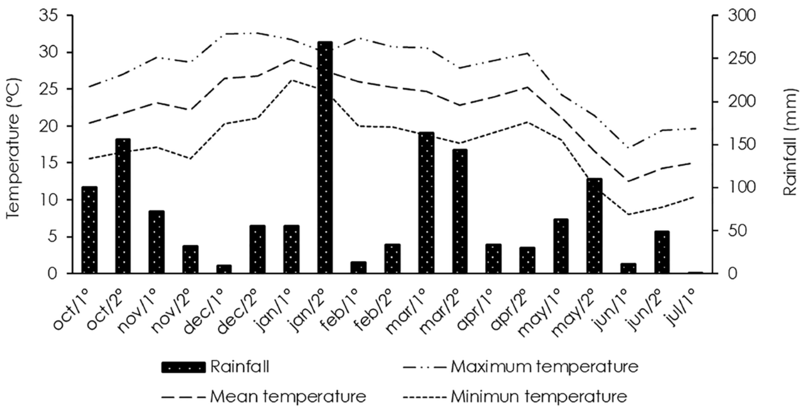

Figure 2. Maximum, mean and minimum air temperatures, and accumulated rainfall biweekly, between October 2017 and July 2018. Itaqui, RS, 2018.

There was a gradual growth throughout crop development about the height of the plants, showing a quadratic trend with the advance of cultivation days (Figure 3a). Due to its habit of indeterminate growth, there is no height stagnation with the passing of the crop cycle, even with a reduction in temperature (Figure 2). The maximum height of the plants (193.7 cm) was found at 175 DAT already in the period of beginning of the senescence of the plant at the end of the plant growing cycle (Figure 3). Besides that, the maximum leaf numbers were observed with a plant height of 134 cm (Figure 5a) which also coincides with the beginning of the decrease in fruit numbers (Figure 5e). These results show that the first basal leaves become senescent when plant has about 134 cm height.

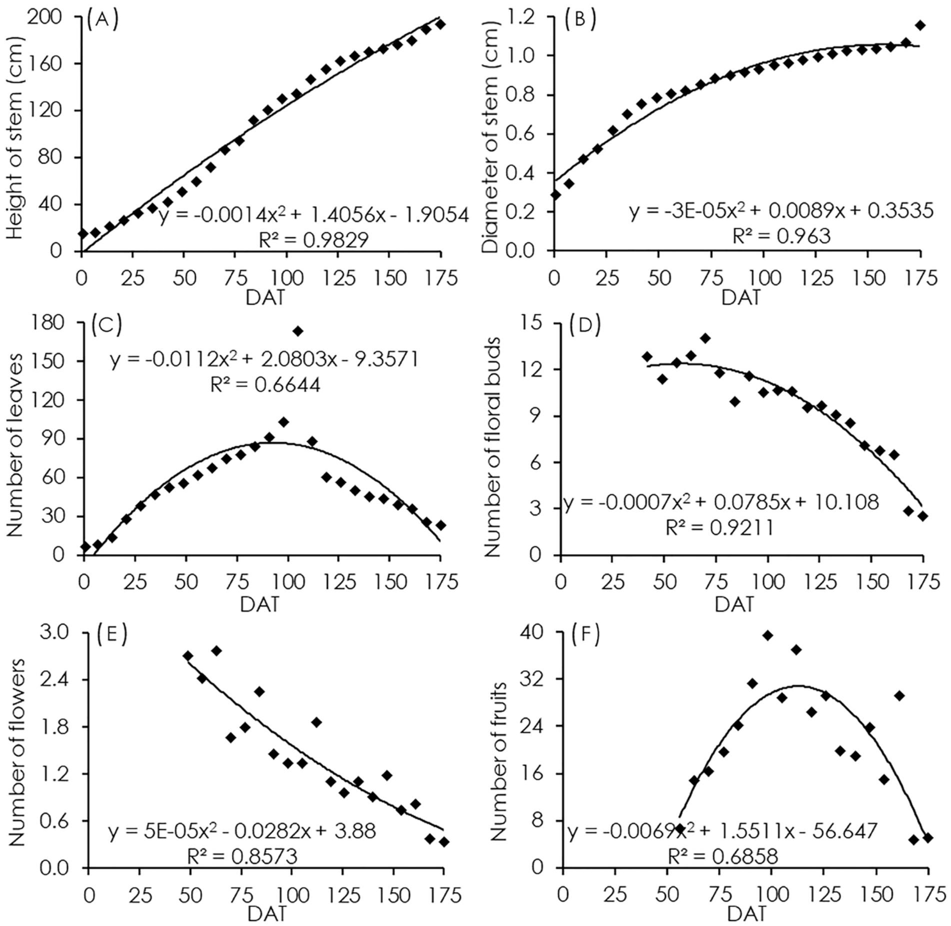

Figure 3. Height (a), diameter of stem (b), number of leaves (c), number of flower buds (d), number of flowers (e) and number of fruits per plant (f) on cape gooseberry depending on the evaluation periods after the transplantation. Itaqui, RS, 2018.

The increase in height over the crop cycle can vary according to the cultivation medium and edaphoclimatic conditions. According to Aldana et al. (2014), the flooding of the soil can have a direct effect on the plant's growth since the occurrence of two days in soil conditions above the ideal water saturation did not provide a difference in the height of the plants about the non-flooding of the soil. However, after four days in this condition, there is a reduction in growth, in six days there is growth interruption, and with eight days, it results in plant senescence. In this way, the meteorological aspect has a high influence on this character, because inadequate thermal and soil water conditions result in the prolongation of the period with stomatal closure, which results in reduced metabolism, decreased assimilation of vital compounds to the plant and, consequently, in the reduction of photosynthate required for plant maintenance and growth (Lima et al., 2017).

The basal diameter of the main stem showed a marked increase in the first 42 DAT, with a trend of constant growth over the other days, with maximum values of 11.6 mm obtained at 175 DAT (Figure 3b). It is observed that the reduction in the growth speed in stem diameter, after a marked initial growth, is related to the beginning of the reproductive period, from the emission of flower buds (Figure 3d), where part of the photosynthate are destinated to the development of new structures, prioritizing the propagation of the species over the vegetative character (Fischer et al., 2015).

The diametrical growth of the stem is the result of the changes that occur throughout the plant cycle, promoting the change from primary to secondary growth, which results in the growth of the stem in thickness by the deposition of new tissues and translocation of solutes, which were later directed for the subsistence of reproductive structures (Rodrigues et al., 2018). The reproductive phases only begin after the stem diameter has minimum of 0.8 cm thickness (Figure 5g, 5h, 5i), which probably results in better photosynthate translocation to the reproductive organs. Besides, the stem of cape gooseberry has mesomorphic characters and adaptive structures to high temperatures and to combating herbivory, such as the high number of trichomes and a significant number of secondary metabolites (Silva et al., 2015).

The emission of nodes shows increasing during the evaluated period, obtaining the maximum number of nodes in the vegetative phase of 52.3 nodes with a thermal peak of 2,054 °C day, while the maximum number of nodes in the phase between the beginning of flowering and the beginning of fruit maturation was 102.4 nodes with a thermal peak of 3,086 °C day (Figure 4). There was a greater thermal accumulation for the emission of nodes (plastochron) in the period between the beginning of flowering and the beginning of fruit maturation (20.6 °C day node^{-1}) (Figure 4b) in relation to the vegetative period (15.7 °C day node^{-1}) (Figure 4a). Zeist et al. (2020) evaluating times of cultivation in open field and greenhouse, found greater thermal accumulation necessary for the emission of nodes in the vegetative phase in relation to the reproductive, with average values of 60.4 and 15.2 °C day node^{-1}, respectively, with the highest values being found in protected cultivation, regardless of the planting season. According to the authors, the reduction of temperature during the cultivation cycle in open field induces the plants to early senescence, reducing the thermal accumulation necessary for the emission of each structure on cape gooseberry.

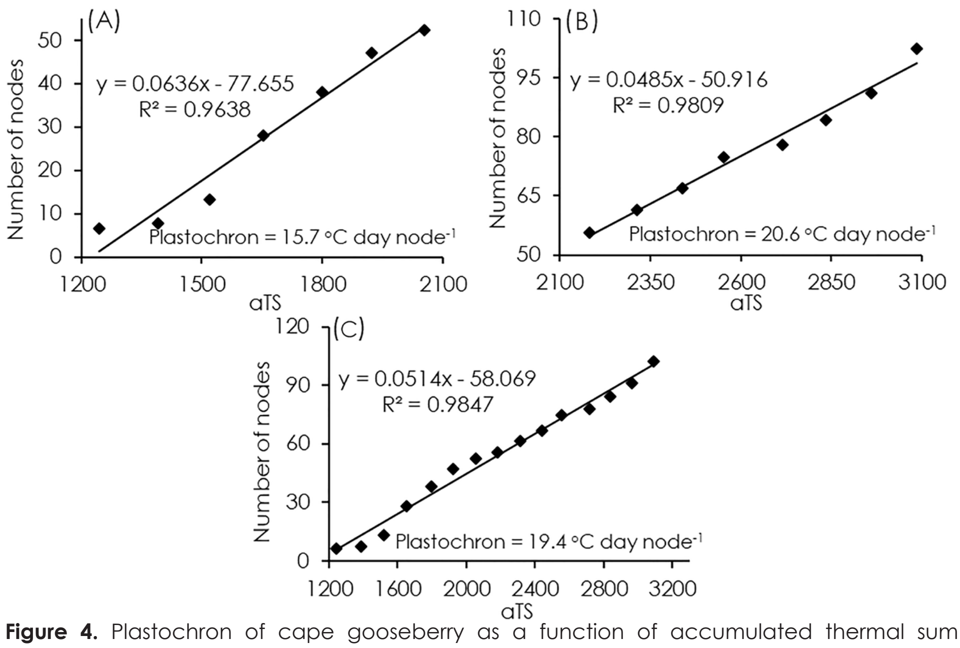

Figure 4. Plastochron of cape gooseberry as a function of accumulated thermal sum (aTS) during the vegetative phase (a), reproductive phase (b) and the period between transplantation and fruit maturation (c). Itaqui, RS, 2018.

The number of leaves rise at a maximum of 174 leaves per plant at 105 DAT, with a subsequent abrupt decrease in leaves number (Figure 3c), which may be associated with the reduction of reproductive structures (Figure 3d, 3e and 3f), characterizing the senescence of the plant. This variable is closely related to the productive structures, wherein the largest number of fruit coincides with the period of greatest leaf emission (Figure 5j, 5k and 5l).

Still, it is possible to relate the leaf emission with the edaphoclimatic aspects, since the maximum emission were characterized by adequate meteorological conditions for the crop development and, subsequently, there is a reduction in the average daily temperatures and water deficit (Figure 2). These data corroborate those obtained by Pedó et al. (2019), evaluating physiological growth attributes of cape gooseberry under leaf mineral supplementation, which found that after 112 DAT the plant has the maximum leaf area, with a subsequent reduction in leaf emission.

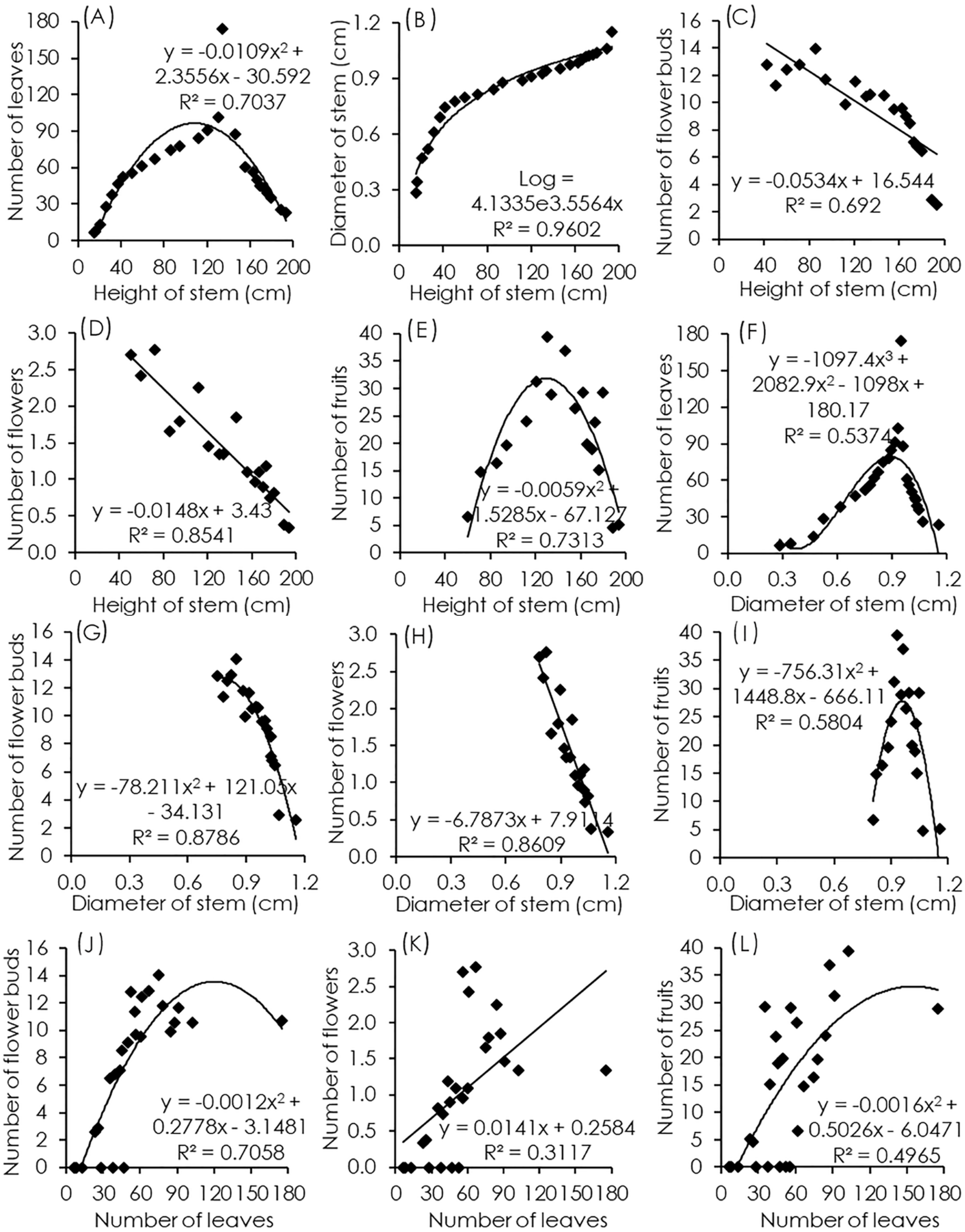

Figure 5. Evaluation of the correlations between agronomic parameters on cape gooseberry plants. Itaqui, RS, 2018.

Flowering started at 42 DAT, with the emission of flower buds, showing the maximum values in the first evaluations, with a total of 14.1 buds per plant at 70 DAT (Figure 3d). The full development of flower buds is linked to the improvement of agronomic techniques, as the nutritional input at the beginning of the buds' emission can increase the germination of pollen grains and, consequently, the number of seeds in the fruit, since the sexual propagation is the main form adopted for plant species and that this factor has a high influence on the fruit size (Silva et al., 2017). In this sense, the presence of a floral bud on the plant indicates that the formation of the fruit will possibly occur, being a relevant parameter for carrying out the cultural treatments, in addition to the logistics of the harvest and the period of storage of the fruit.

The beginning of anthesis occurred at 49 DAT, and the maximum values were obtained at 63 DAT corresponding to 2.8 flowers per plant (Figure 3e). Noteworthy are the discrepant values obtained with the presence of flowers with those found in flower buds and fruit, with each node of the plant developing a floral and a vegetative bud (Rodrigues et al., 2013). This variation may be due to the interval between evaluations during the period considered, being higher than the period covered by pre-anthesis until the beginning of fruit formation and may also correspond to the abortion of reproductive structures, due to meteorological or physiological events (Rodrigues et al., 2018). After the completion of the flowering stage from the basal axillary buds and the beginning of fruiting, the emission of the floral buds continued to occur in each of the nodes in the upper regions, making it possible to fully observe swollen buds, pre-anthesis and anthesis, as well as immature and ripening fruit on the same plant.

The presence of fruit was initially verified at 56 DAT, presenting a quadratic behavior, rising to 98 DAT, with values of 39.4 fruit per plant, corresponding to the maximum obtained. After this period, a downward trend was observed in the number of fruit per plant until reaching the minimum values at 175 DAT and, consequently, associated with the other morphological parameters, characterizes the end of the plant cycle (Figure 3f). It was observed that the fruit were emitted according to the plant development, and each axillary bud had the potential to emit a fruit, in which the average height of the insertion of the basal fruit was at 38.7 cm from the soil (Data not shown). Still, the most expressive values of the number of fruit were attributed to the leaves number, showing a growing positive correlation (Figure 5l), and direct relationship between the structures responsible for the metabolites synthesis and their direction to the recipient organs.

The basal fruit reached the harvest point at 100 DAT, with five harvests being carried out up to 160 DAT, interspersed by 15 days. There is a quadratic tendency for the fruit diameters (vertical and horizontal), fruit weight, and calyx weight in relation to the harvest season (Figure 6a, 6b, 6c and 6d). The period corresponding to the formation of the fruit, initially, is characterized by higher average temperature, of 24.8 °C, and, in the period before the last harvest, the opposite occurs, with an average temperature of 14 °C (Figure 2).

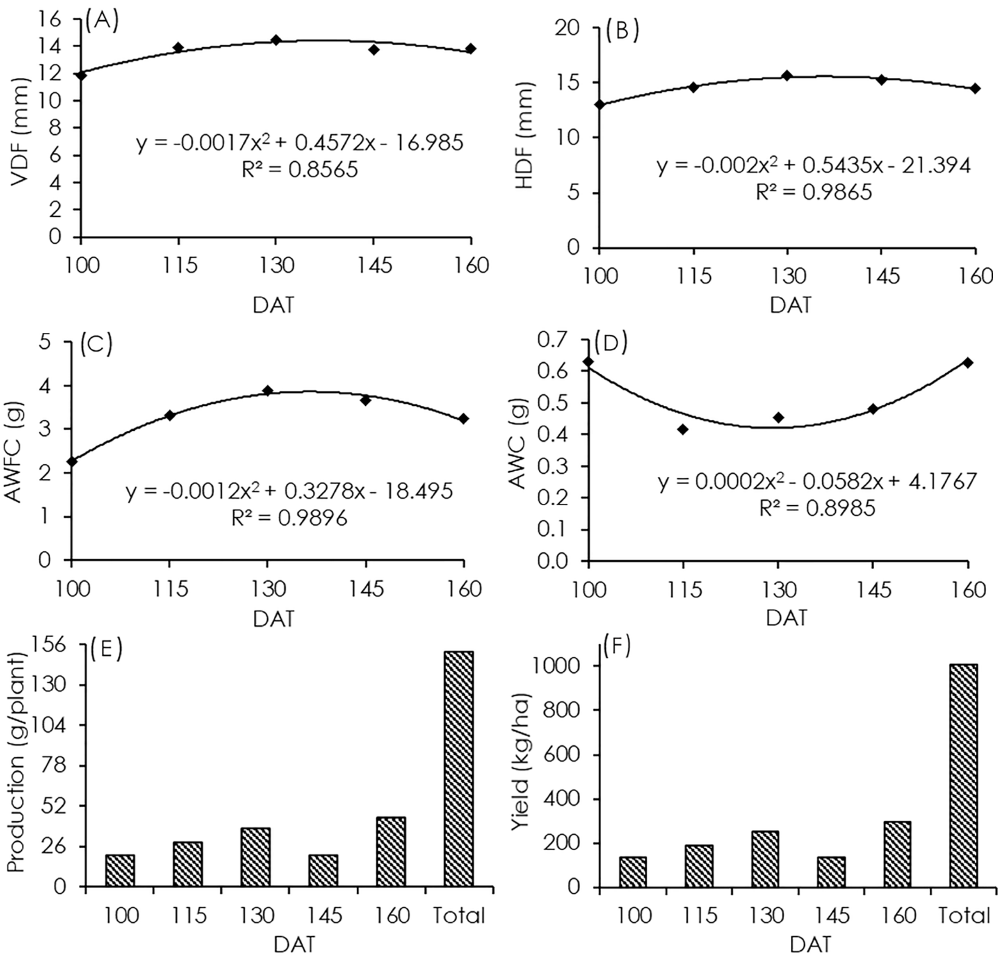

Figure 6. Vertical diameter of the fruit (a), horizontal diameter of the fruit (b), average weight of the fruit with calyx (c), average weight of the calyx (d), production (e) and yield (f) depending on harvest periods in days after the transplantation. Itaqui, RS, 2018.

In this sense, the fruit formation can be linked to the edaphoclimatic conditions during the period of cell division and expansion, as well as the period in which the sowing is carried out, since it is depends on the amplitude of the period necessary to reach the thermal sum changes of each phenological stage. Under cultivation conditions in Colombia, cape gooseberry has a perennial behavior, with harvests carried out over two years (Muniz et al., 2011). However, in conditions of temperate and subtropical climate, with mild temperatures observed since the beginning of the winter period, it results at the end of the crop cycle (Betemps et al., 2014). In this way, the plants are induced to present a greater or lesser vegetative period and accumulation of phytomass, which is essential for adequate productive efficiency.

Considering the fruit size, it was observed that there was an increasing trend of size up to 130 DAT, presenting 14.9 mm of vertical diameter. In subsequent harvests, there was a decrease in this dimension (Figure 6a), which can be attributed to higher leaves number until 105 DAT (Figure 3c) which produces higher photosynthate to fruit growth and weather conditions during the fruit formation period. The behavior of the horizontal diameter of the fruit (Figure 6b) along the harvests has been like those obtained for the vertical diameter. The horizontal diameter of the fruit increased progressively up to 130 DAT, showing maximum values of 15.6 mm, after this period, in sequential harvests, there was a gradual decrease. The transverse and longitudinal diameters have an increasing linear relationship with the fruit weight (Figure 6a and 6b) being an important parameter for cape gooseberry since its use is mainly intended for products for fresh consumption, in which the size is one relevant parameter for classification and commercialization (Rodrigues et al., 2012).

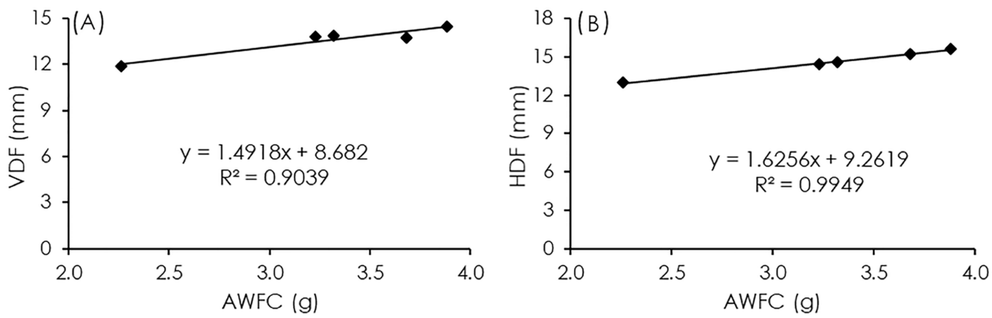

Figure 7. Correlations between vertical diameter (VDF), horizontal diameter (HDF) and average weight of fruits with calyx (AWFC) of cape gooseberry. Itaqui, RS, 2018.

The fresh weight of the fruit with calyx showed similar behavior to the fruit diameters, showing a quadratic trend throughout the harvests (Figure 6c). It is observed a gradual increase in the fruit weight up to 130 DAT, obtaining the maximum values of 3.9 g, and, consequently, there is a decrease until the last harvest, which may be related to climatic events during the formation period (Figure 2) and associated with the physical and physiological parameters of the fruit and plant (Figure 3). Thus, the alternation of quantitative characters of the fruit is noted throughout the reproductive period.

In the early stages of the reproductive period, there is an increasing demand for metabolites necessary for the formation of young vegetative structures, in addition to the formation of reproductive structures, which presumably present themselves as receptor structures (Fischer et al., 2015). Besides, in the final stages of the cycle, defoliation occur, changing the relationship between the synthesis and receptor structures, therefore, a reduction in photosynthate status occur, which in turn would be necessary for plant maintenance and fruit formation. In tomato (*Solanum lycopersicum* L.), the practice of defoliation is widely used in order to increase solar interception and reduce the incidence of diseases (Hachmann et al., 2014; Islam et al., 2016). However, when defoliation exceeds six basal leaves, the number and mass of the fruits are reduced, being justified by the alteration of the source/sink ratio with less accumulation of photosynthate available for metabolic reactions (Islam et al., 2016).

As the fruit with the greatest weight reach the highest prices during commercialization, the dimensions have a high influence on the fruit destination (Passos et al., 2015). The longitudinal and transverse diameters show significant linear positive correlations with the weight of the fruit (Figure 7), being parameters used for selection of higher plants in breeding programs, in addition, to the seeds number, however, the seeds quantification is time-consuming as the measurement is performed (Trevisani et al., 2017). Thus, the correlation obtained between size and fruit weight is positive, which is a variable obtained with relative practicality and with high significance, these measurements are relevant parameters for advances in the genetic improvement of the species.

The fresh weight of the calyx as a function of the harvesting season is represented by Figure 6d. The highest values of calyx weight were obtained in the first and last harvest, corresponding to 100 and 160 DAT, with values of 0.63 g for both periods, while the lowest values were found when the fruit had the largest dimensions. Thus, the weight of the calyx proved to be inversely proportional to the fruit size. This result is relevant for the postharvest of cape gooseberry, because although the calyx contributes to prolong the period of storage and commercialization of the fruits, the cape gooseberry is commercialized mainly without the calyx (Olivares-Tenorio et al., 2017). Therefore, in certain situations, the calyx becomes a waste during the processing of the fruit for commercialization, and with the increase in the fresh weight of the calyx there is also an increase in costs for the disposal of waste.

The values obtained for the calyx weight, throughout the harvest period, may be related to the cape gooseberry fruiting dynamics. The productive period is wide, so that the harvest begins with the fruit located at the base of the plant, followed by the maturation of the upper fruit, resulting in a decrease in the number of fruit and leaves, (Figure 3c and 3f) modifying the source/sink ratio. Lima et al. (2012), evaluating physical and chemical characters of the fruit of cape gooseberry throughout the cultivation period, obtained different results, where the increase in the weight of fruit also increased the weight of the calyx. However, it is noteworthy that edaphoclimatic factors have significant influences on the weight of the fruit and the calyx.

At underwater stress conditions, the transpiratory process is reduced, delaying the development of the plant (Aldana et al., 2014). In unfavorable thermal conditions, this process also occurs, resulting in the senescence of leaves and reduction of the photosynthetically active area (Betemps et al., 2014). At harvest, the low weight of the calyx in relation to the fruit may be due to many carbohydrates in the calyx supplied to the fruit during the first 20 days of development, in addition to the greater water retention capacity and chlorophyll content (Lima et al., 2009). Besides, the non-structural carbohydrates levels are low in the calyx and in the fruit, however, the sucrose concentration in the calyx is accentuated in the same way as the levels found in the fruit (Fischer et al., 2015). This behavior reports the fact that, although the calyx appears morphologically and anatomically like the leaf, its physiology is closely related to the fruit.

The production per plant, as well as the estimated yield (Figure 6e and 6f), has an increasing trend until 130 DAT, with a subsequent decrease. This behavior is closely related to the fruit weight and the fruit emission, which present the maximum values for these parameters in the same period. The productive values correspond to 151.2 g per plant and estimated yield of 1,007.8 kg ha^{-1}.

The yield data were superior to those obtained by Rodrigues et al. (2013), which obtained a production of 215 g per plant and yield of 955 kg ha^{-1}, although lower than those found by Rodrigues et al. (2018), in which assessing the development and yield of cape gooseberry in a greenhouse environment, obtained production of 351.06 g per plant and yield of 2,340 kg ha^{-1}. Muniz et al. (2011), evaluating different conduction systems, in two seasons, obtained yield values that varied between 2,780 to 6,000 kg ha^{-1}. This variation can be attributed to the crop cycle, because due to the reduction in temperatures and the occurrence of frosts (Figure 2), the crop cycle is restricted to eight months, and, in certain cultivation environments, the species shows perennial behavior (Muniz et al., 2011).

Conclusions

The cape gooseberry cycle comprised 254 days with a total of 3,843.6 °C day, with the thermal accumulation being higher in the vegetative period than in the reproductive period.

The plants reached a maximum of 173 leaves, 193 cm height, and 1.16 cm stem diameter.

Plastochron at the vegetative phase was 15.7 °C day $node^{-1}$ and at the reproductive phase (from the beginning of flowering until the beginning of fruit maturation) was 20.6 °C day $node^{-1}$.

The fruit reached the harvest point with 3,045.3 °C day, corresponding to 179 days from the sowing or 100 days after transplantation, and the production period was extended for 60 days.

Fruit diameter (vertical and horizontal) has a linear positive correlation between fruit average weight.

Under current edaphoclimatic conditions, in a subtropical region, the production was 151.2 g per plant, with estimated yield of 1,007.8 kg ha^{-1}.

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