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Research article

Peach tree growth in a tropical climate: shoot formation and fruiting

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ABSTRACT: This study aimed to characterize the occurrence, duration, and intensity of the flushes of vegetative growth in two peach cultivars of *Prunus persica* L. Batsch, grown as a pioneer endeavor at a high-altitude tropical climate site in the State of Minas Gerais, Brazil. The observational experiment was carried out in 2017/18 and 2018/19 on the 'Tropic Beauty' and 'BRS Kampai' cultivars by an evaluation of the number and duration of flushes of vegetative growth during the year over two cycles. The number of fruit-bearing shoots, total number of leaves and shoot length were also assessed. At harvest, fruit load and diameter were determined and grouped into diameter ranges. The number of hours recorded at different temperature ranges, < 10.0 °C; 10.1-15.0 °C; 15.1-20.0 °C; 20.1-25.0 °C; > 25.1 °C, were summed separately and divided into daily and nightly periods. The peach tree has an unusual vegetative growth pattern when cultivated in a tropical area, which occurs in two flushes, with the first flush occurring from budbreak to fruit harvest between June and Sept, forming short shoots (less than 10 cm), with early shoot growth cessation, with a limited leaf number that can potentially diminish the supply of carbohydrates to the fruit, leading to smaller growth. The second flush occurs after harvest, between Oct and Dec, when there is an increase in daily temperature and precipitation, and no competition with fruits. Notabily, these second flush shoots grow with greater vigor and regularization of the growth cycle, forming fruit-bearing shoots with abundant leaf and flower buds for the next production cycle.

Keywords: *Prunus persica*, flushes, phenology, climate change, abiotic stress

Introduction

Under tropical conditions, seasonal changes (mainly in temperature) are less intense, and the length of the peach tree cropping cycle, with leaves present, can be extended by more than eight months. In these areas, endodormancy does not develop in the buds and is therefore attributed to a milder stimulus for the inducement of entry into deep dormancy (Bonhomme et al., 1999; Arora et al., 2003; Gonçalves et al., 2016; Souza et al., 2017).

Milder environmental conditions allow for strong responses to stimuli that break paradormancy, e.g., differentiated pruning (Edwards, 1987), controlled water stress and products to induce bud break (George and Nissen, 1992; Arora et al., 2003; Erez, 2000). This behavior, associated with the use of low-chill cultivars, favors the inducement of budbreak and flowering in these areas, bringing forward the start of the new production cycle, and allows for earlier harvest compared to areas with cold and long winters (Chavarria et al., 2009; Citadin et al., 2014; Tadeu et al., 2020; Ferreira et al., 2022). Early harvest can provide a better market price due to the low fruit supply at that time, increasing the economic return for the peach producer (Bonora et al., 2015).

However, peach production in tropical areas presents challenges such as a lack of leafing and blooming uniformity, poor fruit set and quality (especially fruit size), and unsynchronized vegetative growth (Scorza and Okie, 1991; George and Erez, 2000; Ghrab et al., 2014; Yahmed et al., 2016).

Peach trees cultivated in tropical climates have a differentiated vegetative growth pattern with two or more flushes of vegetative growth per year compared with only one flush per year in traditional areas (Williamson and Coston, 1989; George and Erez, 2000; Penso et al., 2020a). However, when more than one flush occurs in peach trees, the intensity and duration of these flushes are either unknown or poorly understood. This differentiated growth pattern can affect the balance of the plants, such as the source and sink relationships, among other negative consequences (Scorza, 1987; DeJong and Day, 1991; Penso et al., 2020a; Ferreira et al., 2022).

It is necessary to understand the behavior of plants in response to new environmental conditions so as to adopt measures that will benefit and enhance fruit yield and quality. Thus, this work aimed to characterize the occurrence, duration, and intensity of flushes of vegetative growth in two peach tree cultivars grown in a tropical climate.

Materials and Methods

Area, plant material, productive cycles, and management

The experiment was carried out using the peach trees of a commercial orchard located in Ervália, in the State of Minas Gerais, Brazil (20°52′02″ S, 42°38′41″ W, 790 m altitude) during 2017 and 2018. The climate of the macro-region, according to Köppen's classification, is considered as Cwa, with warm summers and dry winters (Alvares et al., 2013), with differentiated characteristics due to saw conditions (Serra do Brigadeiro State Park), classified as the morphoclimatic domain of seas of hills of cultivar fields at an altitude associated tropical characteristics (Safford, 2004; Alvares et al., 2013).

Two low-chill peach cultivars, 'Tropic Beauty' and 'BRS Kampai', were grafted onto the 'Okinawa' rootstock. The experiment was set up in plots, and the trees were two years old at the beginning of the experiment. The peach tree cultivars were in complete reproductive condition, planted in a 'Y' system with a 5.0 × 2.5 m spacing. Irrigation management over the evaluation period was conducted during the night period by a surface drip, using approximately 20 L plant d^{-1} of water.

Based on previous work (unpublished data), pruning was conducted three times annually. The first pruning of each cycle was carried out on 04 Apr 2017 and 23 Apr 2018, around the start of bud swelling. Immediately after production pruning, irrigation was restored, and 0.8 % of Dormex® (hydrogen cyanamide 520 g L^{-1}) and 1 % of mineral oil (456 g L^{-1}) were applied on 25 Apr 2017 and 10 May 2018, respectively.

The second pruning was carried out soon after harvest, on 05 Oct 2017 and 06 Oct 2018 (Figures 1A and B). Pruning was applied with the same intensity in all plants in the orchard (Figures 1C and D). This pruning was necessary since, after harvest, the plants showed almost complete natural leaf abscission (Figures 1A and B). In traditional temperate conditions, this natural defoliation is usually observed only once, near the dormancy period (during autumn and winter). For this second pruning, the top of all shoots was removed (cutting half of the shoot with vegetative growth in the first flush), leaving only three to four buds per shoot.

The third pruning was carried out in the first week of Dec of each year of the evaluated cycles, called summer or green pruning. This pruning was carried out with the same intensity on all trees in the orchard, with the principal objective of reducing excessive vegetative growth by eliminating the vigorous shoots. The control of pests and diseases was carried out by integrated management, and when a critical level of damage was reached, suitable registered control products for the crop were applied.

Observational experiment

The observational experiment evaluated flushes of vegetative growth, in two growing cycles (2017/18 and 2018/19). The cultivars were not considered treatments as they showed no marked difference in cycle length. Due to environmental restrictions, it is challenging to use late-cycle cultivars, which would be in contrast to the cultivars used. Therefore, cultivars were assessed separately to identify a possible common response pattern.

Figure 1 – Plant status after fruit harvest in the 2017/18 (A) and 2018/19 (B) evaluation cycles, with intense natural leaf abscission; Plants before (C) and after (D) the second pruning, conducted soon after harvest under tropical conditions at Ervália, MG – Brazil.

Experimental design and characteristics evaluated

The experiments were carried out on three plots (block), with replications of five plants (experimental units) for each growing period (2017/18 and 2018/19) that occurred in each of the evaluated cultivars. The same plants were kept in each experimental plot in both cycles.

Immediately after the first production pruning, five productive shoots (fruit-bearing shoot type) were marked randomly on each of the five trees (experimental units) of the three replications.

These shoots were initially characterized by the number of vegetative buds (VB) and total number of nodes (TN). After the characterization, the vegetative buds were monitored phenologically weekly to calculate the budburst percentage based on the total of vegetative buds. Budburst was considered when they presented a green tip as described for stage 03 of the BBCH scale for Stone fruit (Meier et al., 1994). The phenological monitoring of budburst, flowering, and fruit development was also carried out until harvest.

Around the harvest date, in the respective experimental units, the total number of fruits per plant was counted (in a non-destructive way) to characterize the fruit load. In addition, for characterization purposes, in the same period, a random sampling was performed (in a non-destructive way) to record the equatorial diameter using digital calipers, with 210 fruits sampled in total per cultivar. During harvest (01 Sept 2017 and 01 Sept 2018 in both cycles), the fruits were grouped into different diameter ranges, according to fruit market standards: < 40.0 mm; 40.1-50.0 mm; 50.1-60.0 mm; > 60.1 mm. The data were transformed into the percentage of fruits in each range based on the total number of fruits and the number of fruits in each diameter class.

The number of fruit-bearing shoots, length of fruit-bearing shoots (cm) and leaf number per fruit-bearing shoot were evaluated biweekly from full budburst to fruit harvest. The fruit-bearing shoots were defined as vegetative structures with leaf emission, with a length greater than 1 cm with more than one internode present.

After fruit harvest and pruning, five new shoots were marked in the same trees, and the number of fruit-bearing shoots, fruit-bearing shoot length (cm), and the number of leaves per fruit-bearing shoot (unit) were evaluated from budburst to leaf fall, for the new growth flush.

Morphological monitoring of shoots by images

In 2018, other shoots from each cultivar were randomly marked during the first flush of vegetative growth. Photographic documentation of the development of the fruit-bearing shoots, from full budburst to fruit harvest, was carried out weekly for each cultivar. To bring the photos together in a single image, it was necessary to edit the images with lighting correction; however, adjustments to the perspective of the shoot length were not made.

Photographic documentation was conducted to record the evolution of vegetative (increase in phytomers units: petiole + internode + axillary bud) and reproductive structures in formations such as the nodes and flower buds for the subsequent cycle, as they can be important visible morphological markers of evolution or progression to different stages of development of vegetative and reproductive growth.

Environmental and meteorological data

Temperature data were collected hourly throughout the experiment using a datalogger in the orchard. The temperature data were separated into night and day and presented as the sum of hours in the temperature ranges: < 10.0 °C; 10.1-15.0 °C; 15.1-20.0 °C; 20.1-25.0 °C; > 25.1 °C. Nighttime was considered the interval between 18h00 to 06h59, and daytime from 07h00 to 17h59 (disregarding the seasonal variations in day length for the area as the variation at latitudes close to 20° N-S is low). The separation of the temperature ranges was based on their influence on different tree structures and relevance to the different phenological phases of the culture, as presented by Souza et al. (2011) and Tadeu et al. (2020).

The estimate of monthly and accumulated precipitation (mm of water) was obtained for both vegetative growth flushes from data collected at station A510, located in Viçosa, MG, Brazil (Instituto Nacional de Meteorologia – INMET).

Statistical analysis

Data were submitted to a Lilliefors normality test, and a Bartlett test assessed homogeneity. When the mathematical assumptions were met, the data were subjected to analysis of variance ($p < 0.05$) using the GENES computer application (Cruz, 2013). The data were submitted to the most appropriate transformation for their analysis when necessary. Regression equations were adjusted for the variables among vegetative growth flushes and cycles of evaluation according to the statistical significance of the interaction.

Results

Budburst was observed to be above 80 % for both cultivars, showing rapid evolution after the applications of the chemical agent (25 Apr 2017 and 10 May 2018). The maximum percentage of budburst was observed on 16 June for 'Tropic Beauty' in 2017 (cycle 2017/18), and 08 June 2018 (cycle 2018/19). In 'BRS Kampai', the maximum budburst percentage was observed on 21 June 2017 and 08 June 2018 (data not shown). These dates were considered as the establishment of full budburst (0 DAFB = Days After Full budburst) for both cultivars in their respective growing cycles. Full bloom for both cultivars was 16 June 2017 (2017/18 cycle) and 10 June 2018 (2018/19 cycle), and fruit harvest was completed on 01 Sept 2017 and 01 Sept 2018, giving an approximate production period of 75 days.

The number of bearing shoots for both cultivars and growing cycles in the first flush was similar, with an average of 1.5 (Figures 2A and B). For the 'BRS Kampai', this pattern was also maintained for the second flush of vegetative growth (Figure 2B), except for 'Tropic Beauty', as in the second flush there was an increase in the number of fruit-bearing shoots, with an average of approximately 2.0 (Figure 2A). After the end of the first flush of vegetative growth (close to the fruit harvest) at 75 DAFB, there was a reduction in the number of bearing shoots (close to zero), due to the fact that plants naturally reduce their structures to form new vegetative structures (Figures 1A and B).

The emission of bearing shoots by 'Tropic Beauty' in the first flush of vegetative growth occurred late in the 2018/19 cycle, reaching the maximum approximately 35 DAFB, whereas in 2017/18, the maximum number of bearing shoots was observed straight after the start of budburst, approximately 20 DAFB (Figure 2A). For 'BRS Kampai', this temporal difference in the emission of fruit-bearing shoots between growing cycles was not observed during this flush (Figure 2B).

In the second flush of vegetative growth, the number of fruit-bearing shoots differed between cycles in the 'Tropic Beauty' cultivar, with the highest averages occurring in 2018/19 (Figure 2A). However, in both growing cycles, there was a rapid increase in the number of fruit-bearing shoots occurring near 150 DAFB (close to 20 Oct 2018), which remained practically constant until the final growing period (Figure 2A). For 'BRS Kampai', there was also a rapid increase in the number of fruit-bearing shoots at the beginning of the second flush of vegetative growth. However, there was a difference in the total time required to reach the maximum number of fruit-bearing shoots between the growing cycles; in 2017/18 the maximum was reached near 150 DAFB (close to 20 Oct 2017), while in 2018/19 the maximum was reached near180 DAFB (close to 16 Nov 2018 (Figure 2B).

In the second vegetative growth flush there was a greater average number of leaves per fruit-bearing shoot compared with the first flush in both cultivars, 'Tropic Beauty' ($p < 0.05$, Figure 2C) and 'BRS Kampai' ($p < 0.05$, Figure 2D). There was a higher average number of leaves per fruit-bearing shoot in the second flush of the 2018/19 cycle' in 'Tropic Beauty' ($p < 0.05$, Figure 2C). Inversely, the average number of leaves per fruit-bearing shoot for both cultivars was higher in the first flush of the 2017/18 cycle ($p < 0.05$ and $p < 0.05$, respectively – Figures 2C and D). Additionally, for both cultivars, the number of leaves was constant from 20 to 60 DAFB, close to the fruit harvest. After this period, there was an intense natural fall of leaves (Figures 1A and B; Figures 2C and D).

In the second flush of vegetative growth, considered as upwards of 100 DAFB, there was a different behavioral pattern compared to the first flush, characterized by an increase in the number of leaves for both cultivars and cycles (Figures 2C and D). The leaf emission for 'Tropic Beauty' stabilized early in 2017/18 (near 150 DAFB or 20 Oct 2017) and proceeded in 2018/19, approaching 180 DAFB (close to 15 Nov 2018) (Figure 2C), while in 2018/19 it continued until approximately 180 DAFB (close to 15 Nov 2018) (Figure 2C). The leaf emission in the second flush of 'BRS Kampai' started at close to 120 DAFB and stabilized at approximately 200 DAFB (close to the end of Nov) in both the 2017/18 and 2018/19 cycles (Figure 2D).

The length of the fruit-bearing shoots was higher in the second flush of vegetative growth than the first one, for both 'Tropic Beauty' ($p < 0.05$) and 'BRS Kampai' ($p < 0.05$). In the first flush, fruit-bearing shoot length was reduced (5 cm) at 20 DAFB, and remained constant until the beginning of the second flush of vegetative growth 130-150 DAFB, 13 Oct and 02 Nov, respectively (Figures 2E and F).

In the 2017/18 cycle, the maximum fruit-bearing shoot length for 'Tropic Beauty' was early in the evaluation period (which is considered very early), around 15 DAFB, with slight variation until the end of the first flush of vegetative growth (Figure 2E). In the 2018/19 growing cycle, a rapid evolution in shoot length was observed until close to 35 DAFB, and it remained constant until the end of this first flush (Figure 2E).

The 'BRS Kampai' showed remarkable differences in fruit-bearing shoot length between the first and second flush of vegetative growth ($p < 0.05$), with differences of approximately 15 cm and 30 cm, in 2017/18 and 2018/19, respectively (Figure 2F). In 2017/18, the fruit-bearing shoots reached a length of approximately 15 cm, while in 2018/19, the average length was approximately 30 cm (Figure 2F). The length of fruit-bearing shoots in the second flush of vegetative growth occurred close to 200 DAFB (near the end of Nov) and remained constant until the final growth period (Figure 2F).

The morphological evaluation of 'Tropic Beauty' and 'BRS Kampai' (Figure 3) led to the observation that the fruit-bearing shoot showed rapid growth starting at the beginning of budburst, on approximately 28 June, equivalent to 14 DAFB during the first flush of vegetative growth. However, growth cessation was confirmed after this period, with no increase in phytomer units (petiole + internode + axillary bud) until the fruit harvesting period (Figure 3). Fourteen DAFB marks the beginning of the shoot maturation process (reddish color), as well as the increase in bud development, especially in the flower buds (larger volume and size), which would be productive in the subsequent cycle (Figure 3). Under traditional cultivation conditions, flower buds only reach a similar size around March of the following year, as dictated by conditions of the temperate and subtropical areas in the Southern Hemisphere.

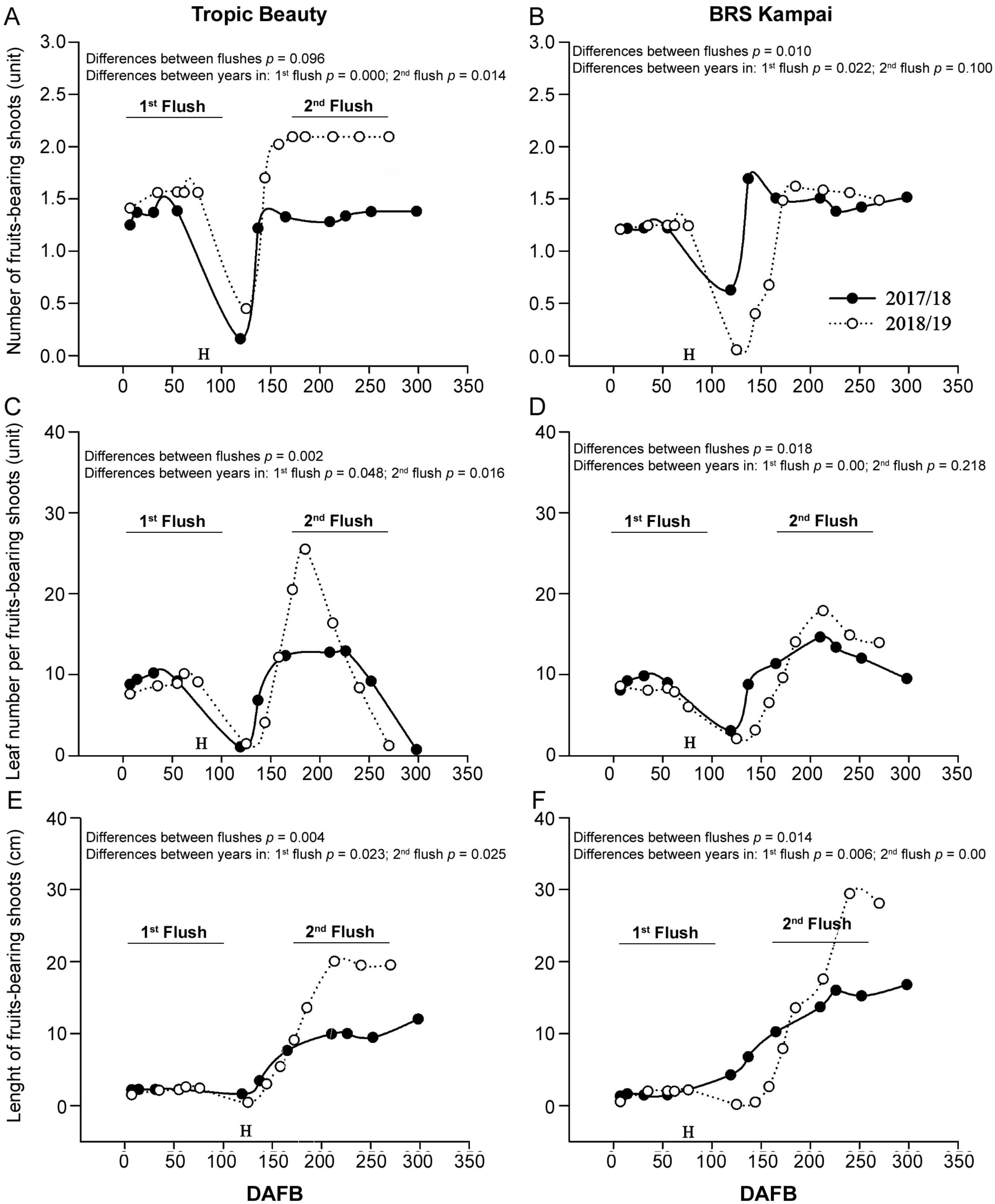

Figure 2 – The average number of fruit-bearing shoots in 'Tropic Beauty' (A) and 'BRS Kampai' (B) leaf number per fruit-bearing shoot in 'Tropic Beauty (C) and 'BRS Kampai' (D), and length of fruit-bearing Scheme in 'Tropic Beauty (E) and 'BRS Kampai' (F) 2017/18 and 2018/19 cycles. DAFB = Days After Full Budburst. The following comparisons were made: Interaction between years of evaluation × Flushes of vegetative growth; Years of evaluation (2017/18 × 2018/19); Flushes of vegetative growth (1st flush × 2nd flush); All means were tested and differences are shown by the Tukey test ($p \leq 0.05$). The "H" indicates the date of the end of the fruit harvest in each cycle.

From 19 Aug to 23 Aug, in practically all the fruit-bearing shoots photographed during the first flush of vegetative growth, there was at least one knot with three buds. The central buds were sharp and thin, flanked by two rounded buds (globe shaped) (Figure 3). The shoot and bud characteristics observed in photographs (Figure 3) were similar to those found in peach shoots with normal growth during the progress of dormancy induction (when natural leaf fall occurs). At this point, the differences between the vegetative buds (which is the central bud of the node) flanked by one or two flower buds became visible.

These results of the number of fruit-bearing shoots (Figures 2A and B), leaf number per fruit-bearing shoot (Figures 2C and D) and length of fruit-bearing (Figures 2E and F), together with the visualized branch growth record (Figure 3), demonstrated an unusual vegetative and reproductive growth pattern for the peach crop. Under the conditions evaluated, growth could be divided into about nine distinct stages, with two moments of vegetative growth natural leaf abscission, but only one period of flowering, fruit production, and replenishment of reserves (Figure 4).

In the analysis of fruit classes, there were no differences between the evaluation cycles for both cultivars (Tropic Beauty $p > 0.05$ and BRS Kampai $p > 0.05$). However, there were differences between the fruit classes (Tropic Beauty $p < 0.05$ and BRS Kampai $p < 0.05$). At about the time of fruit harvesting (01 Sept), a high percentage of small fruits, with a size < 40.0 mm, were observed, 50 % for 'Tropic Beauty' and 60 % for 'BRS Kampai' (Figure 5A). For fruits considered small but still commercially viable, between 40.1 to 50.0 mm, 30 %-40 % were observed for each class. Less than 10 % of the fruits produced were observed to be in excess of 50.1 mm (Figure 5A). There were no differences in fruit load between the evaluated cycles for both cultivars (Tropic Beauty $p > 0.05$ and BRS Kampai $p > 0.05$). Average values for total fruit load were approximately 160 and 140 fruits per plant for the cultivars 'Tropic Beauty' and 'BRS Kampai', respectively, for the growth cycles (Figure 5B).

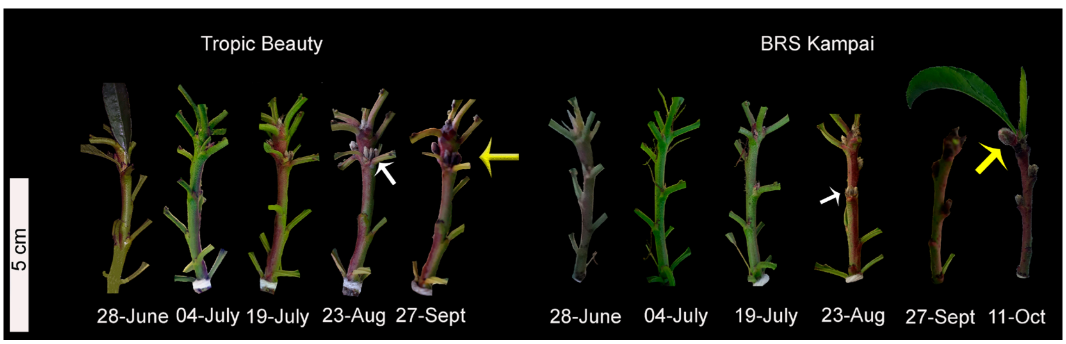

Figure 3 – Development of "fruit-bearing shoots" occurring during the first flush of vegetative growth in 'Tropic Beauty' and 'BRS Kampai' peach cultivars grown in a tropical climate, municipality of Ervália, MG, Brazil. The images refer to the same shoot (a non-destructive record) photographed over the period June to Oct of 2018/19. The white arrows indicate the presence of three buds per node (a vegetative bud flanked by two flower buds) as early as 23 Aug. The yellow arrows indicate the unusual behavior of flower buds, starting early opening (on 27 Sept for Tropic Beauty and 11 Oct for BRS Kampai, both many months before due time) in comparison with what occurs under traditional areas conditions.

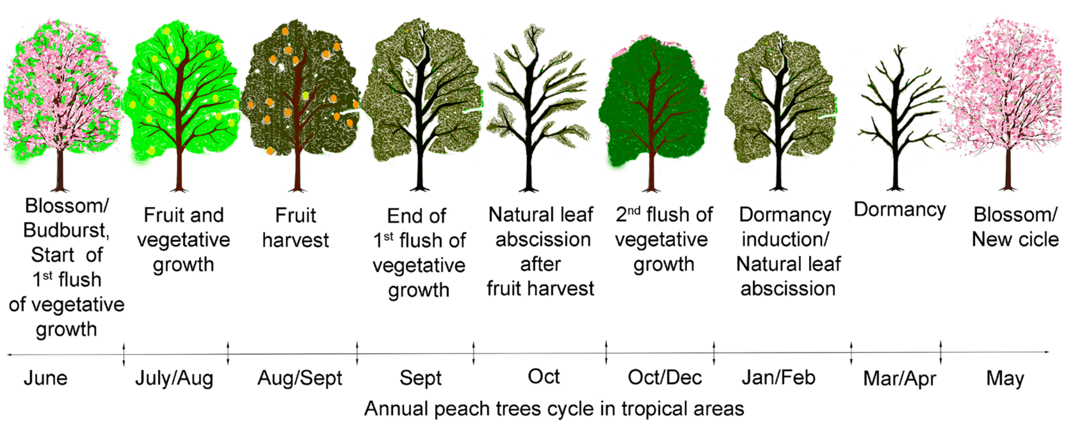

Figure 4 – Diagram representing the annual behavior of peach trees growing in a tropical area. During the year it is possible to observe distinct phases, with two flushes of vegetative growth, the first during fruit growth, and the second after fruit harvest.

Almost no hours were in the temperature range < 10.0 °C, and the mildest temperatures observed were in the 10.1-15.0 °C range (Figures 6A and B) for both cycles. Most of these temperature ranges occurred at night and were above 300 h (Figure 6A), whereas, during the day, the sum of these temperatures did not exceed 10 h (Figure 6B). This range of temperature accumulation was close to 200 h up until budburst induction in 2017/18 and close to an accumulated 300 h up until budburst induction in 2018/19 (Figure 6A). These conditions demonstrate that the evaluation environment of this high-altitude tropical site is characterized by the occurrence of mild temperatures, which almost exclusively occur at night. Temperatures between 15.1 °C and 25.0 °C were frequently observed during both cycles, especially during the day and coincided with periods of growth in both flushes of vegetative growth (Figures 6A and B).

The increase in temperature was more intense for the 15.1-20.0 °C range, in a shorter period in the 2018/19 growth cycle (between Aug and Sept 2018) compared with the first (2017/18) cycle, for which there was a gradual increase in this temperature range (Figure 6B).

There was a wide temperature range (Figures 6A and B) with temperatures frequently above 20 °C (Figures 6 A and B). The temperature range varied between flushes of vegetative growth in both growing cycles, except for the period between Dec and Mar 2017/18, when there were only minor variations between the minimum nightly and maximum diurnal temperatures (Figures 6A and B).

During the autumn and winter, a reduction in relative humidity was common, with significant daily variation and a reduction in total and accumulated precipitation (Figure 6C). The monthly and accumulated rainfall differed between the first and second flushes of vegetative growth in both cycles (Figure 6C). From Oct to Nov, accumulated rainfall was higher than that of all the accumulated rainfall during the first flush of vegetative growth (Figure 6C).

Discussion

Dynamics of shoot emission and phytomer unfolding

The occurrence of endodormancy was discarded in the present experiment, as the temperatures registered, especially during the day (Figures 6A and B), would not be effective in overcoming it (even with the application of sprout inductors). This would result in poor or erratic budburst. However, a satisfactory budburst above 80 %, indicated the potential for the appropriate start of vegetative growth. Under the evaluated conditions, the fruit harvest can be brought forward by almost two months (for Aug or Sept) compared with traditional growing regions in the south of Brazil, where harvest starts at the end of Oct to mid-Nov (Citadin et al., 2014; Tadeu et al., 2020).

Early harvest induces a natural new budburst after harvesting, a second flush of vegetative growth. The occurrence of two flushes of vegetative growth overlaps in part with pruning procedures, budding, and fruit

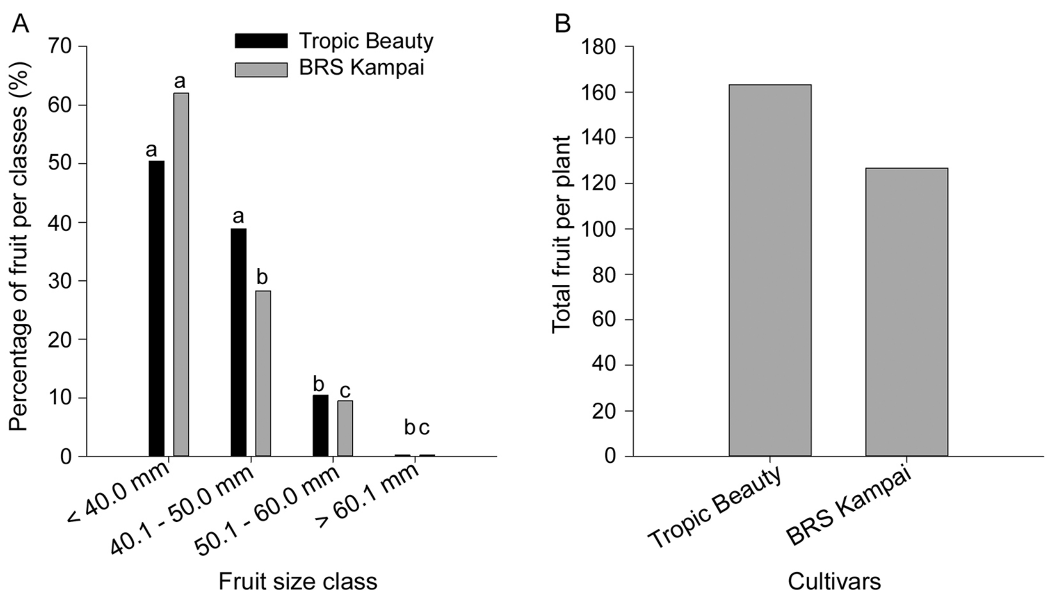

Figure 5 – Percentage of fruits in the commercial diameter ranges: < 40.0 mm; 40.1-50.0 mm; 50.1-60.0 mm; > 60 mm (A) and total fruit load (B) for the cultivars 'Tropic Beauty' and 'BRS Kampai', average of 2017 and 2018 harvest, in a tropical climate at altitude. The lowercase letters compare the percentage of fruits in each size class (bars of the same color). Distinct letters differ from each other by Tukey's test ($p \leq 0.05$).

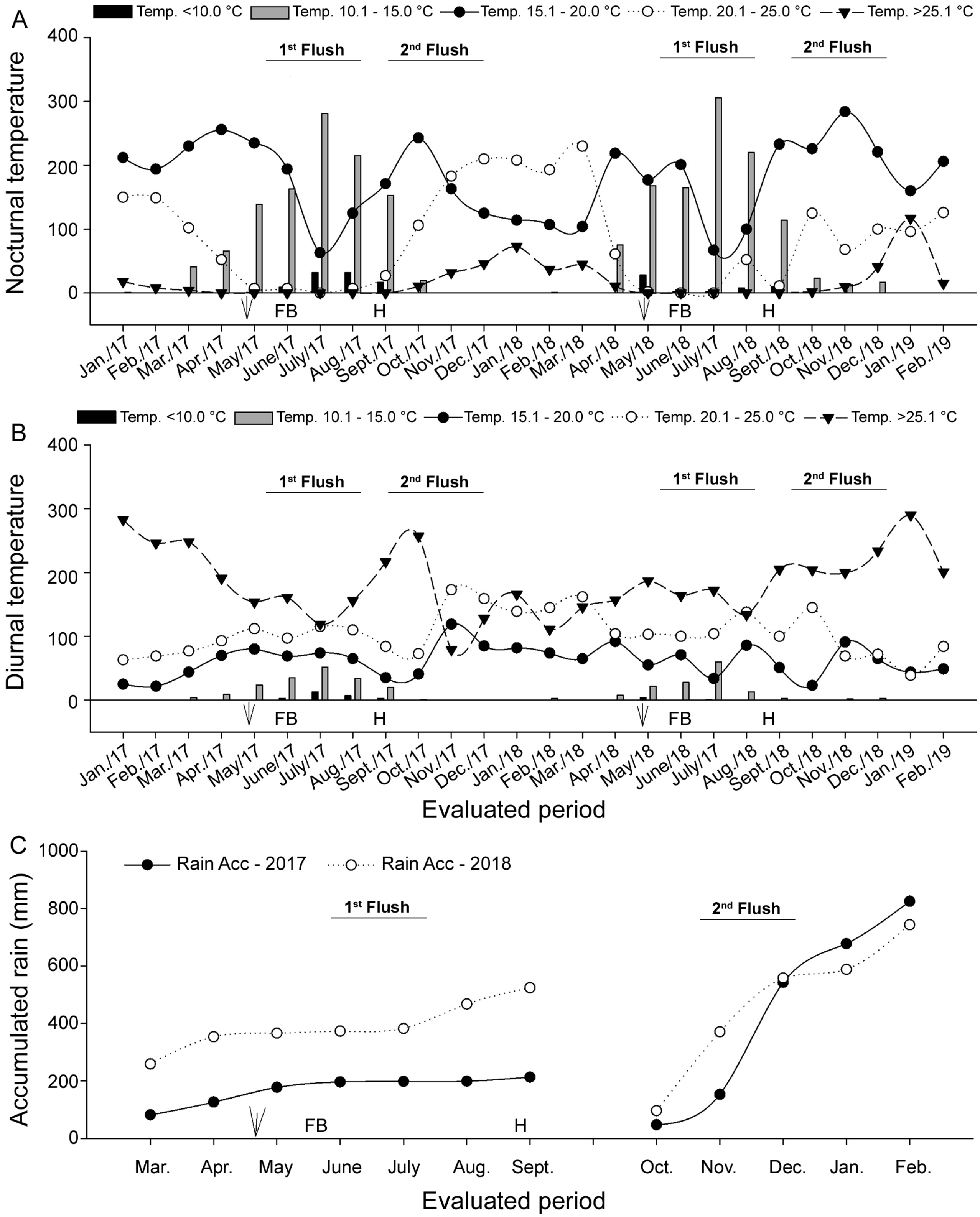

Figure 6 – Sum of hours with temperature ranges < 10.0 °C, 10.1-15.0 °C, 15.1-20.0 °C, 20.1-25.0 °C and > 25.1 °C in nocturnal (A); diurnal (B) periods; accumulated rainfall (C), occurring during the 2017/18 and 2018/19 cycles at the experiment site, in a tropical climate at altitude. ↓, FB, H indicates the beginning and full budburst, and the end of fruit harvest, respectively.

development, representing potential stress conditions for peach trees. However, the higher temperatures and water availability may partially reduce this stress. The first flush occurred from mid-June to mid-July, and the second one occurred from the beginning of Oct to the end of Nov.

In the first flush of vegetative growth, after the induction of bud break, there was rapid initial growth of the fruit-bearing shoots and their respective leaf emissions (Figures 2A and B; 3; and 4). However, the growth and phytomer emission maximum occurred between 20 and 35 DAFB (Figures 2A and B; and 3), with no new emissions or increases in fruit-bearing shoot length until the fruit harvest (Figures 2C and D; 3; and 4). In traditional areas, the growth of fruit-bearing shoots is continuous from budburst until around fruit harvest, with cycles ranging from 100 to 140 days, depending on the cultivar and environmental conditions (Mounzer et al., 2008; Ferreira et al., 2022).

Flower formation in relation to shoot growth

In traditional areas with environmental conditions that are normal for cultivation, flower buds may only reach a similar size and have similar aspects to buds at 35-40 days after full bloom (DAPF), sometime in Mar of the following year (end of cycle), at the start of fall in the Southern Hemisphere (Figure 4). Therefore, under the conditions of this study, the formation of buds occurred about 170 days before normal conditions (Figures 3 and 4).

This extremely early formation of flower buds can result in earlier and atypical flower opening (around Oct), as was observed in some of the photographed shoots, which presented flower buds at the balloon stage and would be productive in the subsequent cycle (Figure 3). Furthermore, this stage occurs during a higher temperature period (Figures 6A and B), which may increase flower bud abortion (Penso et al., 2020a).

Additionally, the imminent abortion of the floral structure formed in this first flush must pay attention to the energy used to form these structures since their formation demands a lot of assimilates (Rodrigo, 2000; Ferreira et al., 2022), which will be lost. Thus, if floral abortion is inevitable, the energy is wasted.

Peach tree organs are subjected to internal competition for assimilates as the fruits are developing (strong sink activity), and there is limited photosynthetic capacity (low source activity) due to the limited formation of leaves associated with the small elongation of the shoots in the first flush (Figures 2B and C). Associated with the fast establishment of phytomers, internodes remain short, forming between eight to ten nodes (Figure 3). The difficulty for shoots to increase in length during the first flush of vegetative growth results in a higher density of phytomers in shoots, but this does not increase the density of productive buds formed for the next cycle (Figure 3).

With the early cessation of vegetative growth at the end of the first flush, the shoots formed had a maximum growth of approximately 10 cm in length (Figures 2E and F; and 3). The early cessation of vegetative growth of the shoot is undesirable as it limits the plant's structure and photosynthetic capacity due to fewer leaves that are smaller and worn, as well as the poor formation of productive buds (Penso et al., 2020a).

The consequence of vegetative growth flushes for fruit development and practical management of peach in tropical climates

The first flush of vegetative growth, particularly its early cessation, occurred during the initial fruit growth (equivalent to stage I of fruit growth), at approximately 30 to 40 DAPF (Figures 2C, D, E and F; 3; and 4). Furthermore, this is concurrent with a high relative growth rate and cell division in the fruit, which is one of the essential factors for determining the final size of fruits (DeJong and Walton, 1989; Moriguchi et al., 1990; Pavel and DeJong, 1993; Grossman and DeJong, 1995). Thus, during this period, there is high demand from the fruits for carbohydrates (Scorza and Okie, 1991; Lopez and DeJong, 2007; Mounzer et al., 2008), and therefore, limitations in source activity during this phase affect the final fruit size.

It is estimated that for adequate peach fruit growth, around 25 to 30 fully expanded leaves in total photosynthetic capacity are required per fruit (Génard and Bruchou, 1992; Nii, 1997; Wu et al., 2005; Rahmati et al., 2018). During the first flush of vegetative growth, the average number of leaves per shoot was approximately 14 (Figures 2C and D). Considering the development of two fruits per productive shoot, there were approximately 7.5 leaves per fruit, far below the ideal required for satisfactory fruit development (Génard and Bruchou, 1992).

In addition, a previous experiment with the same cultivars and environment was evaluated by Penso et al. (2020b), who showed significant variation in leaf size that developed during the first and the second vegetative growth flush.

The ability to produce new leaves is highly restricted in the first flush of vegetative growth. Therefore, there is a limitation of its photosynthetic capacity (Figures 2C and D), as there is a consequent high production of tiny fruits (< 40.0 mm). However, a low fruit load per plant is maintained (Figure 5A). Thus, peaches produced in similar areas have reduced productive potential, with low fruits of an acceptable commercial standard, despite presenting initial satisfactory budbreak, flowering, and early harvest. Thus, efforts should be made to improve these parameters.

The use of complementary technologies such as differentiated fertilization and the use of growth regulators, which act to induce an increase in the formation of new leaves under similar environmental conditions, can be applied to induce an increase in total leaf area or at least increase individual leaf area and thus enable increased plant source activity.

The agents that limit shoot growth during the first flush are: climatic factors, such as mild temperatures and frequent occurrences of temperatures below 15.0 °C (Figures 6A and B) (Heide, 2008); low precipitation and low relative humidity (Figure 6C); competition for carbohydrate reserves between fruits and new vegetative tissue is very intense up to about 20 DAFB, as the plant does not yet have enough leaves and photosynthetic activity to provide energy for these tissues (Pavel and DeJong, 1993; Grossman and DeJong, 1995); and finally, the maturing of fruit whose ethylene synthesis induces the total cessation of shoot growth and increases plant leaf drop (Iqbal et al., 2017) (Figures 1A and B; 2C and D; and 4).

Spring starts with increased temperature (Figures 6A and B) and precipitation (Figure 6C) at the end of the harvest. Concomitantly, vegetative growth is resumed from the apical bud, consisting of the second flush of vegetative growth. However, fruits are absent; therefore, the energy of the plant is directed primarily at developing new shoots. This is one of the hypotheses explaining the high intensity of vegetative growth in the second flush compared with the first, with a length sometimes greater than 15 cm and the abundant occurrence of flowers and vegetative buds (Figures 2E and F). In addition to reduced competition among the organs of the plant, there are also favorable environmental conditions during the second flush of vegetative growth. Average diurnal temperatures of around 25 °C, high Ψw (> –0.4 MPa), and good light availability with a photoperiod in excess of 12 h favor the increased rate of shoot growth (Berman and DeJong, 1997; Davidson et al., 2015).

Therefore, in the second flush, the shoots are prepared for the next production cycle with reserves and productive bud formation (Figure 4). Under tropical climate conditions, alternative plant management is necessary, with an exclusive focus on regulating vegetative growth, aiming at the complete restoration of the plant reserves and rebalancing the formation of reproductive structures for the subsequent cycle. In the first flush of vegetative growth, plant management should be focused on stimulating the emission of new leaves or supplying photosynthetic activity to attend to fruit development.

After the resumption of the second flush, the shoots formed in the previous flush are limited to initial supplier of reserves for the new shoots being formed, with zero or negligible contribution to the next production cycle. Due to this, pruning with shoot reduction is recommended after the fruit harvest, stimulating the budburst from the axillary buds near to the principal trunk. This will then form better quality shoots for the next cycle.

In the second flush, the plant's cycle is restored with growth starting near the beginning of the summer, at the summer solstice when the natural transition from vegetative to reproductive growth occurs (Heide, 2008; Davidson et al., 2015; Maurya and Bhalerao, 2017; Penso et al., 2020a), due to the photosensitivity characteristics of peach trees. Bearing this in mind, the conditions are favorable for better bud formation and the replenishment of reserves for the next cycle.

Vegetative growth of peach trees cultivated under tropical climates occurs in two flushes. The first flush occurs from budbreak to fruit harvest, between June and Sept, forming short shoots (less than 10 cm), with early shoot growth cessation (less than 30 days after budburst) and limited leaf number that potentially diminishes the supply of carbohydrates to fruit, which grow smaller. These shoots formed during the first growth flush bear the second flush of vegetative growth, which occurs after the harvest, between Oct and Dec, when there is an increase in daily temperature, precipitation, and relative humidity. There is no competition with fruits in the second flush of vegetative growth. The shoots grow with greater vigor, and the growth cycle is regularly reestablished, forming fruit-bearing shoots with abundant leaf and flower buds for the next production cycle.

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