



## Phenology and thermal requirements of the atemoya tree (*Annona cherimola* Mill. X *Annona squamosa* L.)

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### ABSTRACT

The present study had as the main objective the documentation and characterization of the different phenological stages, as well as the definition of the thermal requirements, of the atemoya tree for two agronomic seasons. From shoot development to senescence and beginning of the rest period eight main stages were described (shoot development, leaf development, shoot/bud growth, inflorescence appearance, flowering, fruit development, fruit maturity and senescence and the beginning of the rest period). The number of days and the thermal requirements for completing each phenological stage were different between the two agronomic seasons of the atemoya. The first and second agronomic season presented a period of 217 and 206 days, with thermal requirements of 2469 and 2302 degree days, respectively.

**Keywords:** BBCH; degree days; agronomic seasons; pruning; cycles.

### INTRODUCTION

Atemoya is an interspecific hybrid, resulting from the cross between cherimoya and sugar apple (*Annona cherimola* Mill x *Annona squamosa* L.). The most commonly planted hybrids in Brazil are the “Gefner” and “Thompson” (Tokunaga, 2000). “Gefner” is more suited to semiarid conditions with higher temperatures (average annual temperatures around 27 °C and thermal amplitude around 5 °C), whereas “Thompson” is better suited to subtropical climates (average annual temperatures are almost always below 18 °C, with thermal amplitudes between 9 °C and 13 °C) (Pereira *et al.*, 2011).

The hybrid is cultivated on a commercial scale in several Brazilian regions, occupying an area of more than 1,500 hectares. The main national producer is the State of São Paulo, responsible for 43% of the production, followed by Minas Gerais, Paraná and Bahia, each accounting for 18.8% (Lemos, 2014).

The phenological stages of a given species depends on several environmental factors; however, studies indicate that the temperature of the environment is the main meteorological element that affects the development of different cultivars of maize (Stewart *et al.*, 1998). To relate the influence and importance of air temperature in the development of a plant species, studies have indicated the concept of thermal sum or degree days. The concept of degree days is based on an estimate used to define the plant’s response regarding its development to temperature (Warrington & Kanemasu, 1983).

Studies on the phenology and thermal requirements for species of the Annonaceae family are limited. Although it is considered an important family, only two species were evaluated for their phenological stages: cherimoya (Cautín & Agustí, 2005) and sugar apple (Liu *et al.*, 2015; Mendes *et al.*, 2017).

In the present study we proposed characterize the principal development stages according to the general BBCH

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(*Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie*) scale with a numerical system with two digits and to define the thermal requirement of the atemoya tree in two agronomic seasons in the Brazilian semiarid region.

## MATERIAL AND METHODS

The study was conducted in an experimental orchard of "Gefner" atemoya trees. The plants presented seven years old and were grown in 4.0 m x 2.5 m spacing. The commercial orchard is located at the geographic coordinates of 15°47'50" S and 43°18'31" W and is situated at an altitude of 516 m, Janaúba, Minas Gerais, Brazil. The climate is Aw (KÖPPEN). The soil of the site is a clayey Eutrophic Red Latosol. Irrigation was applied with a microsprinkler system. All cultural practices typically recommended for atemoya cultivation were performed (Peireira *et al.* 2011).

The first and second pruning were performed on August 23, 2013 (winter) and May 16, 2014 (autumn), respectively. Defoliation of the branches was accomplished manually in order to stimulate the vegetative development. Ten plants from central area of the orchard were selected, a spacing of 8 x 5.0 m was used among plants, uniformity, vigor, and health were also observed. Four branches of each plant were labeled, distributed in four quadrants (north, south, east, and west), and an intermediate bud was selected from each branch. The meteorological data were recorded during the whole evaluation period, corresponding to the two production cycles (agronomic seasons) (August 2013 to January 2015) (Figure 1 and Table 1).

The phenology and the thermal requirement were determined in two sequential agronomic seasons (August 2013 to April 2014 and May 2014 to January 2015), using the equivalent plants of the commercial area described previously. Three visual observations per week for determination of the principal phenological stages of the crop were performed. External phenological principal development stages were photographed and sequentially characterized by using the general BBCH scale (Hack *et al.*, 1992). A two-digit number system was used, where the first digit was used for the main stages, and the second digit was used for the secondary growth. To characterize the thermal requirement of the plants, the sum in degree days (DD) for the two agronomic seasons (production cycles) was used (Table 2).

The degree days were calculated according to the methodology proposed by Villa Nova *et al.* (1972), the base temperature of 10 °C was adopted, according to Silva *et al.* (2006):

$$DD = \frac{(T_m - T_b) + (TM - T_b)}{2},$$

for  $T_m > T_b$ ;

$$DD = \frac{(TM - T_b) \cdot 2}{2 \cdot (TM - T_m)},$$

for  $T_m < T_b$  and  $DD = 0$ , for  $T_b > TM$ ,

where  $DD$  = degree day,  $TM$  = maximum daily temperature (°C),  $T_m$  = minimum daily temperature (°C), and  $T_b$  = base temperature (°C).

## RESULTS AND DISCUSSION

According to the general BBCH scale, the atemoya tree presented eight of the ten main stages of the phenological stages (Figures 2, 3, and 4). The onset was characterized by bud development (stage 0) and ended with the beginning of the rest period (stage 9). The four vegetative stages included the development of buds (stage 0), leaf development (stage 1), shoot (buds) (stage 3), and the beginning of the rest period (stage 9). The reproductive stages corresponded to the emergence of inflorescence (stage 5), flowering (stage 6), fruit growth (stage 7), and fruit maturation (stage 8).

The phenological stages of the atemoya tree are described below according to the general BBCH identification scale (Hack *et al.*, 1992):

### Principal development stage 0: vegetative bud development

- 00: Dormancy: leaf buds closed and covered by brown scales.
- 01: Beginning of bud swelling; greenish-brown coloration.
- 03: End of the expansion of leaf buds: greenish brown bud.
- 07: Beginning of budding: leaf ends visible with a greenish brown color.
- 09: End of greenish brown leaf with 5 mm above the scale of the bud.

### Principal development stage 1: leaf development

- 10: First leaves separating, with slightly brownish-green coloration.
- 11: First visible unfolded leaves of greenish-white color.
- 12: Development of the 2nd leaf of greenish-white color, total unexpanded.
- 13: Development of the 3rd leaf of greenish-white color, total unexpanded.
- 14 - 18: Leaf development.
- 19: First fully expanded leaves, with leathery appearance.

### Principal development stage 3: shoot/bud growth

- 31: Beginning of shoot growth, with 10% of its final length.
- 32: Bud with 20% of final length.
- 33: Bud with 30% of final length.

34: Bud with 40% of final length.

35: Bud with 50% of final length.

36: Bud with 60% of final length.

37: Bud with 70% of final length.

38: Bud with 80% of final length.

39: Bud reaching the maximum length of the species.

#### Principal development stage 5: reproductive development or inflorescence emergence

50: Floral buds enclosed by whitish scales.

51: Floral buds swelling.

53: Budding, first floral primordium barely visible.

54: Visible sepals and petals begin to lengthen.

55: Lengthening of the petals.

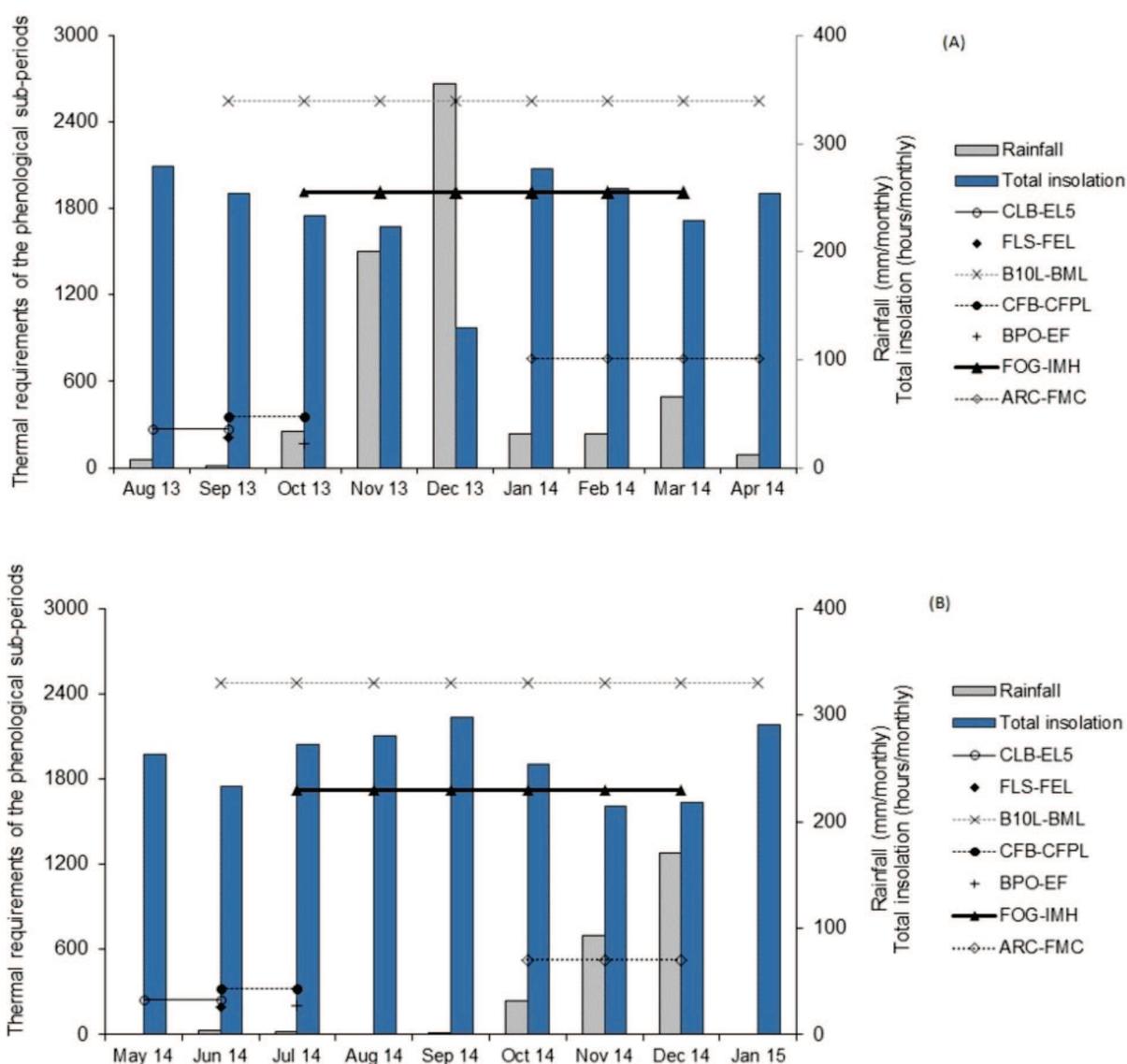
57: Flowers still closed, petals lengthening.

59: Closed flowers, petals completely extended forming a long corolla.

#### Principal development stage 6: flowering

60: Beginning of separation of petals: pre-female state, pollen grain is not viable.

61: First flowers at female state: 10% of flowers open.



**Figure 1:** Meteorological data of rainfall, total insolation and thermal requirements (degree days) of the phenological sub-periods during the first (A) and second (B) production cycles (agronomic seasons) of the “Gefner” atemoya tree in Janaúba, Minas Gerais state, Brazil, 2013/2015. CLB: closed leaf buds; EL5: end of the leaves with 5 mm; FLS: first leaves separating; FEL: first fully expanded leaves; B10L: budding with 10% of its length; BML: budding with maximum length; CFB: closed flower buds covered with light color scales; CFPL: closed flowers, petals form long corolla; BPO: beginning of petal opening: pre-female state; EF: end of flowering; FOG: fruiting: onset of ovarian growth; IMH: fruit size of the species presents ideal maturation for the harvest; ARC: appearance of ripening color for harvesting; FMC: full maturity for consumption.

**Table 1:** Meteorological data of mean monthly relative humidity (RH/monthly) and mean monthly temperature (MeanTemp.) of the first and second production cycles of the "Gefner" atemoya tree in Janatuba, Minas Gerais state, Brazil, 2013/2015

Agronomic season	Month/Year																	
	First production cycle (winter to autumn)						Second production cycle (spring to summer)											
	Aug/2013	Sep/2013	Oct/2013	Nov/2013	Dec/2013	Jan/2014	Feb/2014	Mar/2014	Apr/2014	May/2014	Jun/2014	Jul/2014	Aug/2014	Sep/2014	Oct/2014	Nov/2014	Dec/2014	Jan/2015
RH/monthly (%)	48.8	50.1	52.2	57.3	80.8	58.8	55.9	64.6	58.1	48.8	44.2	42.2	47.1	41.7	43.9	60.9	62.0	44.8
Mean Temp. (±%C)	24.2	26.3	26.7	27.1	25.4	26.6	27.2	26.7	26.9	25.7	24.1	23.8	24.1	25.7	26.9	26.6	26.2	27.6

Jan: January; Feb: February; Mar: March; Apr: April; May: May; Jun: June; Jul: July; Aug: August; Sep: September; Oct: October; Nov: November; Dec: December.

62: 20% of flowers open.

63: 30% of flowers open.

64: 40% of flowers open.

65: Full flowering, at least 50% of flowers open and in completely male state, pollen grain released.

67: Flowering fading: majority of the petals fallen or dried.

69: End of flowering: visible fruiting, all petals fallen or dried.

#### Principal development stage 7: fruit development

71: Ovary growing (green ovaries), sometimes with dry petal.

72: Fruit about 20% of final size.

73: Fruit about 30% of final size.

74: Fruit about 40% of final size.

75: Fruit about half of final size.

76: Fruit about 60% of final size.

77: Fruit about 70% of final size.

78: Fruit about 80% of final size.

79: Fruits have reached the size of their species and are physiologically mature, with light green coloration and carpels distant from one another.

#### Principal development stage 8: ripening or maturity

81: Appearance of coloring of fruits.

89: Full maturation. The fruits detach with ease.

#### Principal development stage 9: senescence and beginning of rest period.

91: End of growth of the branches or buds, but the foliage remains green.

Regardless of the agronomic seasons, the atemoya tree presented the same main stages of development as the sugar apple tree. Liu *et al.* (2015) and Mendes *et al.* (2017), in their studies on the phenology of *A. squamosa*, described eight main stages of development, using the general BBCH scale, with a three- and two-digit number system, respectively. In contrast, the phenological studies performed with the other parent, *A. cherimola*, using the same scale with a two-digit number system, described only seven major stages for the species. For the cherimoya tree, the maturation stage of the fruit was not considered (stage 8). According to the authors, the cherimoya tree did not present alteration of the color of the fruit when physiologically mature (Cautín & Agustí, 2005).

The number of days and the thermal requirements for completing each phenological stage were different between the two agronomic seasons of the atemoya tree (Figure 1, Table 2).

In the first cycle (1), the duration and the thermal requirement for each sub-period were 24 days and 272 DD from the closed leaf buds to the end of the leaf with 5 mm (CLB-EL5); 18 days and 207.2 DD from the first leaves separating until showing completely expanded leaves (FLS-FEL). Around 221 days and 2545 DD from budding with 10% of its length to the maximum length (B10L-BML); 29 days and 357 DD from the closed flower buds covered with light scales until the closed flowers with petals that form a long corolla (CFB-CFPL); 14 days and 163 DD from the beginning of the petal opening in the pre-female stage until the end of flowering (BPO-EF); 168 days and 1911 DD from fruiting at the beginning of the ovary growth to fruits at the ideal maturity size for harvest (FOG-IMH); and 65 days and 760 DD from the appearance of the ripening color for harvest until full maturity (ARC-FMC) (Figure 1, Table 2).

In the second cycle (2), with pruning performed on May 16, 2014 (autumn), the duration and the thermal requirements for each sub-period were 21 days and 248 DD (CLB-EL5), 18 days and 197 DD (FLS-FEL), 218 days and 2474 DD (B10L-BML), 31 days and 326 DD (CFB-CFPL), 19 days and 207 DD (BPO-EF), 152 days and 1719 DD (FOG-IMH), and 46 days and 526 DD (ARC-FMC) (Figure 1, Table 1).

The number of days and the thermal requirements for completing each sub-period in the appearance of the inflorescence and flowering stages were higher in the second cycle. From pruning to the stage where the flowers are closed and the petals form a long corolla, 46 and 52 days were required, and the total thermal requirements were 542 CDD (cumulative degree days) and 563 CDD in the first and second agronomic seasons, respectively. A period of 52 and 59 days were required for completing the

flowering period (pruning until the end of the flowering period), and the total thermal requirements were 600 CDD and 634 CDD in the first and second agronomic seasons, respectively.

According to Kshirsagar *et al.* (1975), although the atemoya tree possesses in its ancestry a genitor from the Andean valleys, the hybrid species is strongly affected by the temperature, especially at night. Studies show that in places of low nocturnal temperatures, a slower development of the flower buds occurs. According to some studies the chronology of the flowering is controlled by multiple and complex characters and are influenced by temperature at different periods of the year (Cook *et al.*, 2012; Guo *et al.*, 2013).

The periods from pruning of the plants until complete fruit ripening for consumption a total of 224 and 210 days and 2548.9 and 2349.6 CDD were observed for the first and second agronomic seasons, respectively. The atemoya tree cycle presented close values in the two production cycles, from pruning until budding, with a maximum length of 245 and 250 days and total thermal requirements of 2804.6 and 2823.1 CDD for both agronomic seasons.

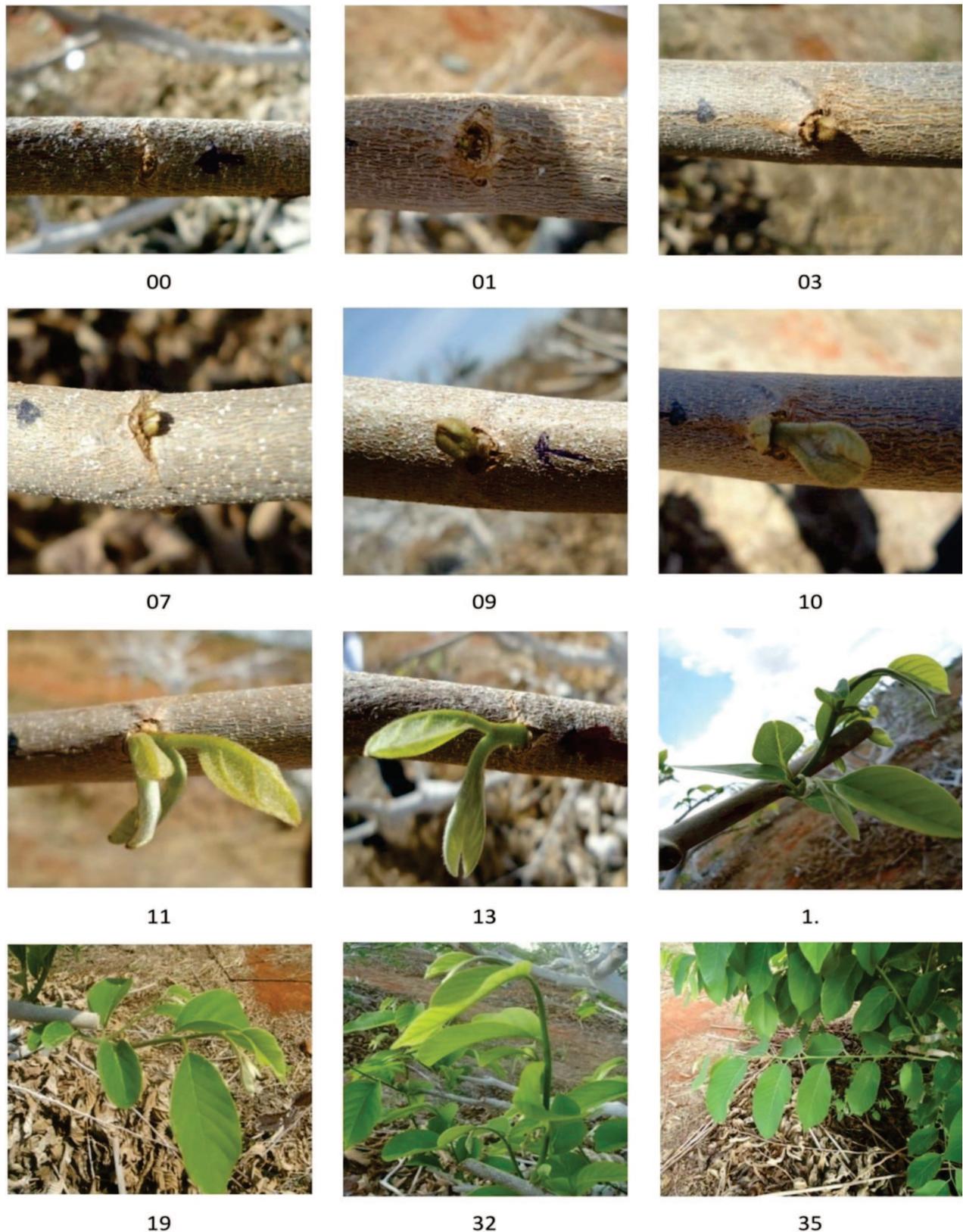
The most remarkable difference among the agronomic seasons (cycles) was the extension of the phenological sub-stages of fruit development and fruit ripening (FOG-FMC). Comparing the cycles, a extension of 35 days was detected considering these sub-stages in the first cycle. In this particular case it seems that two climate factors were very important: rainfall and insolation.

During the cycle 1 a total insolation of 2137 hours and a rainfall of 737,5 mm was observed (Figure 1A), and, a total insolation of 2324 hours and a rainfall of 303,10 mm was detected for the second cycle (Figure 1B).

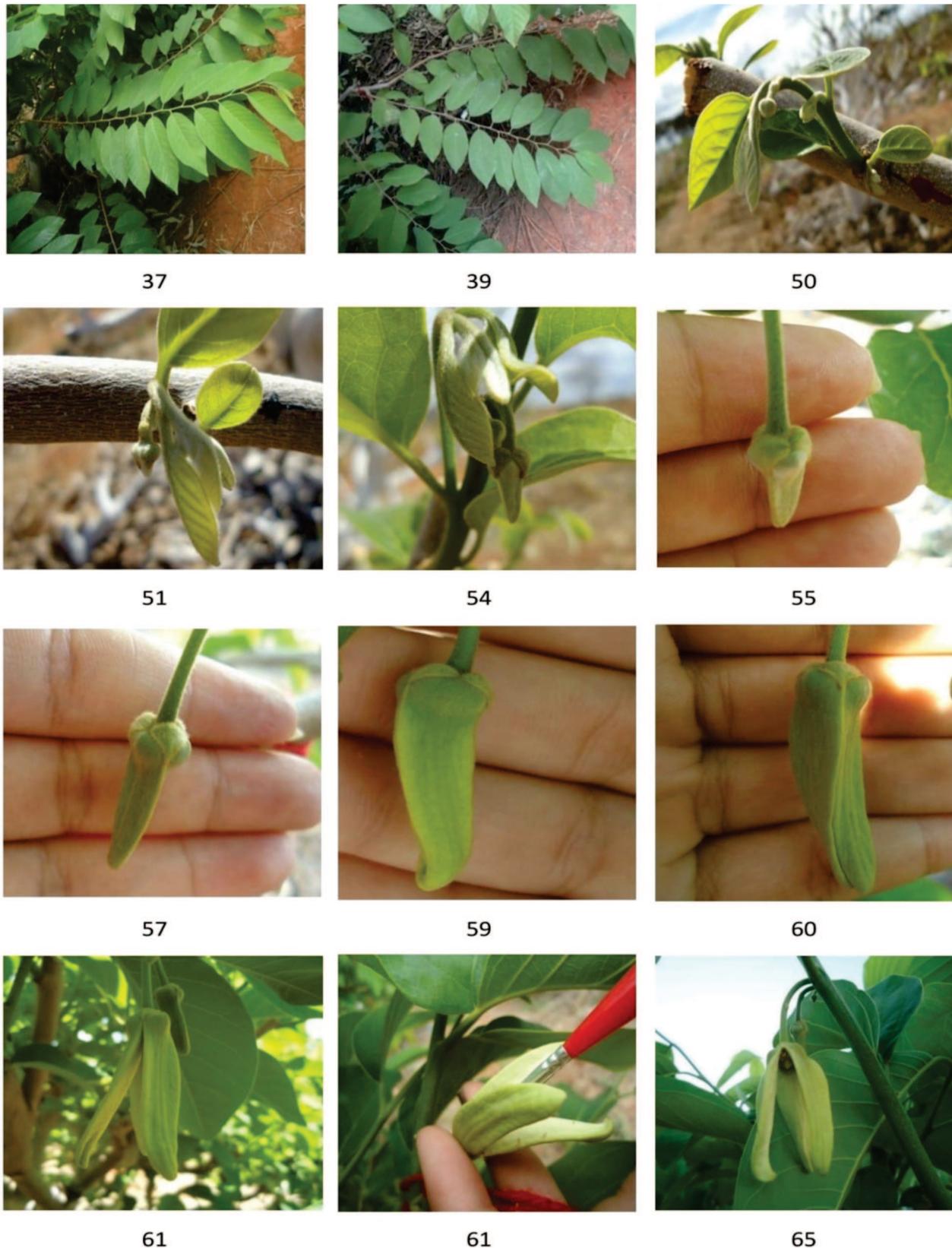
Table 2: Duration of phenological sub-stages and thermal requirements (degree days) of the atemoya tree during different agronomic seasons (1 and 2), Janaúba, Minas Gerais state, Brazil, 2013/2015

Phenological sub-stages		Pruning times							
		(1) Date 08/23/2013				(2) Date 05/16/2014			
Beginning	End	ND	CND	DD	CDD	ND	CND	DD	CDD
(1) CLB	EL5	24	24	272	272	21	21	248	248
(2) FLS	FEL	18	28	207	318	18	35	197	390
(3) B10L	BML	221	245	2545	2805	218	250	2474	2823
(4) CFB	CFPL	29	46	357	542	31	52	326	563
(5) BPO	EF	14	52	163	600	19	59	207	634
(6) FOG	IMH	168	217	1911	2469	152	206	1719	2302
(7) ARC	FMC	65	224	760	2549	46	210	526	2350

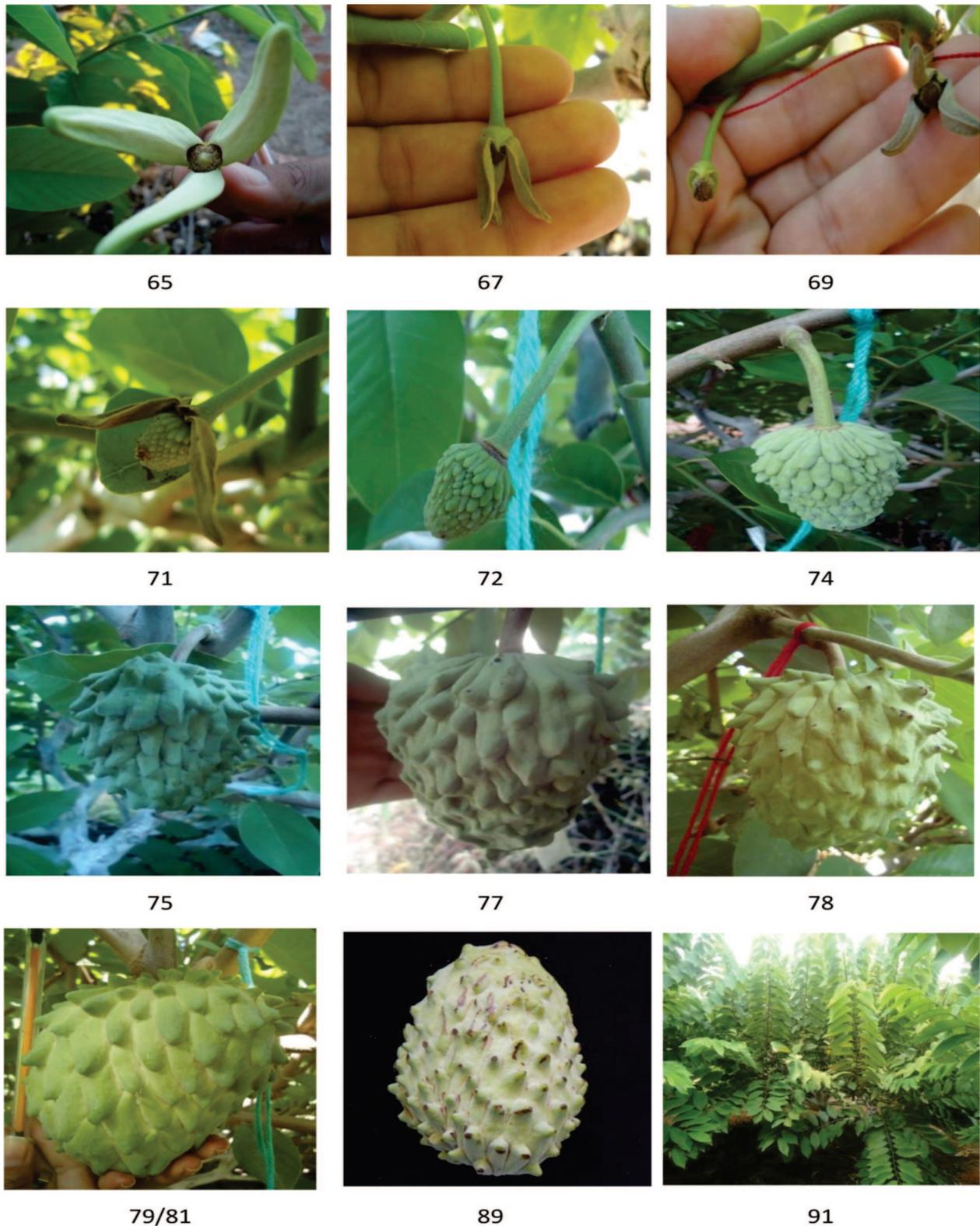
ND: number of days of each stage; CND: cumulative number of days from pruning; DD: degree day of each stage; CDD: cumulative degree days from pruning; CLB: closed leaf buds; EL5: end of the leaves with 5 mm; FLS: first leaves separating; FEL: first fully expanded leaves; B10L: budding with 10% of its length; BML: budding with maximum length; CFB: closed flower buds covered with light color scales; CFPL: closed flowers, petals form long corolla; BPO: beginning of petal opening; pre-female state; EF: end of flowering; FOG: fruiting; onset of ovarian growth; IMH: fruit size of the species presents ideal maturation for the harvest; ARC: appearance of ripening color for harvesting; FMC: full maturity.



**Figure 2:** Main phenological stages of the atemoya tree according to the general BBCH scale as described, for stages 00-35, (00) Dormancy: leaf buds closed and covered by brown scales; (01) Beginning of bud swelling, greenish-brown coloration; (03) End of the expansion of leaf buds: greenish brown bud; (07) Beginning of budding: leaf ends visible with a greenish brown color; (09) End of greenish brown leaf with 5 mm above the scale of the bud; (10) First leaves separating, with slightly brownish-green coloration; (11) First visible unfolded leaves of greenish-white color; (13) Development of the 3rd leaf of greenish-white color, total unexpanded; (1.) Leaf development; (19) First fully expanded leaves, with leathery appearance; (32) Bud with 20% of final length and (35) Bud with 50% of final length, in Janaúba, Minas Gerais state, Brazil.



**Figure 3:** Main phenological stages of the atemoya tree according to the general BBCH scale, as described, for stages 37-65, (37) Bud with 70% of final length; (39) Bud reaching the maximum length of the species; (50) Floral buds enclosed by whitish scales; (51) Floral buds swelling; (54) Visible sepals and petals begin to lengthen; (55) Lengthening of the petals; (57) Flowers still closed, petals lengthening; (59) Closed flowers, petals completely extended forming a long corolla; (60) Beginning of separation of petals: pre-female state, pollen grain is not viable; (61) First flowers at female state: 10% of flowers open and (65) Full flowering, 50% of open flowers in completely male state, pollen grain released, in Janaúba, Minas Gerais state, Brazil.



**Figure 4:** Main phenological stages of the atemoya tree according to the general BBCH scale, as described, for stages 65-91, (65) Full flowering, at least 50% of flowers open and in completely male state, pollen grain released; (67) Flowering fading: majority of the petals fallen or dried; (69) End of flowering: visible fruiting, all petals fallen or dried; (71) Onset of growing of green ovaries, sometimes with dry petal; (72) Fruit about 20% of final size; (74) Fruit about 40% of final size; (75) Fruit about half of final size; (77) Fruit about 70% of final size; (78) Fruit about 80% of final size; (79) Fruits have reached the size of their species and are physiologically mature, with light green coloration and carpels distant from one another; (81) Appearance of coloring of fruits; (89) Full maturation, the fruits detach with ease and (91) End of growth of the branches or buds, but the foliage remains green, in Janaúba, Minas Gerais state, Brazil.

The solar radiation that falls on the leaves, is considered a climatic factor fundamental, since the intensity, quality and duration of light act as a source of energy and developmental stimulus (Rizzini, 1997). Besides, in tropical species the water is a very important component and tend to increase the time required to complete the development stages in periods of dry seasons.

Popenoe (1952) reports that the atemoya tree is considered as member of Annonaceae family, with the greatest capacity for adaptation to diverse climates and geographic regions. Despite this plasticity, the author notes that the hybrid species has better adaptation in tropical regions with higher rainfall. In regions with low rainfall, irrigation practice has been very efficient in supplying water throughout the year.

Although the hybrid species has a few advantages over its parents, one of the problems noted in several studies is the low efficiency of natural pollination. In addition to the phenomenon of protogynous dichogamy, pollen grains of atemoya tree are heavier and sticky, making dispersion of the genetic material difficult. To increase the yield two important characteristics must be improved: number of fruits per plant and fruit size (length and diameter). In this case the artificial pollination is a fundamental practice, and stages 60 to 65 are the ideal moment for this practice (Pereira *et al.*, 2014).

Phenological observations and estimates of heat requirement measured in degree days should be considered as integrative measures of the physical, chemical, and biological environmental conditions to which a species is submitted. In this way, the knowledge, description, and duration of the stages of development of the atemoya tree will allow an increase in the planning of crop management, especially the practices of pruning, fertilization, irrigation, pollination, harvesting, and commercialization. In the case of the atemoya tree, we emphasize that the studies carried out may contribute significantly to the follow-up and monitoring of phenological responses due to climate change, serving as indicators to warn about the impacts of global warming, as well as indicating new strategies to improve the species.

## CONCLUSIONS

The general BBCH scale is efficient in identification of the distinct phenological stages of the atemoya tree, in which the development of two agronomic seasons are divided into eight of the ten main possible stages.

The phenological cycle of the atemoya tree, from the stage of leaf buds closed and covered by brown scales until the complete physiological maturity of the fruits, occurred in the period between 217 and 206 days, with thermal requirements of 2469 and 2302 degree days for the first and second agronomic seasons.

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