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Phenological study of sugar apple (*Annona squamosa* L.) in dystrophic yellow latosol under the savanna conditions of Roraima

Elias Ariel de Moura[1*], Pollyana Cardoso Chagas[2], Edvan Alves Chagas[3], Railin Rodrigues de Oliveira[2], Wellington Farias Araújo[2], Sara Thiele Moreira Sobral[2], Daniel Lucas Lima Taveira[2]

[1]Universidade Federal Rural do Semi-Árido, Programa de Pós-Graduação em Fitotecnia, Av. Francisco Mota, 572, Costa e Silva, 59.625-900, Mossoró, RN, Brasil
[2]Universidade Federal de Roraima, Centro de Ciências Agrárias, Departamento de Fitotecnia. Boa Vista/RR, Brasil
[3]Empresa Brasileira de Pesquisa Agropecuária, Boa Vista, RR, Brasil. CNPq Research Productivity Scholarship.

[*]Corresponding author: eliasariel90@gmail.com

Abstract

Sugar apple (*Annona squamosa* L.) is a commercially significant fruit species due to its nutritional qualities. The state of Roraima has excellent soil and climatic conditions for the cultivation of the species. However, no studies on the phenological behavior of this plant have been reported in the literature. In this context, the objective of this work was to investigate the vegetative and reproductive phenological behavior of sugar apple under the savanna conditions of the state of Roraima. The experiment was carried out in four seasons of the year (2014/2014 and 2015/2015 rainy season and 2014/2015 and 2015/2016 Summer). Production pruning was carried out in February 2014 (2014.1 cycle), September 2014 (2014.2 cycle), February 2015 (2015.1 cycle) and September 2015 (2015.2 cycle). Forty plants were monitored during the experiment and evaluated every three days for the following variables: beginning date of bud swelling; duration of flowering; and fruit harvest time. From the observed data, the periods (days) between each phenological stage were calculated: pruning/bud swelling; pruning/beginning of flowering; bud swelling/anthesis; pruning/anthesis; anthesis/beginning of fruit harvest; duration of fruit harvest, and crop cycle (production pruning/harvest). The duration of the cycle, from the production pruning to the harvest varied according to the productive period, recording 146 days for the 2014.1 cycle and 127 days for the 2014.2 cycle, which proves that the phenological behavior of the species is influenced by climatic conditions.

Keywords: Amazon; Reproductive behavior; Vegetative behavior; *Annona squamosa* L; Cultivation periods.

Introduction

Sugar apple (*Annona squamosa* L.), also known as custard apple and sweet-sop, is adapted to different soil and climatic conditions, which favored its worldwide expansion. The species is native to tropical America, particularly to the Antilles, and can be cultivated in tropical and subtropical areas (Liu et al., 2015). Sugar apple has been commercially cultivated in Africa, South America, Australia, India, Mexico, in the south and the United States, the Philippines, and Thailand (Pinto et al., 2005; Crane et al., 2016). For being a large country, Brazil can produce high yields when compared with other producing countries, especially in the states with hot climate, little rainfall, and a well-defined dry season during the year (Lederman and Bezerra, 1997)

A. squamosa is of great commercial importance and stands out among other species in the genus Annona due to its medicinal and nutritional properties, such as vitamins A, B, C, E, K1, antioxidants, polyunsaturated fatty acids, and essential minerals, besides its pleasant aroma and flavor (Liu et al., 2013; Liu et al., 2015). Despite being mainly consumed *in natura*, sugar apple can be used to produce juices, candies, ice cream, liqueurs, and pharmacopeia.

Northern Brazil has a great fruticulture potential to grow tropical and subtropical species. In northern Brazil, the state of Roraima has increasingly focused on the production of several fruit species owing to its climatic peculiarities. However, few studies on the phenological behavior of these species under the savanna conditions of Roraima have been reported in the literature, which hinders the expansion of crops with productive potential, such as sugar apple.

To obtain production quality and increase the profitability of sugar apple crops, management techniques must be employed, such as: floral induction, artificial pollination, irrigation and fertilization, phytosanitary treatment, weed control, fruit thinning, harvest maturity, and post-harvest strategies, among other practices already used by more technified producers (Salvador, 2013; São José et al., 2014). However, to apply such techniques, a previous phenological study of the vegetative and reproductive behavior of the species is necessary since the phenophase is influenced by the different edaphoclimatic conditions of each region.

Phenology is defined as the study of the cyclical phenomena of the plant in function of the relations with the

environment. This study is based on evaluations of visible development stages of the plants (phenophases), such as bud swelling, leaf development, flowering, fruit development, and senescence (Serrano et al., 2008).
Thus, the phenological knowledge of the species under the desired edaphoclimatic conditions enables crop management, cultural practice at the appropriate time, allowing the advance or delay of fruit harvest, according to the demand of the consumer market.
Therefore, this work aimed to study the vegetative and reproductive phenology of sugar apple under the savanna conditions in the state of Roraima.

Results and discussion

Development of shoots

The data referring to the phenological stages observed in sugar apple trees cultivated under the savanna conditions of Roraima are presented by production cycle: February 2014 to July 2014; September 2014 to February 2015; February 2015 to Agost 2015 and September 2015 to February 2016 (Table 1).
The period (days) between the production pruning and the beginning of bud swelling were of six days for 2014/2014, ten days for 2014/2015, nine days for 2015/2015 and seven days for 2015/2016 in the productive cycles observed (Table 2).
These differences can be attributed to the different climatic conditions observed in each production cycle. These variations in the meteorological elements, with a reduction in the rainfall in the second cycle for 2014/2015 and 2015/2014 being more attenuated, accompanied by a decrease in the relative humidity and a slight increase in the air temperature may have influenced the shorter period of the 2014.2 cycle in the two years of cultivation (Tables 1; 2 and Figure 1).
However, the periods between production pruning and the beginning of bud swelling presented similar results when compared with other Annonaceae producing regions. When studying the vegetative and reproductive performance of sugar apple plants in function of the different lengths of pruned branches in Anagé-BA, Dias et al. (2004) registered ten days from production pruning to the beginning of bud swelling. However, under the climatic conditions of Zhanjiang-China, Liu et al. (2015) observed that bud swelling in sugar apple took eight to ten weeks.
Lemos et al. (2003) studied the effect of defoliation on the induction bud swelling of branches and flowers in an orchard in Maceio-AL and observed that the beginning of bud swelling in fully defoliated branches started about a week later. These results highlight the importance of production pruning together with defoliation to induce a new production cycle. According to Neto et al. (2010), manual or chemical defoliation in association with bud swelling inducers is a great alternative to regulate and increase bud swelling and promote fruiting.
These results are fundamental since no basic information on the crop cycle, management, and technologies necessary for the crop to obtain high yield and production quality, under the savanna conditions of Roraima, has been made available yet.

Development of flowering

Under the savanna conditions of Roraima, the beginning of flowering of sugar apple plants occurred approximately two weeks after production pruning with 17 days in 2014/2014; 16 days in 2014/2015; 21 days in 2015/2015 and 20 days in 2015/2016 after pruning (Table 2 and Figure 2 C). Similar results were observed in a study carried out in São Francisco de Itabapoana-RJ. Santos et al. (2014) reported that pruning performed in September presents a shorter interval until the maximum flowering (15 days) when compared with pruning performed in May, June, July, and August (31, 86, 51, and 45 days, respectively). The longest period of 23 days between the production pruning and the beginning of flowering was observed by Dias et al. (2004) in Anagé-BA. Therefore, sugar apple plants behave differently depending on the region and present variations between each phenophase. This fact may influence the efficiency of the cultural techniques necessary for the cultivation of the species, such as artificial pollination, one of the most important techniques for the achievement of high yield and production quality. According to Nietsche et al. (2009), despite the large amount of flowers produced in each cycle, approximately 5 to 10% of fruits are formed.
Under the conditions of the experiment, the end of flowering was not observed in the evaluated cycles, i.e., flowering was continuous during the evaluation period (Table 1). A period of 34, 26, 32 and 40 days was recorded between the end of bud swelling and anthesis for the cycles 2014/2014; 2014/2015; 2015/2015 and 2015/2016 respectively (Table 2). The periods observed in the present experiment were superior to those reported by Dias et al. (2003), who registered 23 days from bud swelling to anthesis, with pruning carried out in February. Conversely, the period between production pruning and anthesis was 40, 36, 41, and 47 days for the four cycles (Table 2 and Figure 2 H), respectively, under the savanna conditions of Roraima (Table 2). These intervals are similar to those verified by Dias et al. (2003) and Dias et al. (2004), who reported 44 and 33 days, respectively, from pruning to anthesis in Anagé-BA and Tanhaçu-BA, respectively.
The development of the flower varies according to the climatic conditions of the region. Dias et al. (2003) stated that high temperatures tend to advance the development of sugar apple flowers. Although the temperature in the state of Roraima was high during most of the year, little rainfall was observed in the two productive cycles during the periods between production pruning and anthesis, which may have caused the prolongation of flower development in the 2014.1 cycle, even with the high temperatures registered in this period.
The period in which sugar apple flower is viable for artificial pollination is 20 hours after entering the female stage (Figure 2 H).

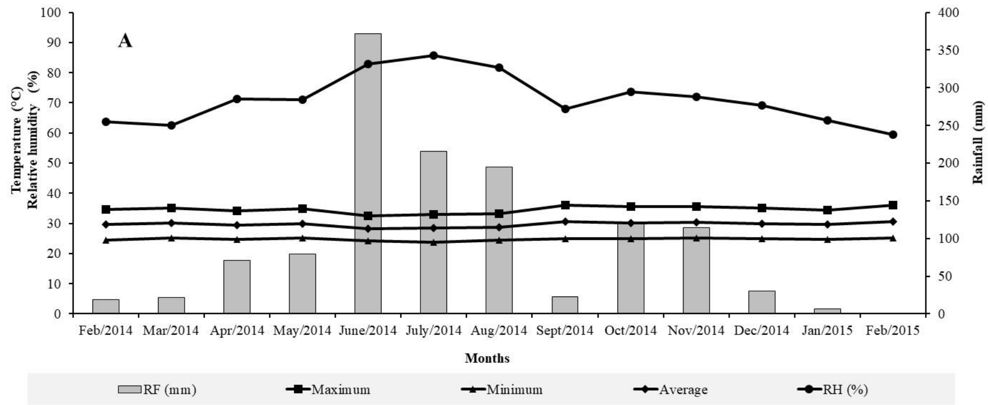
Fruit harvest

In the present study, the period between the anthesis (pollination) and the fruit harvest was 106, 91 101 and 84 days, in the cycles 2014/2014; 2014/2015; 2015/2015 and 2015/2016, respectively (Table 2). Dias et al. (2003) stated that the period between production pruning and fruit harvest might be influenced by several factors, such as

Table 1. Dates observed for each phenological stage during four productive cycles of sugar apple under the savanna conditions of Roraima. Cantá-RR, 2014/2016.

Phenological stage	Productive cycles			
	FEB/JUL (2014/2014)	SEP/FEB (2014/2015)	FEV/AGO (2015/2015)	SET/FEV (2015/2016)
Production pruning	04/02/2014	10/09/2017	11/02/2015	03/09/2015
Beginning of bud swelling	10/02/2014	20/09/2017	20/02/2015	10/09/2017
Beginning of flowering	18/02/2014	15/10/2017	16/03/2015	29/09/2017
End of flowering*	-	-	-	-
Beginning of harvest	30/06/2014	15/01/2017	02/07/2017	12/01/2017
End of harvest	29/07/2014	09/02/2017	04/08/2017	11/02/2017

* Sugar apple plants bloom year-round under the savanna conditions of Roraima



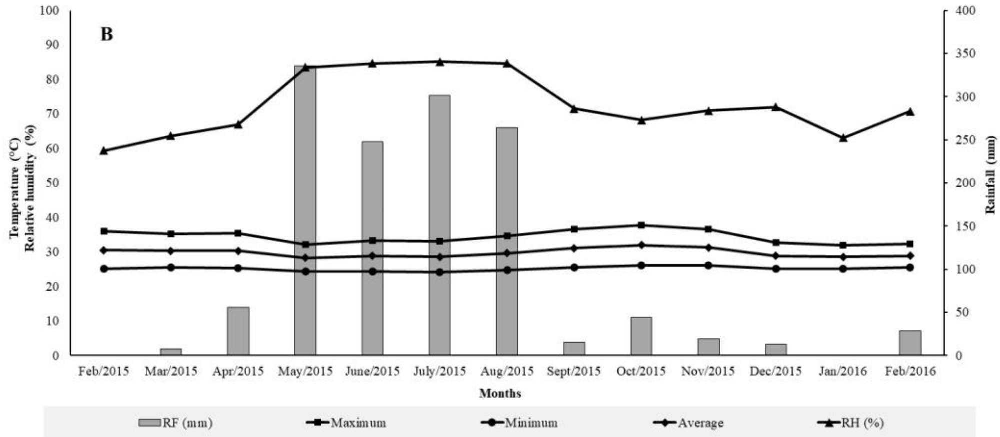


Fig 1. Maximum (T Max), average (T av) and minimum (T min) temperatures, rainfall (RF), and relative humidity (RH) for the months evaluated in the experiment during four growing seasons 2014/2014 - 2014/2015 (A) and 2015/2015 - 2015/2016 (B). Cantá-RR, 2014/2016.

Table 2. Periods (days) between each phenological stage during four productive cycles of sugar apple under the savanna conditions of Roraima. Cantá-RR, 2014/2016.

Periods between phenological stages	Productive cycles			
	FEB/JUL (2014/2014)	SEP/FEB (2014/2015)	FEV/AGO (2015/2015)	SET/FEV (2015/2016)
Production pruning/beginning of bud swelling	6	10	9	7
Production pruning/beginning of flowering	17	16	21	20
Beginning of bud swelling/anthesis	34	26	32	40
Production pruning/anthesis	40	36	41	47
Anthesis/beginning of fruit harvest	106	91	101	84
Duration of fruit harvest	29	25	33	30
Cycle (pruning/beginning of harvest)	147	128	142	132
Total cycle (Pruning/End of harvest)	176	153	175	162

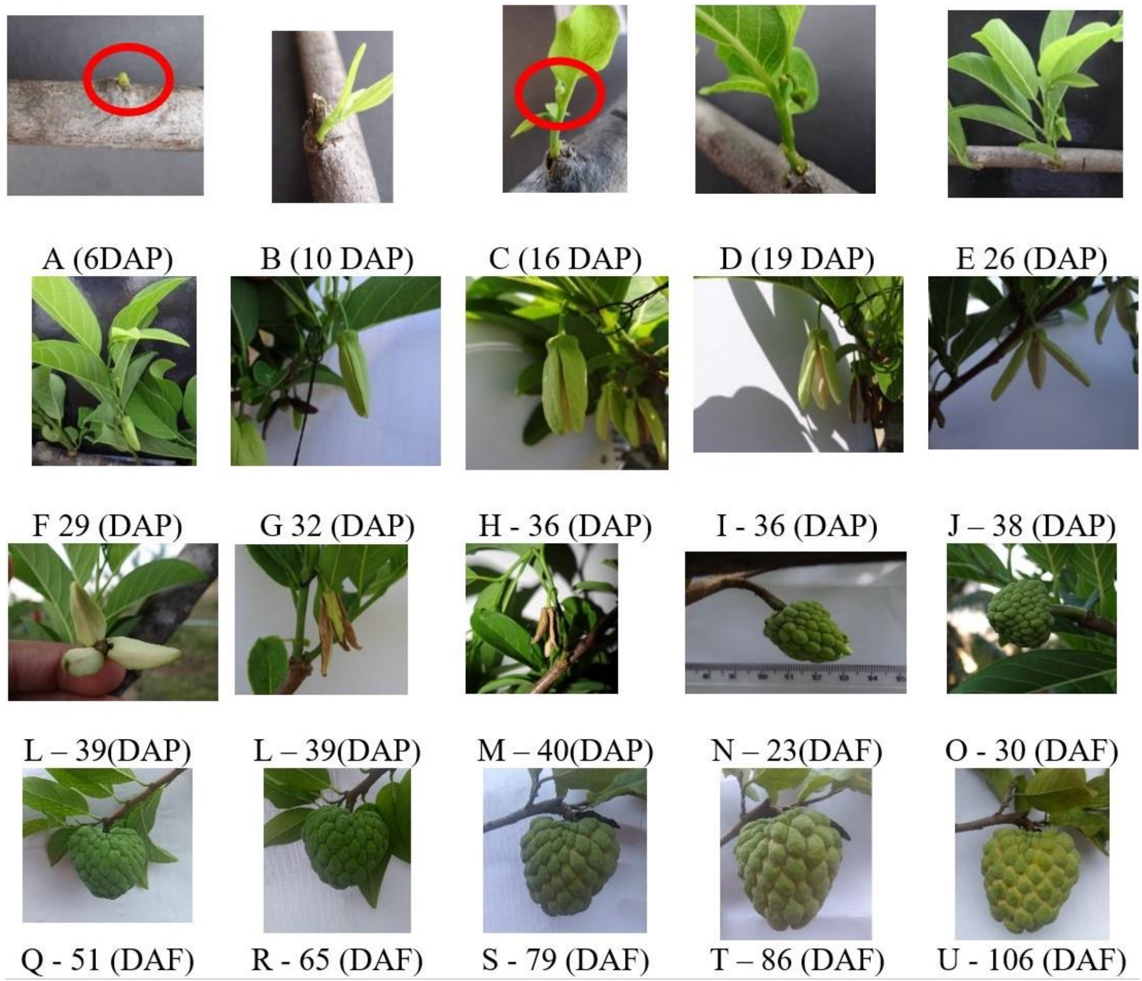


Fig 2. Illustration of the main phenological stages of sugar apple plants (*Annona squamosa* L.) under the savanna conditions of Roraima, in the 2014.2 cycle. Cantá - RR, 2014/2016. * DAP - Days after production pruning. * DAF - Days after fertilization.

climatic conditions, time of the year, nutritional vigor of the plant, irrigation, etc. Salvador (2013), when studying the development of sugar apple flowers in Maceió-AL, reported a 127-day period between the artificial pollination and the full development of fruits (physiological fruit maturation), which is well above those observed in the present experiment. Dias et al. (2004) studied the production pruning in branches of different diameters in the vegetative and reproductive development of sugar apple in Tanhaçu-BA and observed a 101-day period between anthesis (pollination) and fruit harvest. Kavati (1997) observed a 110-120-day period between anthesis and fruit ripening under the edaphoclimatic conditions of the state of São Paulo.

Although sugar apple adapts to different edaphoclimatic regions, it is highly affected by climatic changes, which leads to delays or advances in the development stages of the plant. In the 2015/2016 cycle, in spite of the shorter peaks during the pruning months, rainfall was constant, and temperatures were higher in the first three months of plant growth and development after pruning, which is a fundamental step for the full formation of flowers and fruits. Observations by George and Nissen (1988) show that *A. squamosa* is influenced by different environmental conditions, in which it presented considerable seasonal variation between and within orchards in the same region in Australia (Latitude 27 ° S) and that such variation was a possible cause of poor fruit set. In general, high temperatures favor a faster development. This condition is observed in the extreme north of Brazil due to the strong influence of the equator line.

For the 2014/2014 and 2015/2015 cycles, the rainfall was higher and the temperature were lower compared to the 2014/2015 and 2015/2016 production cycles, which may have led to slow vegetative and reproductive development of plants. Harvest remained constant during in the period of 29, 25, 33, 30 days for the 2014/2014, 2014/2015, 2015/2015, 2015/2016 cycles, respectively (Table 2).

Plant cycle

Production pruning and fruit harvest presented intervals of 146 days for the 2014.1 cycle and 127 days for the 2014.2 cycle (Table 1). This fact is related to the climatic conditions after production pruning in the 2014.1 cycle, which recorded four months of relatively low average rainfall when the plant is at full vegetative and reproductive development, causing the delay between the phenophases.

These conditions were not observed in the 2014/2015 cycle, in which presented constant rainfall in the first three months after pruning (Figure 1). Santos (2014) tested the influence of pruning times in the municipality of São Francisco de Itabapoana-RJ and observed that when pruning was performed in September, plants responded significantly better, with maximum flowering at 15 days after pruning

and shorter period of fruits development after artificial pollination.
Although the 2014/2014 cycle was longer, the duration of the was within the limit reported in the literature for sugar apple. Dias et al. (2003) observed a 145-day period from pruning to fruit harvest in the city of Tanhaçu-BA. The same authors also observed a 130-day period from production pruning to physiological fruit maturation in Anagé-BA. A longer period was observed by Liu et al. (2015), who studied the phenological stages of sugar apple using the expanded BBCH scale in Zhanjiang-China and reported a 215-day period between pruning and fruit harvest.
Therefore, regardless of the desired season to produce sugar apple under the savanna conditions of Roraima, the producer will be able to compete with the national market by advancing or delaying the production.
In semi-arid conditions Mendes et al. (2017) observed that the sugar apple fruits are suitable for harvesting at 135 days in the first cycle studied (Agu 2013 / Mar 2014) and 144 days in the second cycle (Mar 2014 / Sep 2014).
For the production cycle 2014/2015, a scale was elaborated to illustrate the main phenological stages of the development of sugar apple (Annona squamosa L.) under the savanna conditions of Roraima. Figure 2 A shows the beginning of the bud swelling at six days after production pruning. The beginning of flowering was observed at 16 days after pruning (Figure 2 C). The opening of the flower (anthesis) occurred at 36 days after pruning (Figure 2 I). The optimal harvesting time of the fruits was at 106 days (Figure 2 U), 91 days, 101 days and 84 days after pollination and 147 days for 2014/2014 cycle, 128 days for 2014/2015 cycle (Figure 2 U), 142 days for 2015/2015 and 132 days for 2015/2016 after production pruning. The total cycle (pruning the last fruits harvest) was 176, 153, 175 and 162 days for the 2014/2014, 2014/2015, 2015/2015 and 2015/2016 cycles, respectively (Table 2).

Materials and methods

Description of the area: location, soil and climate

The experiment was carried out in a commercial orchard belonging to Paricarana farm, located in the municipality of Cantá, state of Roraima (lat. 2º43'52.5"N, 60º38'12.1"W, at 90 m), from January 2014 to February 2016.
The climatic condition of the region is considered as AWi (tropical rainy climate), according to the Koppen classification, with an average temperature of 27.4 °C, minimum annual rainfall of 944.7 mm total annual rainfall of 1678.6 mm, and relative air humidity of 70% (Araujo et al., 2001). The soil of the experimental area is classified as Dystrophic Yellow Latosol (EMBRAPA, 2013).
The maximum, average, and minimum temperature, rainfall, and relative humidity were collected during the experimental period, and the climatic data were obtained from INMET (National Institute of Meteorology), as shown in Figure 1.

Plant material

Phenological data were collected from adult trees with 6 years old of A. squamosa, which were planted in a 4 x 4 meters and conducted in open pot. The experiment was carried during four growing seasons: February - July 2014 to February - August (rainy season) and September 2014 - February 2015 and September 2015 to February 2016 (dry season). The plants were manually pruned using pruning shears and the pruning was performed on February 04, 2014 (2014.1 cycle), September 10, 2014 (2014.2 cycle), February 11, 2015 (2015.1 cycle) and September 03, 2015 (2015.2 cycle). The established size of the branches was 40 cm (± 2) in de length from the base of the branch apex. In addition, plants were manually defoliated from the apex to the base of the branch.

Irrigation, Fertilization and phytosanitary control

Irrigation was performed twice daily for 30 min, using a fixed conventional irrigation system, with sprinklers at 1.5 meters from the ground, with a flow rate of 2450 liters per hour $^{-1}$. Weed control was performed mechanically using a hoe. After production pruning, 990 g of ammonium sulfate, 120 g of potassium chloride, 250 g of superphosphate, 40 g of borax, and 20 g zinc sulfate were applied per plant. The source of nitrogen and potassium was applied in three splits after pruning. The Bordeaux mixture was applied every 15 days to prevent fungal attacks, using 100 g of copper sulfate, 100 g of agricultural lime for 20 liters of water, until the period before flowering, using an automatic knapsack sprayer (13 L).

Experimental design

The present study followed a randomized block experimental design with four blocks and ten plants per block. Plants were evaluated every three days, from pruning to fruit harvest (physiological maturation), to accurately identify each of the phenological stages under the savanna conditions of Roraima. The growth and development stage were evaluated observing all the plants of the experiment every 3 days.
The following variables were evaluated: beginning of bud swelling, when 5% of the buds began to swell; flowering duration, considering the dates between the beginning of flowering, recorded when 5% of the floral buds were observed in the plants, and the end of flowering, registered when plants presented no more flowers in the experimental area; harvest period, considering the dates between the beginning of harvest, when the first fruits were at physiological maturation stage (distancing of the carpels and change of color from green to cream), and the end of harvests, when plants showed no more fruits.
From the observed data, the periods (days) between each phenological stage were calculated: production pruning/beginning of bud swelling; production pruning/beginning of flowering; beginning of bud swelling/anthesis; production pruning/anthesis; anthesis/beginning of fruit harvest; and crop cycle (production pruning/fruit harvest).
For the preparation of the phenological scale of sugar apple under the savanna conditions of Roraima, four plants were randomly selected in the orchard, and four branches were marked in each quadrant of the plant, totaling 128 buds located in 64 different branches. The development of shoots, flowers, and fruits was monitored by photographic records every two days.

Conclusion

The duration of sugar apple cycle, from production pruning to fruit harvest, varies according to the productive period.
The shortest cycle was observed in the productive period of 2014/2015, with 128 days of production pruning the initial fruit harvest. In general terms, the productive cycles of the second half of 2014/2015 and 2015/2016 were shorter. The anthesis in the flowers occurs between 36 to 47 days after the pruning of production and the flower is viable for artificial pollination is 20 hours after entering the female stage. The phenological behavior of the species is influenced by the climatic conditions of the region and their phenophases present considerable variations with the seasonality

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References

Araujo WF, Andrade Junior AS, Medeiros RD, Sampaio RA (2001) Precipitação pluviométrica mensal provável em Boa Vista, estado de Roraima, Brasil Rev Bras Eng Agríc E Ambient. 5:563–567

Araújo WF, Costa SAA, Santos AE (2007) Comparação entre métodos de estimativa da evapotranspiração de referência (eto) para Boa Vista, RR Rev Caatinga. 20:88–88

Crane JH, Balerdi CF, Maguire I (2016) Sugar apple growing in the Florida home landscape: In : http://edis.ifas.ufl.edu/mg330. Accessed in August 2017.

Dias NO, Matsumoto SN, Rebouças TNH, Viana AES, São José AR, Souza IVB (2003) Influência da poda de produção em ramos de diferentes diâmetros no desenvolvimento vegetativo e reprodutivo da pinheira (Annona squamosa L.) Rev Bras Frutic. 25:100–103

Dias NO, Souza IVB, Silva JCG, Silva KS, Bomfim MP, Alves JFT, Rebouças TNH, Viana AES, José S, Rebouças A (2004) Vegetative and reproductive performance of custard apple (Annona squamosa L.) according to different pruning branches lengths Rev Bras Frutic. 26:389–391

George AP, Nissen RJ (1988) The effects of temperature, vapour pressure deficit and soil moisture stress on growth, flowering and fruit set of custard apple (Annona cherimola × Annona squamosa) 'African Pride' Sci Hortic. 34:183–191

Kavati R (1997) Melhoramento em fruta-do-conde. In: SÃO JOSÉ, A. R.; SOUZA, I. V. B.; MORAIS, O. M.; REBOUÇAS, T. N. H. Anonáceas, produção e mercado (Pinha, Graviola, Atemóia e Cherimólia). DFZ/UESB, Vitória da Conquista, BA, p 47–54

Lederman IE, Bezerra JEF (1997) Indução e polinização de anonáceas. In: SÃO JOSÉ, A.R.; SOUZA, I.V.B.; MORAIS, O.M.; REBOUÇAS, T.N.H. Anonáceas, Produção e mercado (Pinha, Graviola, Atemóia e Cherimólia). DFZ/UESB, Vitória da Conquista, BA, p 330

Lemos EEP, Marinho G A, Almeida MC (2003) Efeito da desfolha de ramos sobre a indução de brotos e flores em atemoia (Anonna cherimola Mill x Anonna squamosa L.) Rev Bras Frutic 4:4–08

Liu K, Li H, Yuan C, Huang Y, Chen Y, Liu J (2015) Identification of phenological growth stages of sugar apple (Annona squamosa L.) using the extended BBCH-scale Sci Hortic 181:76–80

Liu K, Yuan C, Jing G (2013) Effect of exogenous oxalic acid treatment on ripening and preservation of annona squamosa L. fruits during postharvest storage Food Sci. 14:329–334

Mendes DS, Pereira MCT, Nietsche S, Silva JF, Rocha JS, Mendes AH, Xavier HRA, Santos RCD (2017) Phenological characterization and temperature requirements of Annona squamosa L. in the Brazilian semiarid region An Acad Bras Ciênc. 89:2293–2304

Neto ML M, Bezerra JEF, Lederman IE, Assis JS (2010) Efeito da cianamida hidrogenada associada à desfolha química e manual na indução floral de pinheiras (Annona squamosa L.) Pesq agropec pernamb. 15:45–50

Nietsche S, Pereira MCT, Oliveira C, Dias MM, Reis ST (2009) Viability of the sugar apple (Annona squamosa) pollen grains at different hours of the day Ciênc e Agrotecnologia. 33:527–531

Pinto ACDQ, Cordeiro MCR, Andrade SRM, Ferreira FR, Filgueiras HAC, Alves RE, Kinpara DI (2005) Annona species. International Centre for Underutilised Crops, University of Southampton, Southampton, UK

Salvador T L (2013) Estudo do Desenvolvimento de Flores e Caracterização Físico-Química de Frutos de Pinheira (Annona squamosa L.).pdf. Dissertação (mestrado), Universidade Federal de Alagoas, Rio Largo

Santos PC, Nogueira AS, Freitas MSM, Freitas JAA, Carvalho AJC (2014) Influence of pruning time and pollination types in flowering and fruit of sugar apple Rev Bras Frutic. 36:192–201

São José AR, Pires M M, Freitas A, Ribeiro DP, Perez L (2014) Atualidades e perspectivas das Anonáceas no mundo Rev Bras Frutic. Jaboticabal-SP 36:86–93

Serrano LAL, Marinho CS, Lima I de M, Martins MVV, Ronchi CP, Tardin FD (2008) Fenologia da goiabeira "Paluma" sob diferentes sistemas de cultivos, épocas e intensidades de poda de frutificação Bragantia. 67:701–712