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Agrometeorology/ Original Article

Acai palm base temperatures and thermal time requirements in eastern Amazon

Abstract – The objective of this work was to determine the base temperatures, thermal time requirements, and length of the main reproductive growth stages of acai palm (*Euterpe oleracea*) in the northeast of the state of Pará, in eastern Amazon, Brazil. The experiment was carried out from 2017 to 2019 in a 10 ha acai plantation, using the time-series analysis. Plant phenology was monitored weekly, and local weather conditions were monitored daily. The lower and upper base temperatures were of 12.92 and 32.46°C, respectively, for pre-flowering; 13.50 and 32.23°C for flowering; 12.14 and 32.55°C for green fruit stage; 11.64 and 32.78°C for fruit color-changing stage; and 11.23 and 32.94°C for maturation. The thermal time requirement and the average cycle length for the ideal harvest time of acai palm were 3,893.15 degree-days and 283 days, respectively. The thermal time requirement and the duration of the reproductive growth stage for acai palm are influenced by the period of the year and the variability of air temperature, which, when high, reduces the cycle of the crop, and when mild, increases it.

Indexing terms: *Euterpe oleracea*, cardinal temperatures, degree-days, phenological development.

Temperaturas basais e exigências térmicas do açaizeiro na Amazônia Oriental

Resumo – O objetivo deste trabalho foi determinar as temperaturas basais, as necessidades térmicas e a duração dos principais estádios fenológicos reprodutivos do açaizeiro (*Euterpe oleracea*) no Nordeste do estado do Pará, na Amazônia Oriental, Brasil. O experimento foi realizado de 2017 a 2019, em plantio de açaizeiro de 10 ha, tendo-se utilizado análise de série temporal. A fenologia das plantas foi monitorada semanalmente, e as condições meteorológicas dos locais foram monitoradas diariamente. As temperaturas basais inferiores e superiores foram de 12,92 e 32,46°C, respectivamente, na prefloração; 13,50 e 32,23°C na floração; 12,14 e 32,55°C no estádio de frutos verdes; 11,64 e 32,78°C no estádio de mudança de cor dos frutos; e 11,23 e 32,94°C na maturação. A exigência térmica e a duração média para o ponto ideal de colheita do açaí foram de 3.893,15 graus-dias e 283 dias, respectivamente. A exigência térmica e a duração dos estádios da fase reprodutiva do açaizeiro são influenciadas pelo período do ano e pela variabilidade da temperatura do ar, que, quando elevada, reduz o ciclo da cultura, e, quando amena, o estende.

Termos para indexação: *Euterpe oleracea*, temperaturas cardinais, graus-dia, desenvolvimento fenológico.

Introduction

Acai palm (*Euterpe oleracea* Mart.) is a multi-stemmed plant, native to the Amazon estuary (Trevisan et al., 2015), with different stages of development. It is the most important of the ten species of the genus Euterpe in the Amazon biome (Oliveira et al., 2002).

In recent years, the acai palm fruit has gained space in the market, with its commercialization expanding beyond the borders of the Amazon due to its nutritional composition, which is rich in fibers, lipids, phenols, and anthocyanins that are associated with the prevention of cardiovascular diseases (Yamaguchi et al., 2015). As a result of the commercial "boom" of the acai berry, Brazilian producers have been expanding its cultivation to non-flooded areas, using technologies such as irrigation management (Martinot et al., 2017). However, for a successful expansion to other regions, it is necessary to know how the crop behaves in environmental conditions that differ from those that are considered natural for the species, i.e., Amazonian floodplain areas.

Several climatic elements are considered when analyzing the adaptability and development of crops outside their places of origin (Gray & Brady, 2016). Air temperature stands out, being the main meteorological variable that affects and statistically better explains the growth and development of annual and perennial species (McMaster, 2005).

The increase in temperature can damage the growth of a crop by reducing its photosynthetic rate, increasing its photorespiration, and, consequently, decreasing the net carbon gain by plants, reducing the life cycle of the crop, which leads to losses in yield and productivity (Hatfield & Prueger, 2015). To mitigate the effects caused by the increase in temperature in plants, several studies have focused on the modeling of agricultural crops (Santos et al., 2011).

Although Lima & Silva (2008), Rodrigues et al. (2013), and Freitas et al. (2017) assessed the thermal time requirements (base temperatures and thermal constant) for perennial species, such as coffee (*Coffea arabica* L.), mango (*Mangifera indica* L.), and eucalyptus (*Eucalyptus urophylla* S.T.Blake), studies like these are still scarce, particularly for species native to the Amazon, due to the difficulty in evaluating the duration of each phenology growth stage for a long period of time. However, determining the thermal time requirements for a crop, as well as its adaptation to the climatic conditions of a given cultivation site, is important for feeding the agrometeorological model used to estimate the growth and yield of any crop (Trentin et al., 2013).

Studies on crop modeling consider the growth stages and life cycle of a crop, which are fundamental for the definition of crop phenology (Renato et al., 2013). The degree-day method is a technique widely used to define the growth stages of a crop, representing thermal time requirement in terms of the base temperatures that the plant supports and uses in its daily physio-metabolic processes (Streck et al., 2008).

To contribute to the development and expansion of the acai palm crop in the state of Pará, the greatest producer in Brazil, it is key to know the thermal time requirements for the reproductive growth stage – from pre-flowering to fruit maturation – of the species, in order to optimize management strategies that help in the decision-making process, taking into account the climatic conditions to which the crop can be subjected.

The objective of this work was to determine the base temperatures, thermal time requirements, and length for the main reproductive growth stages of acai palm in the northeast of the state of Pará, in eastern Amazon, Brazil.

Materials and Methods

The experiment was carried out in the northeastern region of the state of Pará, Brazil, between 2017 and 2019, in two areas: one of 10 ha, at the Ornela farm, located in the municipality of Capitão Poço (1°44'42"S, 47°03'54"W, at 71 m of altitude); and the other of 0.5 ha, at the experimental farm of Universidade Federal Rural da Amazônia, located in the municipality of Castanhal (1°17'0"S, 47°55'20"W, at 41 m of altitude). The experimental design chosen was the time-series analysis since continuous data on climate and plant phenology were recorded for more than a year.

The soils of the experimental areas were classified as Latossolo Amarelo distrófico (Santos et al., 2013), which corresponds to an Oxisol, with: sandy texture and 40 g kg^{-1} clay in the 0–20 cm layer, and sandy loam texture and 150 g kg^{-1} clay in the 20–40 cm layer in Castanhal; and sandy loam texture and 140 and 280 g kg^{-1} clay in the 0–20 and 20–40 cm layers, respectively, in Capitão Poço (Table 1). The local climate in the two municipalities is characterized as

Ami, according to Köppen-Geiger's classification, with an average annual rainfall ranging from 2,500 to 3,000 mm. In Castanhal, relative air humidity was 80%, average annual temperature was 26ºC, and the driest quarter of the year occurred between July and September (Farias et al., 2017). In Capitão Poço, relative air humidity was 85%, average annual temperature was 25.85ºC, and the driest quarter of the year was observed between September and November (Oliveira et al., 2016).

The acai palm trees were planted in 2011 in Castanhal and in 2012 in Capitão Poço, using the BRS Pará cultivar, ecotype "chumbinho", at a spacing of 4.0×4.0 and 6.0×4.0 m, respectively, with the management of three tillers per plant. Cultivation was carried out on non-flooded land, with daily irrigation using a micro sprinkler system at a mean gross irrigation depth of 2.81 and 3.64 mm per day in Castanhal and in Capitão Poço, respectively, during the dry period.

Of the total area of the experiment, 1.0 ha was demarcated to be monitored in Capitão Poço and 0.5 ha in Castanhal. At the center of the experimental area in both municipalities, a 12 m high metal tower was installed, to which an automatic meteorological station was attached; the following equipment were also connected: the TB4 rain gauge (Campbell Scientific, Inc., Logan, UT, USA) above the plant canopy, the HMP45 thermohygrometer (Campbell Scientific, Inc., Logan, UT, USA) at the acai palm inflorescences and infructescence level, and the CS615 time-domain reflectometer (Campbell Scientific, Inc., Logan, UT, USA) at 0.3 m depth. The sensors were linked to the CR1000 Datalogger (Campbell Scientific, Inc., Logan, UT, USA), with a reading schedule every 10 s and total averages every 20 min. The meteorological and phenological data were collected between October 2017 and April 2019.

The reproductive growth stages of acai palm were analyzed, by adapting the scale proposed by Garcia & Barbedo (2016), which includes the following four reproductive growth stages: inflorescence emergence or pre-flowering, flowering, green fruit, and fruit-color changing (fruit development), plus maturation (fruit ripening) described by Nogueira et al. (2005) (Table 2).

Phenology was monitored every seven days. A total of 300 plants were previously selected (corresponding to 24% of the individuals of 1.0 ha) and then observed by naked eye to register the presence or absence of flowering (spathe and flower) and fruiting (panicles of green, black, or ripe fruits) events, including the total count of the reproductive structures found in each individual.

The activity index (AI) was used to quantify and indicate the percentage of individuals in the observed population that manifested a certain phenological event, i.e., the percentage of individuals found in each phenophase, classified as: non-synchronous or asynchronous, less than 20%; poorly synchronized or with low synchrony, 20 to 60%; and with high synchrony, more than 60% (Bencke & Morellato, 2002). The following equation was used:

$$AI = (NIP / TNSP) \times 100$$

Table 1. Soil chemical and physical properties at the experimental site in the municipalities of Castanhal and Capitão Poço, in the state of Pará, Brazil.

Municipality	Depth (cm)	pH (H_2O)	P	K^+	Ca^{2+}	$Ca^{2+} + Mg^{2+}$	Al^{3+}
			(mg dm^{-3})		($cmol_c$ dm^{-3})		
Castanhal	00–20	5.92	11	21	0.85	1.35	0.40
	20–40	5.69	21	15	0.35	0.45	1.10
Capitão Poço	00–20	4.07	45	65	0.90	1.30	0.20
	20–40	4.82	51	10	0.50	0.90	0.50
Municipality	Depth (cm)	Sand	Silt	Clay	SD[(1)] ($g\ cm^{-3}$)	FC[(2)]	PWP[(3)]
		(g kg^{-1})				($m^3 m^{-3}$)	
Castanhal	00–20	865	94	41	1.54	0.24	0.07
	20–40	740	111	149	1.62	0.32	0.08
Capitão Poço	00–20	792	68	140	1.43	0.37	0.23
	20–40	633	87	280	1.68	0.32	0.21

[(1)]Soil density. [(2)]Field capacity. [(3)]Permanent wilting point.

where NIP is the number of individuals at a given phenological stage, and TNSP is the total number of sampled plants.

For the estimation of the lower base temperature (Tb), first, the degree-day (DD, °C day) for each growth stage and each plant under study was determined, according to the thermal time required (Arnold, 1959), through the equation:

$$DD = \sum (Tmax - Tmin / 2) - Tb$$

where Tmax is the daily maximum air temperature (°C) and Tmin is the daily minimum air temperature (°C).

To obtain the DD, a series of Tb ranging from 0 to 20ºC was used, at intervals of 0.5ºC. From the thermal time requirements found for each growth stage, the standard deviation in DD (DPgd) was determined for each temperature, considering, as a baseline, a temperature lower than the lowest standard deviation in days (DPd) (Schmidt et al., 2018), using the equation:

$$DPd = DPgd / (Tmean - Tb)$$

where DPgd is the standard deviation in degree-day using a series of Tb, and Tmean is the mean air temperature (ºC) of the whole period.

Table 2. Reproductive growth stages for acai palm (*Euterpe oleracea*).

Growth stage	Description
Pre-flowering	Appearance of the spathe – considered the time in which the inflorescence is still covered by bracts.
Flowering	Interval from the opening of the spathe and presence of the floral buds until the fall of the flowers.
Green fruits	Stage of immature fruit – from the visualization of the first small fruits still in formation until the beginning of their maturation.
Fruit-color changing	Appearance of the first fruits with dark-purple coloration.
Maturation	Fruits with an intense dark-purple coloration and a glossy surface, but not at the exact point for harvest ("açaí parau"), maintaining their color but becoming covered by a layer of powder with a gray-white hue, indicating they are ripe, at the ideal point for harvest ("açaí tuíra").

After Tb was determined, the upper base temperature (TB, °C) was also obtained, using case two (Tb < Tmin; Tmax < TB) and four (Tb < Tmin; TB < Tmax) described by Ometto (1981), according to the following two equations, covering the thermal conditions during the experimental period:

$$DD = (Tmax - Tmin / 2) + (Tmin - Tb)$$

$$DD = 2 \times (Tmax - Tmin) \times (Tmin - Tb) + (Tmax - Tmin)^2 - (Tmax - TB) / 2 \times (Tmax - Tmin)$$

Temperatures ranging from 20 to 40ºC, analyzed every 0.5 degree, were used to calculate TB. Air temperature was also determined for TB, in which the coefficient of variation became constant (Schmidt et al., 2018).

TB and Tb were used to characterized the thermal time for each acai palm reproductive growth stage. For this, randomly selected plants, apart from those used for Tb and TB calculations, were analyzed during the four months in which the pre-flowering stage of the crop is evidenced, i.e., starting in November, December, January, and February, which represent experimental periods 1, 2, 3, and 4, respectively.

The phenological and climatic data collected at the Castanhal site, following the same methodology used in Capitão Poço, were used to validate the occurrence of the reproductive growth stages (in days of the year) of acai palm, simulated by the DD method. The root mean square error (RMSE) and agreement index were the statistical criteria used to evaluate the performance simulation of acai palm development.

Results and Discussion

At the experimental areas of Capitão Poço and Castanhal, the peaks of maximum phenological activity occurred sequentially, first for the spathe stage (pre-flowering stage), between November and January, followed by the flowering stage, between January and March (Figure 1). The inflorescence stages (pre-flowering and flowering) presented low synchrony according to the AI, which allows extending the cycle of the acai crop (Garcia & Barbedo, 2016) due to a better distribution of fruit maturation during a longer period.

Between March and October, the stages of infructescence (green fruit, fruit-color changing, and ripening) predominated (Figure 1). In this period of the acai palm cycle, the stage of green fruit had two production peaks: the first between March and April, and the second in September, both with a high synchrony according to the AI.

The stages of fruit-color changing and ripening stood out in the same period, presenting two production peaks that occurred with low synchrony between July and August and October and November, respectively, extending until the end of the acai palm season, i.e., until December (Figure1).

The phenological results obtained in the present study corroborate those of Cifuentes et al. (2013), who, using the AI, found low synchrony for the pre-flowering, flowering, and maturation stages, besides high synchrony for the green fruit stage, when studying the phenological behavior of acai palm in the biogeographic province of Chocó, Colombia, from 1999 to 2001 and from 2006 to 2009.

The average air temperature close to plant inflorescences and infructescences in Capitão Poço was 26.75°C, with minimum and maximum of 25.41 and 27.45°C in January and October, respectively. In Castanhal, the average air temperature was 27.69ºC, with a minimum of 25.50ºC in March and a maximum of 31.55ºC in December (Figure 1). The higher values observed for average air temperature in Castanhal may be related to the micro- and topoclimate factors of the experimental area, such as altitude and surrounding soil cover, since the site of Capitão Poço is a homogeneous 100 ha vegetation cover and that of Castanhal is not only smaller, but also closer to the urban area.

In Capitão Poço, where four different pre-flowering periods were evaluated, it was observed that the plants

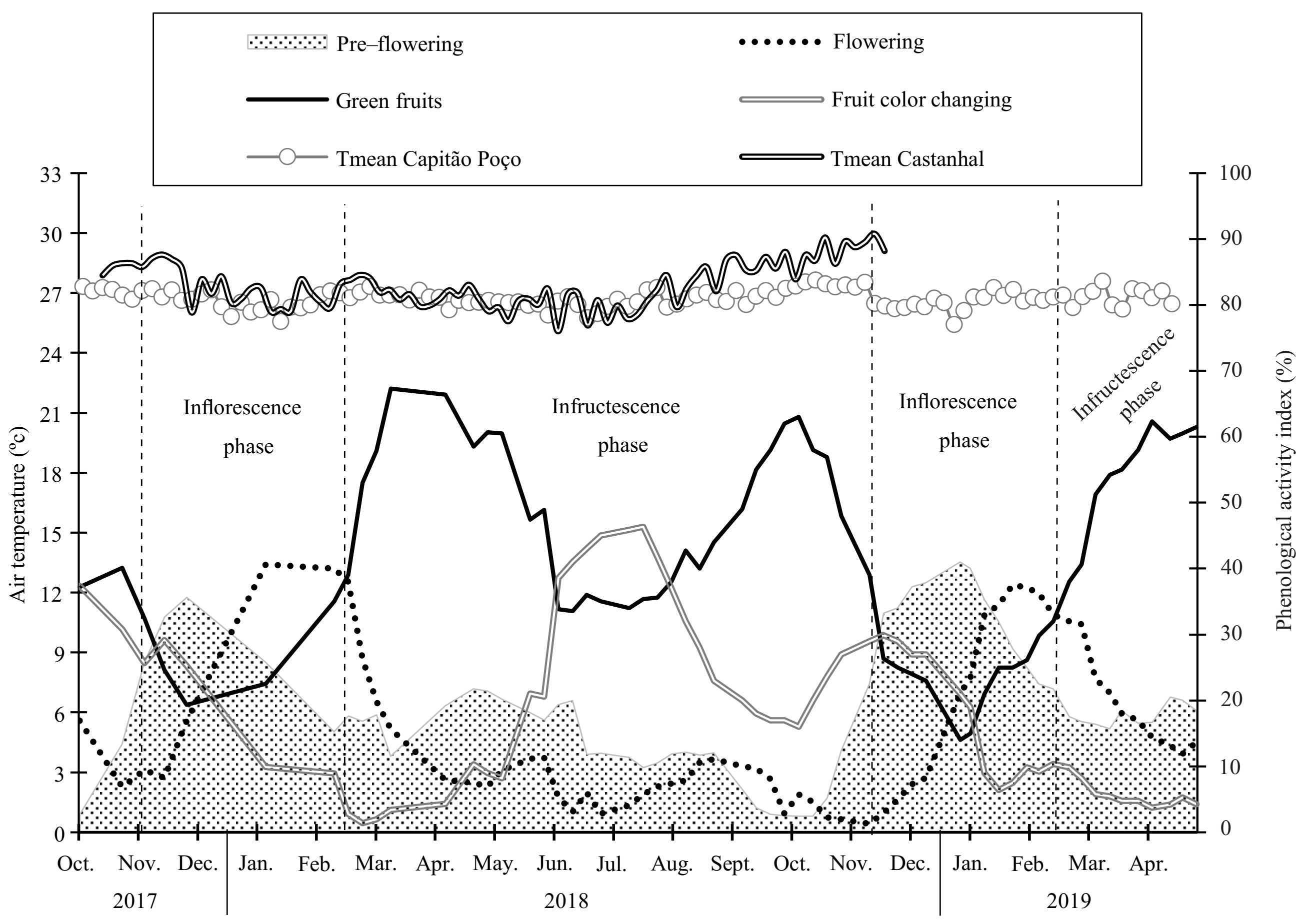

Figure 1. Variability of the mean air temperature and acai palm (*Euterpe oleracea*) reproductive growth evolution in eastern Amazon, Brazil.

that started pre-flowering in December (period 2) and in January (period 3) went through minimum and maximum temperatures during the pre-flowering stage, but also during the maturation and fruit-color changing stages in periods 2 and 3, respectively (Table 3).

At the beginning of the pre-flowering stage in November (period 1), the instantaneous minimum and maximum temperatures were 20.25 and 32.87°C in the pre-flowering and maturation stages, respectively, while, at the beginning of the pre-flowering stage in March (period 4), the minimum temperature was 20.66°C in pre-flowering and the maximum one was 33.80ºC in the green fruit stage. The variations in temperature observed throughout the experiment (Figure 1) increase the reliability of the estimation of base temperatures, allowing the plant to develop in different ways.

The precipitation registered between December and April in Capitão Poço and between December and August in Castanhal ensured that the water in the soil was above the amount of readily available water, with an average of 65.2 and 71.38% available water in Capitão Poço and Castanhal, respectively, resulting in an adequate water supply for the full development of the crop (Figure 2).

During the less rainy season from July to November in Capitão Poço and from August to November in Castanhal, the volumetric water content in the soil reached an average of 0.288 and 0.149 $m^3\ m^{-3}$, respectively, which represents 40.20 and 46.64% of the total available water in the soil. It should be noted that both of these values are below the satisfactory water conditions (readily available water) for the full development of the crop, which causes physio-metabolic changes in the plant, influencing its productivity.

In the Capitão Poço experiment, in period 1, harvest coincided with the highest incidence of rain, which reached 2,188 mm in the reproductive cycle, while, in period 4, it occurred during the lowest rainfall of 1,586 mm. For the harvests in periods 2 and 3, total rainfall was of 2,173 and 1,870 mm, respectively (Table 3). In Castanhal, the total amount of rainfall registered was 41.82 and 19.74% less than that of the period of greater and less rainfall in Capitão Poço, respectively.

In period 1 at Castanhal and in periods 1 and 2 at Capitão Poço, during the inflorescence stage (pre-flowering and flowering), the accumulated total water (rain + irrigation) was 431, 1,042, and 1,264 mm, respectively, of which 6, 10, and 3% referred to the irrigation carried out until the beginning of December 2017, coinciding with the pre-flowering stage of the three periods. The total amount of water applied during the infructescence stage (green fruit, fruit-color changing, and maturation) was 1,246 and 1,077 mm, of which 7 and 15% corresponded to irrigation between August and November 2018.

For periods 3 and 4, beginning in January and February 2018, the only source of water in the inflorescence stage was rainfall – 1,212 and 965 mm, respectively. In the infructescence stage, the total water supply was 907 and 922 mm, of which 27 and 33% were added by irrigation.

Tb values were obtained for each of the five growth stages. The lowest standard deviation in DD was found for the Tb of 12.92ºC, in the pre-flowering stage. Tb was 13.50, 12.14, 11.64, and 11.23ºC, respectively, for the flowering, green fruit, fruit-color changing, and maturation stages (Figure 3). Differences in these

Table 3. Meteorological conditions, total irrigation, and acai palm (*Euterpe oleracea*) cycle length, during the experiment at different periods, at the beginning of the pre-flowering stage in the municipalities of Capitão Poço and Castanhal, in the state of Pará, Brazil.

Municipality	Period(1)	Cycle length (days)	Irrigation (mm)	Meteorological variables(2)			
				Rain (mm)	Tmean (ºC)	Tmax (ºC)	Tmin (ºC)
Capitão Poço	1	287	180	2,188	26.73	32.87	20.25
	2	285	184	2,173	26.63	33.80	20.25
	3	283	250	1,870	26.81	33.80	20.25
	4	280	299	1,586	26.93	33.80	20.66
Castanhal	1	279	27	1,273	27.23	35.05	20.40

(1)Four months in which the pre-flowering stage is evidenced: November, December, January, and February. (2)Tmean, mean air temperature; Tmax, daily maximum air temperature; and Tmin, daily minimum air temperature.

values are common for different growth stages of several species with diverse genetic materials, since most of the crops present a more sensitive stage, which, for acai palm, is that of flowering, when, under abiotic stress, the tree ends up aborting flowers and producing dry racemes, causing a decrease in its productivity (Aguiar et al., 2017).

TB values were also determined for each growth stage. It was verified that the coefficient of variation became constant at a TB of 32.46ºC in the pre-flowering stage. The TB values were 32.23, 32.55, 32.78, and 32.94ºC for the stages of flowering, green fruit, fruit-color changing, and maturation, respectively (Figure 4).

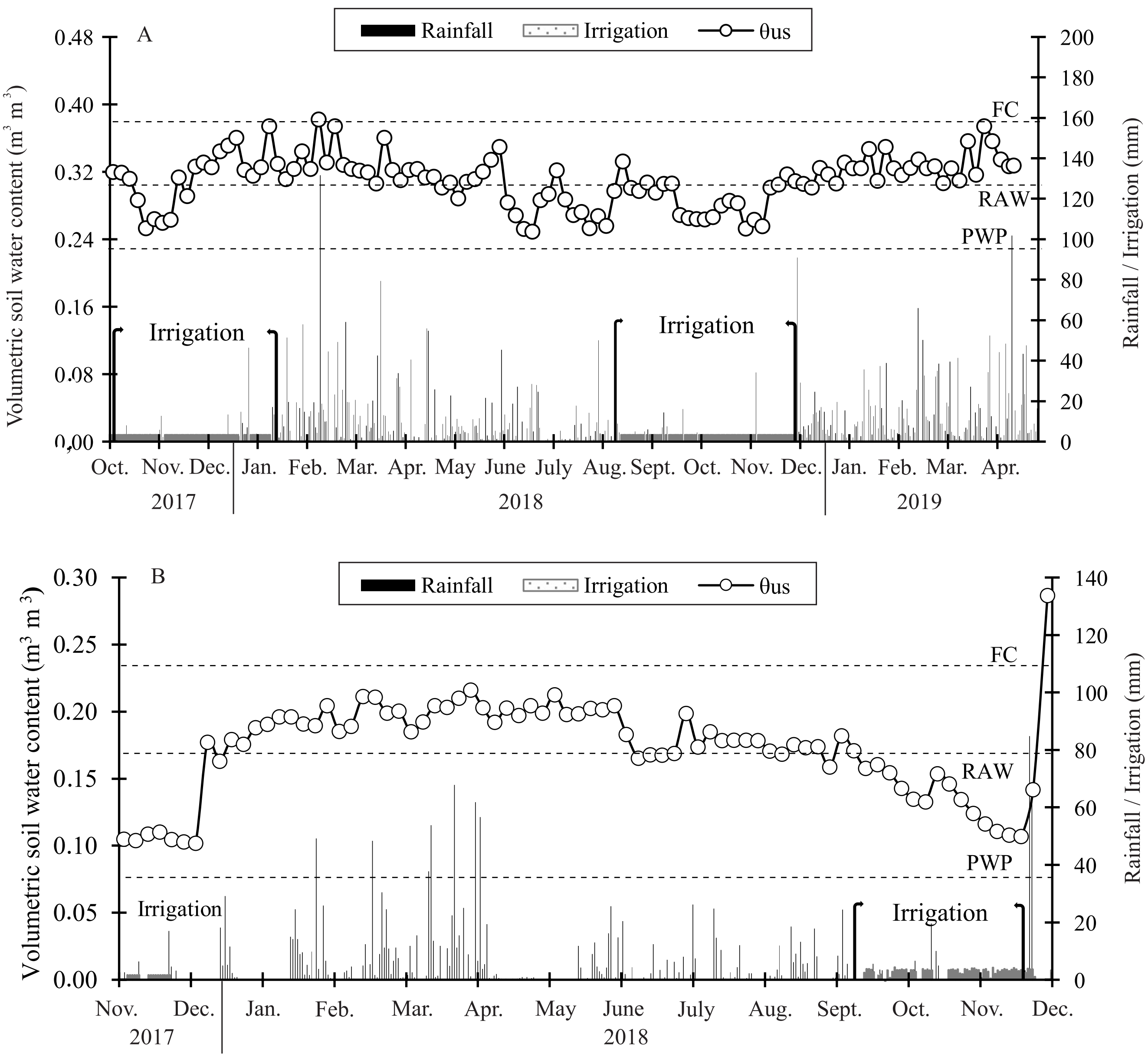

Figure 2. Variation of the volumetric water content in the soil (θus), rainfall, and irrigation during the acai palm (*Euterpe oleracea*) reproductive growth stages in the municipalities of Capitão Poço (A) and Castanhal (B) in the state of Pará, Brazil. Black bars represent rainfall, and the arrows indicate the beginning and the end of the irrigation period. FC, field capacity; RAW, readily available water; and PWP, permanent wilting point.

High TB values are expected since they represent the maximum temperature limit, above which the metabolic and physiological processes of the plant are compromised (Freitas et al., 2017). According to Soltani & Sinclair (2012), high temperatures may induce anomalies in plant growth and development, favoring the reduction of new inflorescences and leaves, floral abortion, and an expressive decrease in photosynthetic rate.

Among the reproductive growth stages of acai palm, flowering is the most sensitive because it presents a lower thermal amplitude of 18.73ºC, considering the base temperatures for the crop's full development. Maturation, however, presents the greatest thermal amplitude of 21.71ºC, followed by the fruit-color changing, green fruit, and pre-flowering stages, with, respectively, 21.14, 20.41, and 19.54ºC. Those information are important for decision-making regarding the best sites to produce the acai berry, allowing farmers to check if local thermal conditions are or not favorable for the full development of the crop.

Considering the values of Tb and TB obtained, respectively, by the lowest standard deviation and the coefficient of variation methods for each growth stage of the crop, the heat sum required for the reproductive growth stage, from pre-flowering to maturation, was calculated, showing an average accumulation of 3,893.15ºC per day, ranging from 3,659.13 to 4,015.23ºC per day.

The acai palm reproductive cycle lasted 283 days, of which 78 days corresponded to the length of the pre-

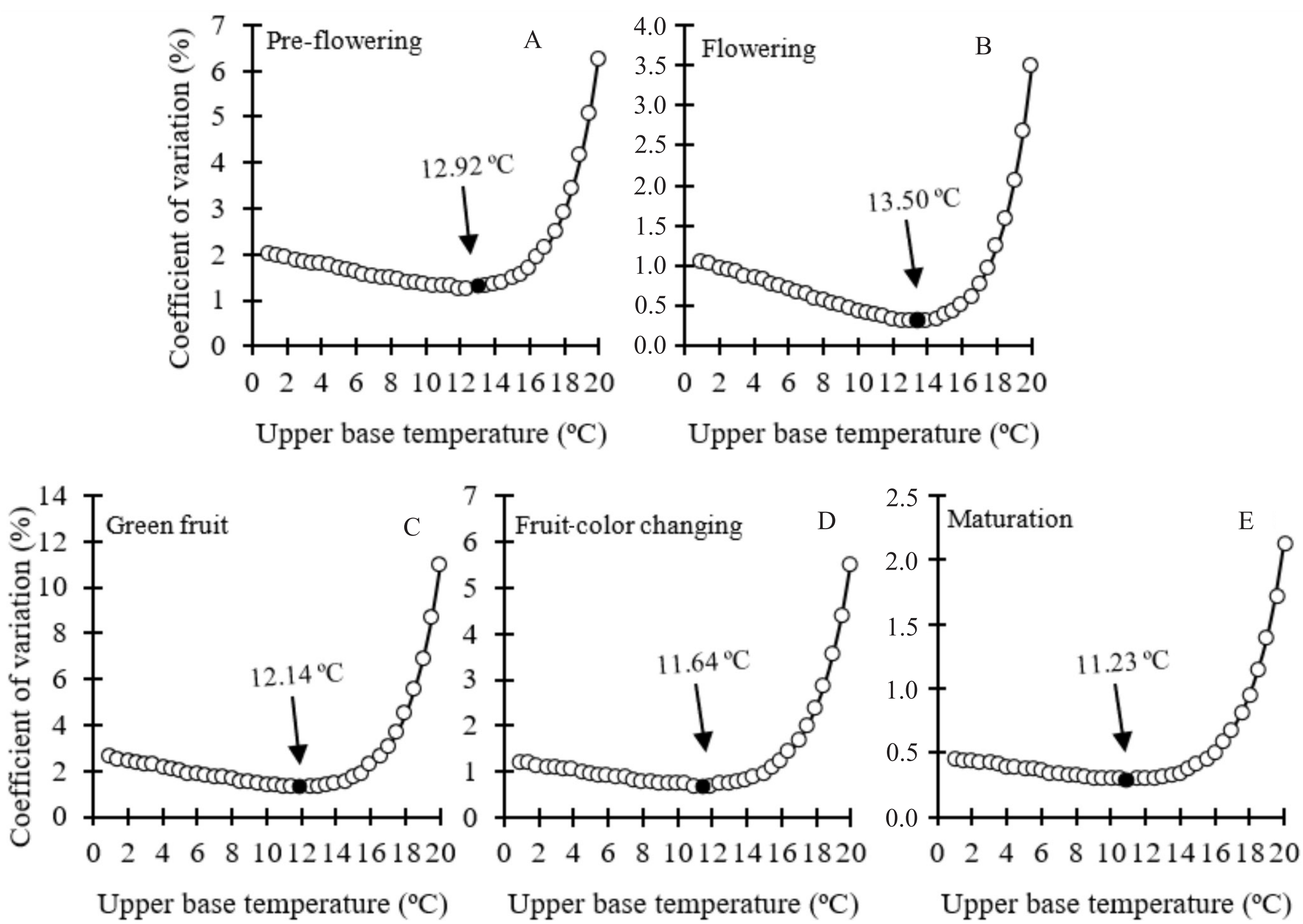

Figure 3. Lower base temperature for the pre-flowering, flowering, green fruit, fruit-color changing, and maturation stages of acai palm (*Euterpe oleracea*) by the method of lowest standard deviation, in degree-days.

flowering stage, 27 days to that of the flowering stage, 119 days to the green fruit stage, 53 days to the fruit-color changing stage, and 15 days to the maturation stage (Table 4). The mean length (in days) of the reproductive growth stages of acai palm found in the present study is longer than that reported by Oliveira et al. (2002), which was of 58, 26, 110, and 65 days, respectively, for the pre-flowering, flowering, green fruit, and fruit-color changing/maturation stages of a common type of acai, cultivated in non-flooded land, without irrigation, in the municipality of Belém, also in the state of Pará.

These different results may be related to the variation in precocity of the genetic material used in both studies, as well as to the environmental conditions in which the experiments were carried out, since, during the less rainy season, water was supplied daily through irrigation in Capitão Poço, but not in the research of Oliveira et al. (2002). A water shortage during the less rainy season of the year could accelerate and shorten the duration of the phenological stages, reducing plant growth, by inhibiting cell growth, and also affecting several physiological processes such as photosynthesis (Mar et al., 2013).

The highest DD coefficient of variation (7.38) was found for pre-flowering (Table 4), which could be associated with the fact that this stage occurs during the transition period from the less rainy to the rainiest season (Figure 2), causing a greater fluctuation between temperatures and, consequently, in the accumulation

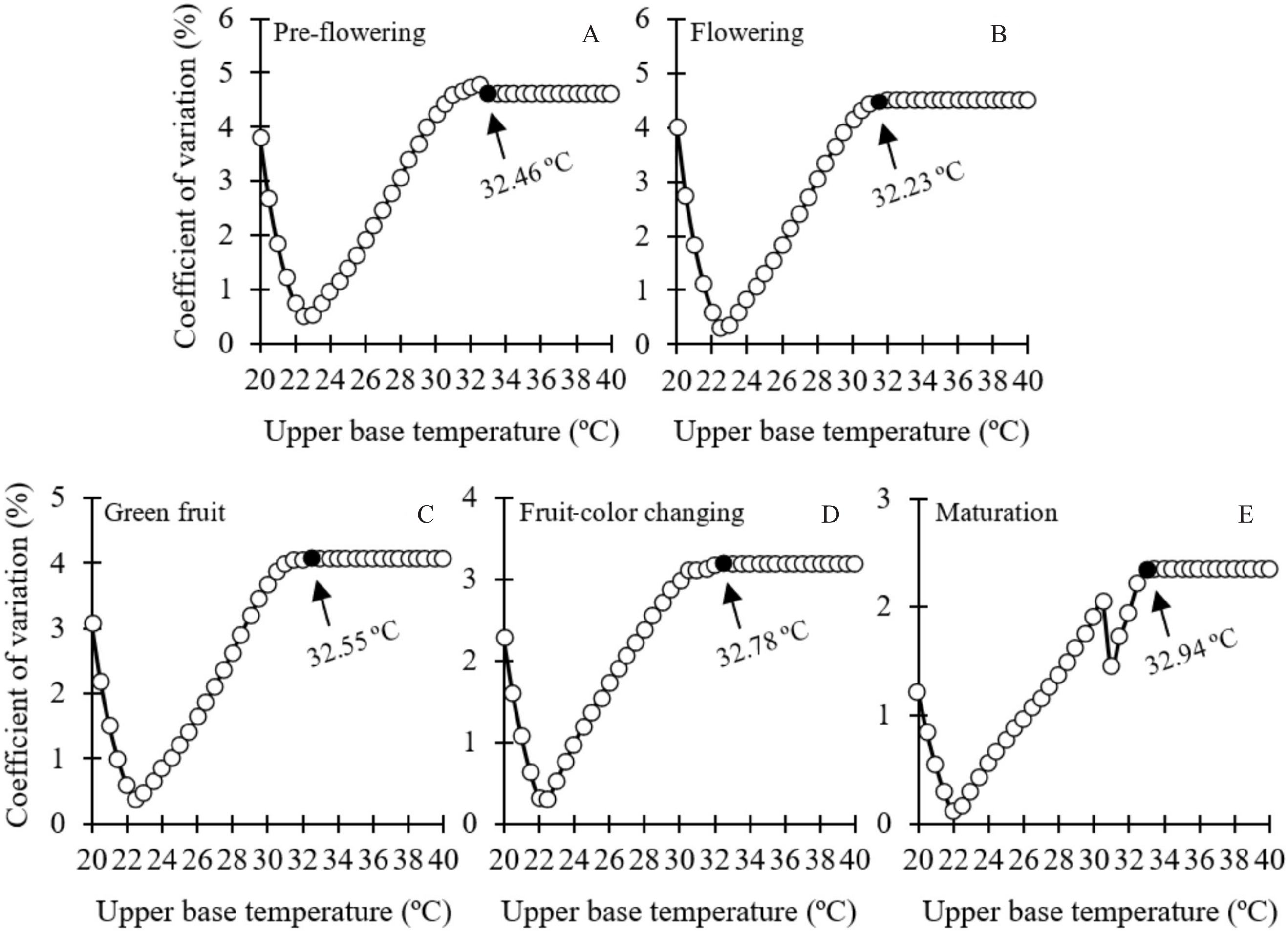

Figure 4. Upper base temperature for the pre-flowering, flowering, green fruit, fruit-color changing, and maturation stages of acai palm (*Euterpe oleracea*) by the method of constant coefficient of variation.

of energy by the plant, in the heat sum, and in cycle length.

The Tb and TB and thermal time requirements found for each stage of development of acai palm in the four different periods evaluated in Capitão Poço were used to simulate acai palm phenology and reproductive cycle length in Castanhal (Table 5).

The simulation of the phenological development of acai palm was based on the DD required to reach each of reproductive stage, from the beginning of the harvest period (pre-flowering) to the ideal harvest time (maturation). An average length of 73, 23, 119, 42, and 15 days was obtained for the pre-flowering, flowering, green fruit, fruit-color changing, and maturation stages, respectively. These results were considered satisfactory due to low estimation errors, with RMSE ranging from 3 days for maturation to about 10 days for pre-flowering (Figure 5).

When contrasting the rainfall regime during the experiments in the two municipalities, it was verified that Capitão Poço received, on average, 1,954 mm of rain, while Castanhal received 1,273 mm, i.e., there was about 34.8% less water available to the soil in Castanhal, resulting in 16.8% soil available water on average.

These differences in the amount of water in the soil influenced the simulation of the lengths of the phenological stages and, consequently, of the total cycle, which culminated in an overestimation of the simulated data, presenting an error of 8.49% for the whole acai palm cycle (Figure 5). This factor may have been determinant to the errors generated by the simulation for Castanhal, since the rainfall conditions were different from those of Capitão Poço. According to Nogueira & Santana (2016), the availability of water in the soil is the main factor interfering with the growth of acai palm in non-flooded areas.

The results obtained in the present study, on base temperatures and thermal time requirements during the different reproductive growth stages of acai palm, are important to predict the adaptability of the crop when subjected to atypical climatic conditions, as well as to plan pest management and fertilization practices in the different stages of plant development.

Table 4. Length in days, degree-days by stage, and accumulated degree-days for the reproductive growth stage of acai palm (*Euterpe oleracea*) in the municipality of Capitão Poço, in the state of Pará, Brazil.

Stage	Length (days)	Degree-day by stage (ºC)	Accumulated degree-day	Standard deviation	Standard error	CV (%)
Pre-flowering	69	957.89	957.89	61.15	19.34	7.38
Flowering	27	372.29	1,330.18	21.06	6.66	5.66
Green fruit	119	1,635.46	2,965.64	105.62	33.40	6.46
Fruit-color changing	53	735.64	3,701.28	40.08	12.67	5.45
Maturation	15	191.87	3,893.15	10.14	3.21	5.28

Table 5. Statistical performance of the simulation of the length of acai palm (*Euterpe oleracea*) reproductive growth stages during the data validation process.

Stage	Rain (mm)	Irrigation (mm)	Observed length (days)	N	Simulated Length (days)	D[(1)]	Dif (%)
Pre-flowering	283.40	8.45	71.03±2.24	6	73.89±6.59	0.62	+0.04
Flowering	95.00	0.00	22.00±2.15	6	23.46±2.75	0.74	+0.06
Green fruit	747.80	0.00	115.33±6.71	6	119.92±5.45	0.63	+0.04
Fruit-color changing	151.20	0.00	41.33±3.82	6	42.71±4.25	0.72	+0.03
Maturation	6.40	0.00	14.00±0.95	6	15.23±1.68	0.76	+0.08

[(1)]Agreement index.

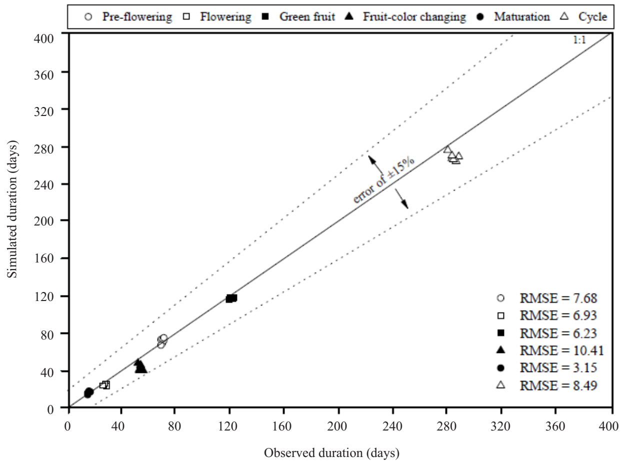

Figure 5. Observed and simulated reproductive phenology of acai palm (*Euterpe oleracea*) in a non-flooded area in the municipality of Castanhal, in the state of Pará, Brazil. RMSE, root mean square error.

Conclusions

1. The thermal time requirement and the length for the acai palm (*Euterpe oleracea*) reproductive growth stages are influenced by the period of the year in which pre-flowering begins and by the variation in air temperature, which, when higher, reduces the cycle of the crop and, when milder, increases it.

2. The base temperatures vary according to the different stages of plant development, with the lower base temperatures ranging from 11.23 to 13.5ºC and the upper ones from 32.23 to 32.94ºC.

3. Of the total energy required for acai palm reproductive growth, 42.00% are used for the green fruit stage, followed by 24.60, 18.90, 9.57, and 4.93% for the pre-flowering, fruit-color changing, flowering, and the maturation stages.

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