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# Seasonal Dynamics of the Phenology of Native Species from the Seasonally Dry Tropical Forest

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## Abstract

Phenological processes are strongly affected by environmental conditions. In this study we investigate the phenological patterns of six tree/shrub species in three *Caatinga* fragments and analyze the influence of rainfall and air temperature on these processes. Circular statistics was used to analyze the vegetative and reproductive phenophases over 12 months (dry and rainy seasons) in the years 2016 to 2017 and 2018 to 2019. Spearman's linear correlation test (r) was applied to verify the influence of meteorological variables of the two years of study on the phenological stages for each species. All species showed a seasonal pattern for vegetative phenophases. Reproductive phenophases were recorded in the two study periods only for one species. There was correlation of the phenophases only with rainfall, but not for all species. The amount of rainfall below the historical average indicates that precipitation is the most limiting factor for flowering in the evaluated species.

**Keywords:** *Caatinga*, air temperature, rainfall, phenophases, Rayleigh test.

## 1. INTRODUCTION AND OBJECTIVES

The Brazilian Dry Forest (*Caatinga*) presents double seasonality, marked by a dry period with great water deficit and another with torrential rains. The biome is composed of a complex set of phytophysiognomies, forming a mosaic of thorny shrubs and seasonally dry forests, predominantly in the semiarid region of northeastern Brazil (Leal et al., 2005; IBGE, 2019).

The *Caatinga* is a seasonally tropical dry forest that is among the richest in plant species diversity (Dryflor et al., 2016), but which has been suffering, over the years, drastic effects caused by the use of unsustainable techniques derived from anthropic action (Araújo et al., 2014; Ribeiro et al., 2019), as well as the fragmentation of the ecosystems. Thus, to support actions related to the management and conservation of this ecosystem, studies are needed to investigate the complex adaptations presented by species in these environments and what modifications they undergo as a result of changes in environmental conditions.

In the *Caatinga* there is great variability in flowering and fruiting patterns between species (Amorim et al., 2009; Souza et al., 2014; Vieira, 2018; UFERSA, 2021), which can vary between years, depending on local environmental factors, which can be more or less severe (Souza et al., 2014). Morellato (2007) consider phenological studies as the main tool for understanding the ecological organization of populations, communities and ecosystems, as well as the distribution and availability of resources.

Some researchers, in an attempt to define the mechanisms that regulate the onset of flowering of plants in tropical

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ecosystems, have linked the phenological behavior of flowering to biotic and abiotic factors. Individual and environmental factors influence the reproductive phenology. Among the individual factors are the leaf anatomy and woody density (Brito et al., 2022); among the environmental ones are drought stress, climate changes and the length of the day (photoperiod) which changes between seasons (Brito et al., 2022; Cecilio-Junior, 2012; Mendoza et al., 2017), being that rainfall can be the main parameter in up to 73% of the variations in the reproductive phenology of Neotropical species (Mendoza et al., 2017).

Studies are essential to understand the vegetative and reproductive phenomena of plants and how biotic and abiotic factors can influence development at each phenological stage (Vilela et al., 2018; Novaes et al., 2020). Furthermore, they make it possible to have knowledge of likely intervals for the occurrence of certain biological events (Ferrera, 2012), which can produce information from individual plants to populations and communities (Biondi et al., 2007). Many studies on plant phenology have been developed using remote sensing, in order to understand the effects of climate change on phenology (Wu et al., 2021; Song et al., 2022). However, field observations are still needed to validate these findings.

Since the *Caatinga* plants have developed physiological modifications to withstand long periods of drought, such as leaf abscission, reduced conductance and transpiration due to stomatal closure (Marques et al., 2020), it is expected that the phenology of the *Caatinga* species be deeply correlated with rainfall and air temperature. In Tropical species, the fundamental phenological drivers are different from Temperate especies and seasonal climate cues are often subtler (Davis et al., 2022). Thus, the objective of this study was to analyze the phenological phases of six plant species in Brazilian Dry Forest fragments, in order to identify vegetative and reproductive patterns, as well as to correlate such patterns with meteorological variables in the dry and rainy seasons of the years 2016-2017 and 2018-2019.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The study was carried out in the municipality of Bom Jesus - PI, which is located between 09º04’28” S and 44º21’31” W at an altitude of 273m, located in a transition area (ecotone) *Cerrado-Caatinga*. The soil of the study area is a Yellow Latosol, with a sandy frank texture. The local climate, according to Köppen’s classification, is Tropical, type Aw, with a dry winter season (Alvares et al. 2013). The research was carried out on a private property, which covers an area of 480 hectares, called Lagoa do Barro.

### 2.2. Climate variables

Rainfall and air temperature data were downloaded from the National Institute of Meteorology website (INMET, 2019), which provides all hourly values recorded by sensors in automatic stations located in the municipality (code A326). These values were transformed into monthly averages for temperature and monthly totals for rainfall. Historical monthly averages of rainfall and average temperature for the municipality of Bom Jesus were also obtained from this same source, which were transformed into annual averages. Although not part of the initial objective, the photoperiod was also analyzed. The daily value was estimated, according to the methodology described by Baldisera & Dallacort (2017), and the monthly averages were made for the years 2016 to 2019, distinguishing the weather seasons.

### 2.3. Field data

Six species in this study (Table 1) were selected from the importance value index, calculated after a phytososiological survey in the area (Ivanov et al., 2022). Twenty individuals per species were randomly marked within the study areas, with circumference at breast height (CBH) ≥ 10 cm and height ≥ 1.5 m.

**Table 1.** Species selected for phenological observations in *Caatinga* in the municipality of Bom Jesus, Piauí, Brazil.

| Family | Species | Habitat | DBH (cm) | h (m) |
|---|---|---|---|---|
| Fabaceae | *Bauhinia ungulata* L. | Riparian Forest | 3.9 | 3.5 |
| Fabaceae | *Lonchocarpus sericeus* (Poir) Kunth ex DC | Riparian Forest | 7.4 | 7.0 |
| Fabaceae | *Mimosa verrucosa* Benth | Shrubby *Caatinga* | 4.5 | 3.8 |
| Salicaceae | *Casearia sylvestris* Sw | Shrubby *Caatinga* | 3.3 | 3.9 |
| Annonaceae | *Annona leptopetala* (R. E. Fr.) H. Raine | Arboreal *Caatinga* | 4.9 | 4.3 |
| Fabaceae | *Piptadenia moniliformis* Benth | Arboreal *Caatinga* | 5.6 | 4.6 |

DBH = diameter at 1.30 m above ground level, h = height.

The phenological phases were expressed monthly for each species analyzed in the dry and rainy seasons of the years 2016/2017 and 2018/2019, with visits carried out fortnightly. The phenophases analyzed were flowering, fruiting, leaf flushing and fall.

## *2.4. Data analysis*

The phenological analyzes were performed using the activity index method, where individuals of each species with the presence or absence of the observed event were recorded. The activity index indicates the percentage of individuals of each species by which the presence or absence of the observed event is verified. In this method, adapted by Castellani et al. (1999), the data are calculated using monthly averages of occurrence according to the number of observations made throughout the phenological year, according to Eq. 1:

$$F(\%) = \frac{n \times 100}{N} \qquad \text{(Eq. 1)}$$

*F (%)* = frequency of occurrence of the i-th species in the i-th phenophase;
*n* = number of individuals in the i-th phenophase;
*N* = total number of individuals of the i-th species.

To test the occurrence of seasonality in the phenophases, circular statistics were used, using the frequency of occurrence of species in the four phenophases. For this, the frequency of occurrence of the phenological event for the total of species per month was calculated. The months were converted into angles, with 0° = the starting month, successively up to 360° = the last month analyzed, in intervals of 30°. The following were considered in the analysis: the sample size (n), related to the number of observation of the event that occurred over the study period for each individual of the species, the length of the vector r, which corresponds to the average concentration of the data around of the year, ranging from 0 to 1 and tested the significance of the angle by the Rayleigh test ($p < 0.05$) to verify whether the phenological phenomena occurred uniformly throughout the study period or if they were concentrated at a certain time of year.

According to Morellato et al. (2010) the Rayleigh test should be avoided when the data are bimodal, so a visual inspection of the data was carried out before applying the test, from circular histograms of frequencies. A bimodal distribution occurs when there are two peaks (modes) on opposite sides of the circular frequency histograms, which was not observed. The ORIANA 4.0 package (Kovach, 2004) was used for the calculation of circular statistics and the plotrix package (Lemon, 2006) of the free software R (R Core Team, 2021) was used to make the graphs. The Watson–Williams was applied when phenophase was observed in both periods.

The mean angles were compared among using the Watson–Williams F-test to determine whether the timing of phenological events (2016/2017 and 2018/2019) differed significantly from each other. The circular package (Agostinelli & Lund, 2022) was used to calculate the Watson–Williams F-test.

Spearman's linear correlation test (r) was applied to verify the influence of meteorological variables of the two years of study on the phenological stages for each species. The ggpubr package (Kassambara, 2020) of the software R (R Core Team, 2021) was used for the analysis and to make the graphics.

# 3. RESULTS AND DISCUSSION

## *3.1. Rainfall and temperature*

The period 16/17, the rainy season was between the months of October 2016 and May 2017, totaled 614mm of rainfall, and the dry season followed from June to September 2017 (Figure 1). In the period 18/19, there was 5.2 mm of rainfall in August, however, the rainy season started in November 2018 and extended until May 2019 (Figure 1), totaling only 379 mm of rainfall.

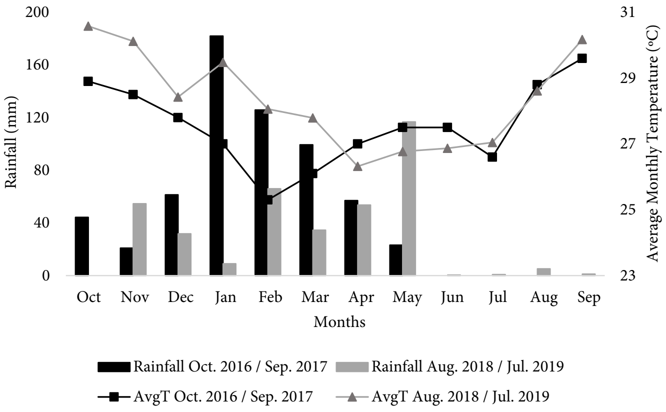

**Figure 1.** Average Temperature and Monthly Rainfall of the municipality of Bom Jesus-PI, Brazil. Seasons 16/17 (October 2016 to September 2017) e seasons 18/19 (August 2018 to July 2019). Data source: INMET (2019).

The average temperature was 27.26 °C (16/17) and 27.91 °C (18/19) in the rainy periods and 28.12 °C (16/17) and 28.65°C (18/19) in the dry periods. It ranged from 25.3°C (February) to 29.6 °C (September) in seasons 16/17 (Figure 1) and from 26.3°C (April) to 30.5 °C (October) in seasons 18/19 (Figure 1), thus in the period 18/19 it was 0.8°C higher than in 16/17, considering the annual average of the two periods.

Annual rainfall and average temperatures of the studied periods were compared to historical values (1981-2010) (Figure 1). The historical average annual temperature is 27.7±0.96 °C, while the average for the period 16/17 was 27.5±1.25 °C and in 18/19 it was 28.3±1.47 °C. As for rainfall, what is observed is a trend of higher monthly HA values compared to the evaluated periods, the exceptions are in January 2017, when it rained more, and in May 2019, when it rained less (Figure 1). The historical average for the municipality is 986.1 mm of annual rainfall, thus, both studied years had lower rainfall than HA.

## *3.2. Vegetative phenophases*

Individuals of the six species studied showed seasonal patterns for vegetative phenophases (leaf flushing and leaf fall), with r values ranging from 0.2 to 0.8 and significant Rayleigh test ($p < 0.05$) (Tables 2 and 3). Leaf fall was observed for the six species evaluated over the two study periods, with the average date of this phenomenon being from April to July (transition from the rainy to the dry season).

*L. sericeus* is deciduous, with 100% of the individuals in leaf fall from June to August (Figure 2). *B. ungulata* is also deciduous. In the period 16/17 it was found in this phenophase from January to September, with more than 80% of frequency, while in 18/19 this percentage was registered only from July to October. The leaf flushing occurs predominantly in November and December (Figure 2).

**Table 2.** Analysis of circular statistics of phenophases evaluated in *Caatinga*, from October 2016 to September 2017.

| Species | Phenophase | Avg Date (month) | Avg Angle | ALVR | Rayleigh Test (Z) |
|---|---|---|---|---|---|
| *Lonchocarpus sericeus* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | November | 304.792° | 0.81 | 19.55* |
| | leaf fall | April | 90.000° | 0.48 | 0.48* |
| *Bauhinia ungulata* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | December | 332.979° | 0.75 | 14.08* |
| | leaf fall | April | 97.393° | 0.30 | 0.30* |
| *Mimosa verrucosa* | flowering | May | 130.208° | 0.78 | 13.33* |
| | fruiting | June | 165.000° | 0.98 | 15.27* |
| | leaf flushing | December | 330.082° | 0.55 | 13.89* |
| | leaf fall | April | 107.026° | 0.51 | 14.14* |
| *Casearia sylvestris* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | November | 307.460° | 0.57 | 14.28* |
| | leaf fall | April | 104.450° | 0.50 | 13.54* |
| *Annona leptopetala* | flowering | - | - | - | - |
| | fruiting | April | 180.000° | 1.00 | 1.00* |
| | leaf flushing | December | 339.563° | 0.59 | 21.55* |
| | leaf fall | May | 139.008° | 0.83 | 24.50* |
| *Piptadenia moniliformis* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | December | 341.248° | 0.57 | 7.72* |
| | leaf fall | May | 123.068° | 0.62 | 7.48* |

Avg = average; ALVR = Average length of the vector R; * = Significance test, $p < 0.05$.

**Table 3.** Analysis of circular statistics of phenophases evaluated in *Caatinga* from August 2018 to July 2019.

| Species | Phenophase | Avg Date (month) | Avg Angle | ALVR | Rayleigh Test (Z) |
|---|---|---|---|---|---|
| *Lonchocarpus sericeus* | flowering | November | 300.000º | 1,00 | 4.00* |
| | fruiting | - | - | - | - |
| | leaf flushing | December | 344.243º | 0.46 | 18.954* |
| | leaf fall | July | 160.570º | 0.30 | 13.207* |
| *Bauhinia ungulata* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | January | 1.523º | 0.46 | 19.307* |
| | leaf fall | July | 181.523º | 0.28 | 12.001* |
| *Mimosa verrucosa* | flowering | May | 123.068º | 0.94 | 8.932* |
| | fruiting | June | 165.000º | 0.98 | 57.637* |
| | leaf flushing | January | 10.771º | 0.41 | 17.856* |
| | leaf fall | July | 206.972º | 0.30 | 11.053* |
| *Casearia sylvestris* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | December | 351.186º | 0.53 | 22.507* |
| | leaf fall | July | 171.186º | 0.26 | 11.253* |
| *Annona leptopetala* | flowering | - | - | - | - |
| | fruiting | February | 45.000º | 0.85 | 5.728* |
| | leaf flushing | January | 15.318º | 0.55 | 32.723* |
| | leaf fall | July | 198.243º | 0.53 | 35.082* |
| *Piptadenia moniliformis* | flowering | - | - | - | - |
| | fruiting | - | - | - | - |
| | leaf flushing | January | 0.582º | 0.56 | 29.929* |
| | leaf fall | July | 180.582 | 0.37 | 19.609* |

Avg = average; ALVR = Average length of the vector R; * = Significance test, p < 0.05.

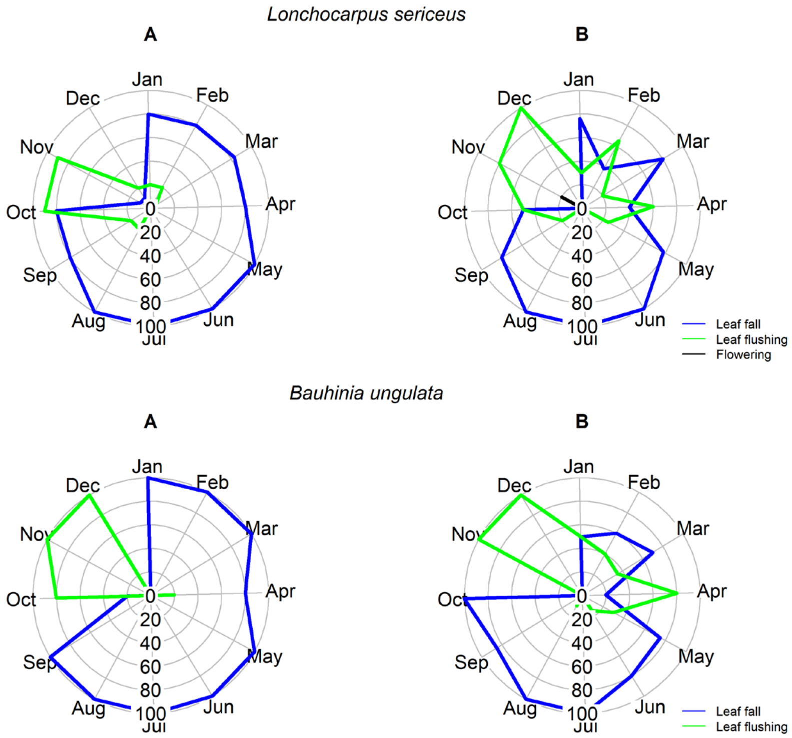

**Figure 2.** Circular histogram of phenophase frequency for seasons 16/17 (A) and 18/19 (B) for *L. sericeus* and *B. ungulata* species.

For *M. verrucosa*, 100% frequency of leaf fall was only recorded in December 2016, when no other species presented this phenophase, and from August to October 2018 (Figure 3), following the phenological behavior of the other species analyzed. The leaf flushing took place in the rainy season in both periods of study, but with a difference in relation to the months with higher frequency: February to May in 16/17 and November to December in 18/19. *C. sylvestris* showed high frequency leaf fall (80% or more) from May to September, in the period 16/17, and from May to October, in 18/19.

In the months of November and December, *C. sylvestris* individuals presented 100% of leaf flushing, in both periods evaluated (Figure 3). *C. sylvestris* occurs in a wide range of ecosystems, from restinga forests to *caatingas* or even in rainforests, in all states of the country (REFLORA, 2020), indicating a broad niche. Naturally, the different environmental conditions existing in different regions lead to variations in the phenological pattern (Bencke & Morellato 2002). The flowering of the species occurs in different months, depending on the environment in which it is inserted (Pissato, 2016), which is common in tropical species.

*A. leptopetala* and *P. moniliformis* presented very similar vegetative phenophases (Figure 4). A frequency of 100% of individuals was recorded in the leaf fall from May to September (16/17) and from July to October (18/19), and leaf flushing was more frequent from October to February (16/17) and in November and December (18/19) (Figure 4). Figueiredo-Lima et al. (2018) reported for *A. leptopetala*, in an area of seasonally dry tropical forest, that leaf fall occurred in the month of July, a wet-dry transition period, with increased levels of abscisic acid (ABA), and regrowth of leaves began with the first rains of January, with the reduction of the ABA. These findings reveal the influence of soil water content, which is correlated with rainfall intensity and duration of the rainy season, on the physiological processes of the species, and consequently on the phenological behavior.

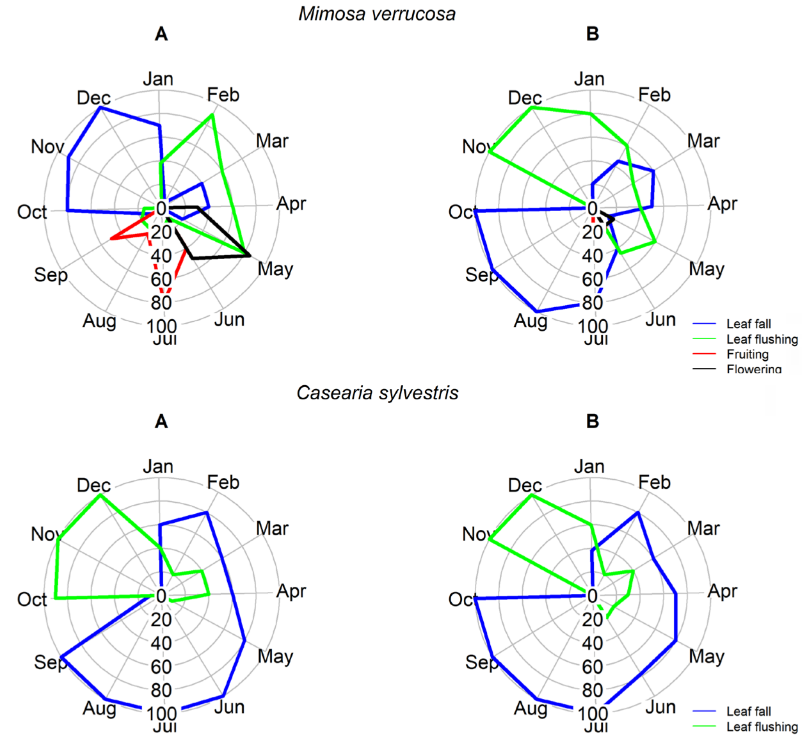

**Figure 3.** Circular histogram of phenophase frequency for seasons 16/17 (A) and 18/19 (B) for *M. verrucosa* and *C. sylvestris* species.

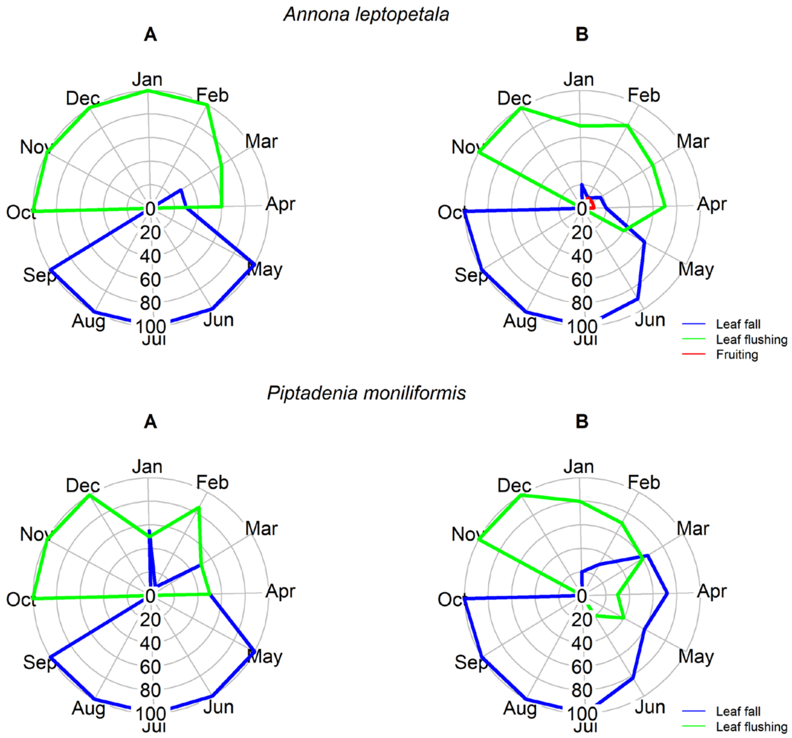

**Figure 4.** Circular histogram of phenophase frequency for seasons 16/17 (A) and 18/19 (B) for *A. leptopetala* and *P. moniliformis* into *Caatinga.*

## *3.3. Reproductive phenofases*

The reproductive phenophases were registered only for *M. verrucosa*, *L. sericeus* and *A. leptopetala*, with r values ranging from 0.7 to 1.0, indicating a highly seasonal pattern (Tables 2 and 3). The Rayleigh test was significant ($p < 0.05$) (Tables 2 and 3), showing that the occurrence of phenomena (flowering and/or fruiting) are concentrated with higher frequencies in a given season of the year for species that manifested the events. *M. verrucosa* flowered from April to June (autumn) and fruited from June to September (winter). *L. sericeus* just registered flowering, in November (spring). For *A. leptopetala*, only fruiting was recorded in the months of March and April (autumn), indicating that its fruiting took place in the Summer and quickly.

*M. verrucosa* was the only species whose reproductive phenophases were recorded in the two periods of study (Figure 3). However, the frequency of individuals flowering on 16/17 was higher (reaching more than 80% in May) than on 18/19 (with just over 20% of individuals showing phenophase in May) (Figure 3). This species is heliophyte, widely disseminated by the different phytophysiognomies of the *Caatinga*, pioneer in secondary succession, growing well on the roadside (UFERSA, 2021). Thus, in general, the study area is favorable to the physiological processes of the species.

For *A. leptopetala*, flowering was not recorded, only fruiting was observed in the in the months of April and May 2019 (Figure 4), the end of the rainy season. Lorenzi (2009) highlights that the species blooms during almost the entire rainy season, which was not found in this research, and the ripening of the fruits occurs from March onwards. It is valid to report the manifestation of this event in other individuals of this species that were not sampled in the area, which were found close to clearings. Thus, being a heliophyte species (Lorenzi 2009), such individuals may be investing more in vegetative growth, and competing for light (Araújo et al., 2014), than in reproduction, since it is found in the arboreal physiognomy of the studied *Caatinga*.

For *L. sericeus*, only 20% of individuals bloomed in one of the study periods (November 2018) (Figure 2). Flowering may have occurs in a short period, not being possible to record it for almost all individuals or did not occur in the other individuals analyzed. The evaluated individuals of this species were in riparian forest, which suffers flooding in years with greater volume of rain. Even so, it survives well by developing anatomical adaptations. The month in which the species was found blooming refers to the beginning of the rainy period, when there is still no flooding in the area. Pott & Pott (1994) describe the species as a pioneer, xerophilic, occurring in sandy soils of the *Caatinga* and in riparian forest, which bloom from November to April. Since the amount of rainfall in November 2018 was double the same month in 2016, it is possible that it found better moisture conditions that year and therefore it flourished, although for few individuals.

At mid-latitudes (23º S), the day length in summer and autumn is longer than in winter-spring, reaching a difference of three hours (Cecílio-Junior, 2012). However, at low latitudes (as in the case of the study area) this difference becomes less pronounced and, thus, the effect of the day length is smaller, which makes the species less sensitive to this factor, and may until there are species that are not sensitive to photoperiod (Körner & Basler, 2010). The entry of light into plants is detected by phytochromes (protein pigments) that help to perceive the oscillations in the circadian clock in the activity of proteins that act as sensors of day length, which activate genes that induce flowering (Ding & Nilsson, 2016). Day length in the study area is longer between spring and summer (12.39 and 12.26h) and shorter between autumn and winter (11.61 and 11.74h) (Figure 5). Flowering of the species occurred in autumn for *M. verrucosa*, with a shorter photoperiod, in spring for *L. sericeus* and summer for *A. leptopetala*, with a longer one. Thus, it appears that, apparently, the variations between seasons in the length day is not the primary factor influencing the flowering of these plants in *Caatinga*.

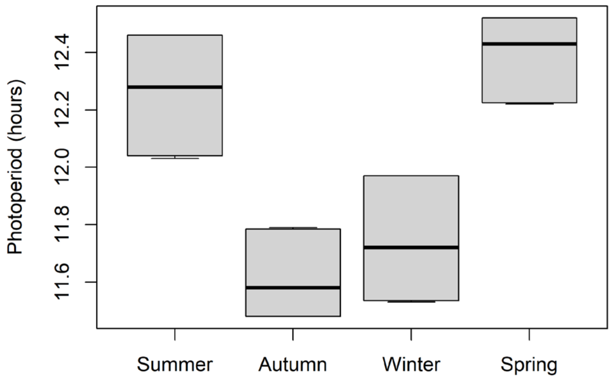

**Figure 5.** Photoperiod by weather seasons for the municipality of Bom Jesus, Piaui. Average for the years 2016 to 2019. The bars represent the standard deviation.

Silva et al. (2020) observed that species of the *Caatinga* could flower and fruit in different periods: some in the rainy season, others in the dry season, which works as a strategy to avoid competition for pollinators and fruit dispersers. On the other hand, Lima et al. (2021) reveal that deciduous low wood density species have their phenophases regulated by the availability of soil water and the high wood density species by the photoperiod. This implies that the factors most influence will vary depending on the individuals characteristics of the species.

The average angles of vegetative phenophases (leaf fall and flushing) differed significantly ($p < 0.001$) between periods (16/17 and 18/19) for all species (Table 4). For the reproductive phenology (flowering and fruiting) of the *M. verrucosa*, the only one that flowered in both study periods, the mean angles also differed significantly ($p < 0.001$) (Table 4). This indicates that there is some factor that was differentiated between the periods evaluated which affected the interannual phenology of the species.

**Table 4.** Watson-Williams test (F) for the comparisons of mean angles between seasons 16/17 and 18/19 of six species of the *Caatinga*.

| Phenophase | Species | Watson–Williams F-test | p-value |
|---|---|---|---|
| Flowering | *Mimosa verrucosa* | 0.65 | < 0.001 |
| Fruiting | *Mimosa verrucosa* | 1.43 | < 0.001 |
| Leaf fall | *Lonchocarpus sericeus* | 0.47 | < 0.001 |
|  | *Bauhinia ungulata* | 0.92 | < 0.001 |
|  | *Annona leptopetala* | 1.73 | < 0.001 |
|  | *Pipitadenia moliniforme* | 1.18 | < 0.001 |
|  | *Casearia sylvestris* | 0.69 | < 0.001 |
|  | *Mimosa verrucosa* | 1.53 | < 0.001 |
| Leaf flowering | *Lonchocarpus sericeus* | 1.36 | < 0.001 |
|  | *Bauhinia ungulata* | 1.48 | < 0.001 |
|  | *Annona leptopetala* | 1.45 | < 0.001 |
|  | *Pipitadenia moliniforme* | 1.04 | < 0.001 |
|  | *Casearia sylvestris* | 1.27 | < 0.001 |
|  | *Mimosa verrucosa* | 0.95 | < 0.001 |

## 3.4. Phenology vs climatological data

Temperature and rainfall are two environmental conditions that have a strong influence on plant physiology. In the *Caatinga*, where most plant species are deciduous, the leaf fall is a fundamental adaptation for their survival. Thus, when soil water decreases and air and soil temperatures rise, the water potential in plants becomes more negative, leading them to water stress (Trovão et al. 2007), which respond with leaf abscission as a water loss prevention measure.

In the period of 16/17 the species lost their leaves earlier (April and May) than in 18/19 (June and July). This is especially due to the intensity of the rains that occurred in May 2019, the wettest month of that year (Figure 1) which led to greater soil water availability and later leaf fall, as soil water availability it is one of the main factors influencing phenology (Paloschi et al. 2021).

The fact that the species exhibit a high synchrony in the leaf flushing, between October and December (16/17) and in November and December (18/19), is attributed to water availability, through rainfall at the beginning of the rainy season (October/16 and November/18), as both deciduous and perennial species await this availability to activate their leaf production mechanisms, at least more intensely (Souza et al. 2014).

Some species were not found in reproductive phenophases in the two periods evaluated, which suggests that either the environmental conditions are not favorable or the resources are scarce, which leads to interactions of competition and can potentialize the low energy investment in reproduction. Variations in temperature and in the amount of rainfall between years can lead to earlier or later flowering in plants, as demonstrated by Pissato (2016), a fact that can also be understood for other phenophases. Leite and Machado (2010) analyzed 15 plant species of *Caatinga* and observed that all flowered in the evaluated period (April /2004-April /2005), most of them in the dry period, in one of the most arid regions of Northeastern Brazil, with annual rainfall of 330 mm per year$^{-1}$. However, the species evaluated in this study are not included in those authors' study. On the other hand, Machado et al. (1997) observed different flowering and fruiting patterns among the analyzed species in *Caatinga*, with an average rainfall of 803 mm yr$^{-1}$, with some species that did not produce flowers or fruit in the two years of analysis, while others produced flowers and fruits in just one year of study. The species evaluated in this study were also not on the list of the cited authors. These data seem to lead to the conclusion that *caatingas* with greater water availability (as in this study, in Machado et al. 1997 and Amorim et al. 2009) can lead to greater irregularity in reproductive phenophases than in those with less rainfall (such as in Leite & Machado 2010).

There was no correlation between vegetative phenophases and temperature, while there was for rainfall only for some species (Figure 6), differing from the observations by Neves et al. (2022), who found a negative correlation between rainfall and leaf fall, for all analyzed species in different phenological groups (brevideciduous, deciduous and evergreen). As for leaf fall, only the two species (*A. leptopetala* and *P. moniliformis*) (Figure 6) showed correlation (r = -0.73, p = 0.000061 and r = -0.67, p = 0,00031, respectively), demonstrating that in periods with absence or low rainfall the number of individuals in this phenophase was maximum. As for leaf flushing, *M. verrucosa* (r = 0.42, p = 0.039), *P. moniliformi* (r = 0.67, p = 0.0031), and *A. leptopetala* (r = 0.73, p = 0.000044) were correlated with rainfall (Figure 6), indicating that a higher frequency of individuals in the leaf flushing stage is related to increases in monthly rainfall.

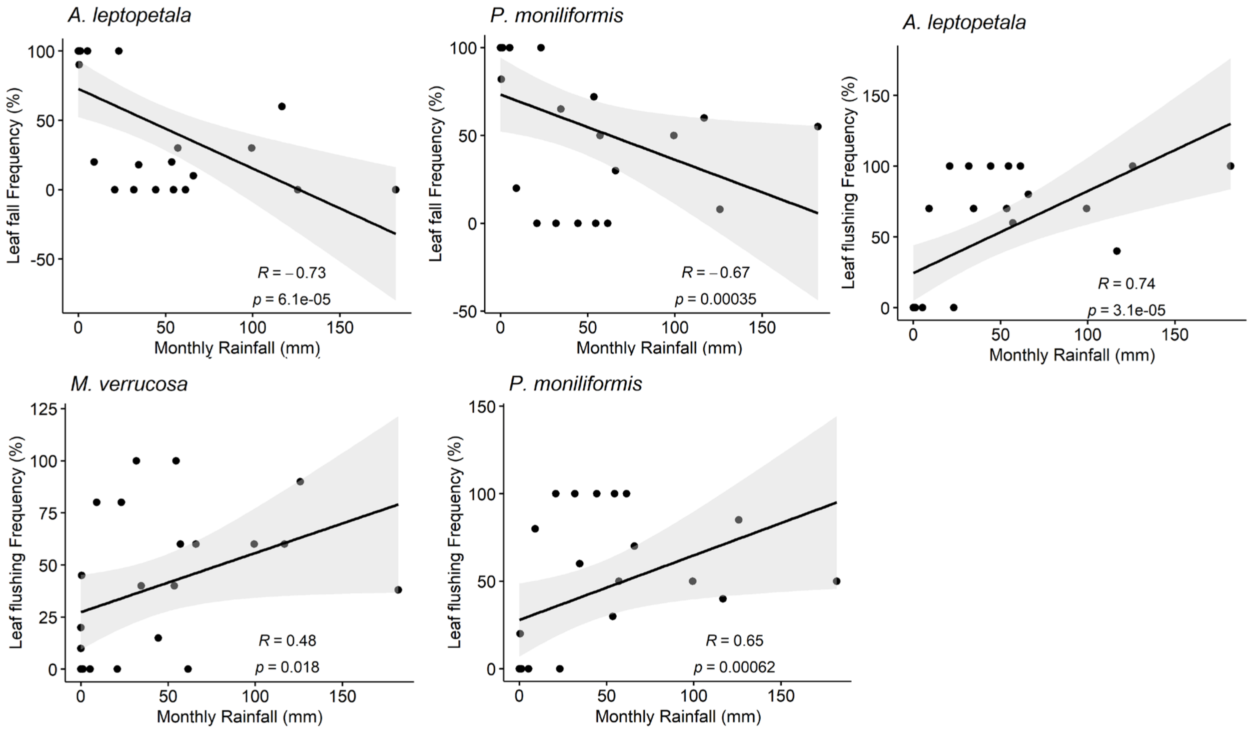

**Figure 6.** Linear correlation between frequency of vegetative phenophases (leaf fall and flushing) and rainfall for three species from the *Caatinga*.

There was no correlation of reproductive phenophases with temperature or rainfall. However, the effect of seasonality (dry/rainy periods) was striking on phenophases and, as in the quote by Paloschi et al. (2021) above, it is possible that soil water content has more effect on phenology than the variations that occur in rainfall and temperature each month.

It is necessary to emphasize that total rainfall in the two years evaluated is below the historical average. The study area is in transition zone (ecotone) *Caatinga-Cerrado*; thus, rainfall levels are higher than in *caatinga stricto sensu* (around 300mm). Since the evaluated species are adapted to the highest annual rainfall (defined by the historical average), the rainfall in the years of this study, 36.4% (16/17) and 60.7% (18/19) lower than the historical average – which may be linked to droughts that occurs during El Niño Southern Oscilation (ENSO) that impacts vegetation dynamics (Pereira et al., 2020), may have been the main factor limiting the reproduction of the analyzed plants.

## 4. CONCLUSIONS

The differences in the occurrence and intensity of the phenological phases point to a strong influence of environmental factors. Our main hypothesis was that air temperature and precipitation were the main parameters. There was no influence of the air temperature on vegetative or reproductive phenophases. Rainfall influenced the vegetative phenophases only in three analyzed species and, in this aspect, it is possible that soil moisture has more influence than rainfall. In view of these results, explanations were still sought in photoperiod data, but no relationship was found between the flowering of the species and the length day. Finally, the amount of rain below the historical average may have greatly limited the flowering of the species in the two periods evaluated.

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## REFERENCES

Agostinelli C, Lund U. R package 'circular': Circular Statistics (version 0.4-95). CA: Department of Environmental Sciences, Informatics and Statistics, Ca'Foscari University, Venice, Italy. UL: Department of Statistics, California Polytechnic State University, San Luis Obispo, California, USA 2022.

Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 2013; 22(6): 711-728. Doi: 10.1127/0941-2948/2013/0507.

Amorim IL, Sampaio EVSB, Araujo EL. Fenologia de espécies lenhosas da caatinga do Seridó, RN. Revista Árvore 2009; 33(3): 491-499. Doi: 10.1590/S0100-67622009000300011.

Araújo VKR, Santos DM, Santos JMFF, Lima KA, Souza DNN, Araújo EL. Influência do status da floresta e da variação sazonal sobre o banco de sementes no semiárido brasileiro. Gaia Scientia 2014; 8(1):136 -149. Doi: 10.21707/GS.V8I1.19674.

Baldisera RS, Dallacort R. Influência das variáveis climáticas - declinação solar, fotoperíodo e irradiação no topo da atmosfera, em regiões agricultáveis do Brasil. Revista De Ciências Agroambientais 2017; 15(2): 108–115. https://doi.org/10.5327/rcaa.v15i2.1964

Bencke CSC, Morellato LPC. Estudo comparativo da fenologia de nove espécies arbóreas em três tipos de floresta atlântica no sudeste do Brasil. Revista Brasileira de Botânica 2002; 25(2): 237-248. Doi: 10.1590/S0100-84042002000200012.

Biondi D, Leal L, Batista AC. Fenologia do florescimento frutificação de espécies nativas dos Campos. Acta Scientiarum Biological Sciences 2007; 29(3): 269-276.

Brito NDS, Medeiros MJS, Souza ES, Lima ALA. Drought response strategies for deciduous species in the semiarid Caatinga derived from the interdependence of anatomical, phenological and bio-hydraulic atributes. Flora 2022; 288:152009. Doi: 10.1016/j.flora.2022.152009.

Castellani TT, Caus CA, Vieira, S. Fenologia de uma comunidade de duna frontal no sul do Brasil. Acta Botânica Brasilica 1999; 13(1):99-114. Doi: 10.1590/S0102-33061999000100009

Cecílio-Junior EP. A study on the chance in the lenght of the day during the year for each local latitude. Simposio Nacional de Educação em Astronomis, II, São Paulo, 2012.

Davis CC, Lyra GM, Park DS, Aspirino R, Maruyama R, Torquato D, et al. New directions in tropical phenology. Trends in Ecology & Evolution 2022; Doi: doi.org/10.1016/j.tree.2022.05.001

Ding J, Nilsson O. Molecular regulation of phenology in trees – because the seasons they are a-changin'. Current Opinion in Plant Biology 2016; 29:73-79. Doi: 10.1016/j.pbi.2015.11.007

Dryflor KBR, Delgado-Salinas A, Dexter KG, Linares-Palomino R, Oliveira-Filho A, Prado D, et al. Plant diversity patterns in neotropical dry forests and their conservation implications. Science 2016; 353(6306):183-1387. Doi: 10.1126/science.aaf5080

Ferrera TS. Fenologia de espécies arbóreas nativas no jardim botânico da Universidade Federal de Santa Maria, Santa Maria – RS [dissertation]. Rio Grande do Sul: Universidade Federal de Santa Maria; 2012.

Figueiredo-Lima KV, Pereira S, Falcão HM, Arruda ECP, Albacete A, Lima Ala et al. 2018. Stomatal conductance and foliar phytohormones under water status changes in *Annona leptopetala*, a woody deciduous species in tropical dry forest. Flora 2018; 242: 1-7. Doi: 10.1016/j.flora.2018.02.010.

Instituto Brasileiro de Geografia e estatística (IBGE). Biomas e sistema costeiro marinho do Brasil Compatível com a escala 1:250 000. Rio de Janeiro; 2019.

Instituto Nacional de Metereologia (INMET). BDMEP: Dados Históricos. 2019.

Ivanov MMM, Santos, JS. Leite, RS. Maria, DMB. Karasinski, MA. Dissimilaridade Florística entre Três Fitofisionomias de Caatinga. In: Jesus RL, editor. Ciências botânicas: Evolução e diversidade de plantas 2. 2ed. Ponta Grossa, Paraná: Atena Editora, 2022. https://doi.org/10.22533/at.ed.6362214023

Kassambara A. 2020. Ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.4.0. https://CRAN.R-project.org/package=ggpubr. Accessed 22 Out 2021.

Körner C, Basler D. Phenology under global warming. Science 2010; 327(5972):1461-1462. Doi: 10.1126/science.11864

Kovach WL. Oriana for Windows. Kovach Computing Services 2004.

Leal IR, Silva JM, Tabarelli M, Lacher Jr TE. Mudando o curso da conservação da biodiversidade na Caatinga do Nordeste do Brasil. Megadiversidade 2005; 1(1):139-146.

Leite AVL, Machado IC. Reproductive biology of woody species in Caatinga, a dry forest of northeastern Brazil. Journal of Arid Environments 2010; 74(11):1374-1380. Doi: 10.1016/j.jaridenv.2010.05.029.

Lemon J. Plotrix: a package in the red light district of R. R-News 2006; 6:8-12.

Lima ALA, Rodal MJN, Castro CC, Antonino ACD, Melo AL, Souza TG, Sampaio EVSB. Phenology of high- and low-density wood deciduous species responds differently to water supply in tropical semiarid regions. Journal of Arid Environments 2021; 193:104594. Doi: 10.1016/j.jaridenv.2021.104594

Lira JMS, Ferreira RA, Silva-Júnior CD, Santos-Neto EM, Santana WS. Análise de crescimento e trocas gasosas de plantas de Lonchocarpus sericeus (Poir) D.C. sob alagamento para uso na recuperação de matas ciliares. Ciência Florestal 2013; 23: 655-665. Doi: 10.5902/1980509812349.

Lorenzi H. Árvores brasileiras: manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Editora Plantarum; 2009.

Machado ICS, Barros LM, Sampaio EVSB. Phenology of Caatinga species at Serra Talhada, PE, Northeastern Brazil. Biotropica 1997; 29(1):57-68. Doi: 10.1111/j.1744-7429.1997.tb00006.x.

Marques TV, Mendes K, Mutti P, Silva L, Perez-Marin AM, Campos S, et al. Environmental and biophysical controls of evapotranspiration from seasonally dry tropical forests (Caatinga) in the Brazilian semiarid. Agricultural and Forest Meteorology 2020; 287:107957. Doi: 10.1016/j.agrformet.2020.107957

Mendoza I, Peres CA, Morellato LPC. Continental-scale patterns and climatic drivers of fruiting phenology: A quantitative Neotropical review. Global and Planetary Change, 148, 227-241. v. 148, p. 227-241, 2017.

Morellato LPC, Alberti LF, Hudson IL. Applications of Circular Statistics in Plant Phenology: a Case Studies Approach. In I. L. Hudson & M. R 2010.

Morellato LPC. A pesquisa em fenologia na América do Sul, com ênfase no Brasil, e suas perspectivas atuais. In: Rego, GM. Negrelle, RB. Morellato, LPC. Fenologia como ferramenta para conservação e manejo de recursos vegetais. Curitiba: EMBRAPA, 2007.

Neves SPS, Santos MGM, Vitoria AP, Rossato DR, Miranda Ld'AP, Funch LS. The roles of functional traits in canopy maintenance along a savanna/seasonally dry tropical forest gradient in northeastern Brazil. Flora 2022; 292(152090). Doi: 10.1016/j.flora.2022.152090

Novaes LR, Calixto ES, Oliveira ML, Alves-de-Lima L, Almeida O. Torezan-Silingardi, HM. Environmental variables drive phenological events of anemocoric plants and enhance diaspore dispersal potential: A new wind-based approach. Science of the Total Environment 2020; 730, 139039.

Paloschi RA, Ramos DM, Ventura DJ, Souza R, Souza E, Morellato LPC et al. Environmental drivers of water use for caatinga woody plant species: combining remote sensing phenology and sap flow measurements. Remote Sensing 2021; 13(1):75. Doi: 10.3390/rs13010075.

Pereira MPS, Mendes KR, Justino F, Couto F, Silva AS, Silva DF, Malhado ACM. Brazilian Dry Forest (Caatinga) response to multiple ENSO: the role of Atlantic and Pacific Ocean. Science of the Total Environment 2020; 705(135717). Doi: 10.1016/j.scitotenv.2019.135717

Pissato M. Fenologia reprodutiva de *Prunus myrtifolia* (L.) Urb. e *Casearia sylvestris* Sw em clima subtropical no sul do Brasil [dissertation]. Rio Grande do Sul, Universidade Federal de Santa Maria; 2016.

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing [cited 2021 jan. 1]. Available from: https://www.R-project.org/.

Reflora. Salicaceae in Flora do Brasil 2020. [cited 2021 mar. 24]. Available from: http://floradobrasil.jbrj.gov.br/reflora/floradobrasil/FB214.

Ribeiro EM, Lohbeck M, Santos BA. Arroyo- Rodríguez, V. Tabarelli, M. Leal, I. R. Functional diversity and composition of Caatinga woody flora are negatively impacted by chronic anthropogenic disturbance. Journal of Ecology 2019; 107(5):2291-2302. Doi: 10.1111/1365-2745.13177.

Silva EEM, Paixão VHF, Torquato JL, Lunardi DG, Lunardi VO. Fruiting phenology and consumption of zoochoric fruits by wild vertebrades in a seasonally dry tropical forest in the Brazilian Caatinga. Acta Oecologica 2020; 105(103553). Doi: 10.1016/j.actao.2020.103553.

Song G, Wu S, Lee CK, Serbin SP, Wolfe BT, Ng MK, Wu J. Monitoring leaf phenology in moist tropical forests by applying a superpixel-based deep learning method to time-series images of tree canopies. ISPRS Journal of Photogrammetry and Remote Sensing 2022; 183:19-33. Doi: 10.1016/j.isprsjprs.2021.10.023.

Souza DNN, Camacho RGV, Melo JIM, Rocha LNG, Silva NF. Estudo fenológico de espécies arbóreas nativas em uma unidade de conservação de caatinga no Estado do Rio Grande do Norte, Brasil. Revista Biotemas 2014; 27:31-42. Doi: 10.5007/2175-7925.2014v27n2p31.

Trovão DMBM, Fernandes PD, Andrade LA, Dantas-Neto J. Variações sazonais de aspectos fisiológicos de espécies da Caatinga. Revista Brasileira de Engenharia Agrícola 2007; 11:307-311. Doi: 10.1590/S1415-43662007000300010.

Universidade Federal Rural Do Semiárido (UFERSA). Projeto Caatinga: Revivendo o Semiárido [cited 2021 jul. 22]. Available from: https://projetocaatinga.ufersa.edu.br/.

Vieira DD. Flora of Rio Grande do Norte, Brazil: Boraginales. Phytotaxa 2018; 357(4):235-260. Doi: 10.11646/phytotaxa.357.4.1.

Vilela AA, Del Claro VTS, Torezan-Silingardi HM, Del-Claro K. Climate changes affecting biotic interactions, phenology, and reproductive success in a savanna community over a 10-year period. Arthropod-plant interactions 2018; 12(2):215-227.

Wu W, Sun Y, Xiao K, Xin, Q. Development of a global annual land surface phenology dataset for 1982–2018 from the AVHRR data by implementing multiple phenology retrieving methods. International Journal of Applied Earth Observation and Geoinformation 2021; 103:0102487. Doi: 10.1016/j.jag.2021.102487.