PHENOLOGICAL SYNCHRONICITY OF *Byrsonima pachyphylla* A. JUSS. AND *B. verbascifolia* (L.) DC. (MALPIGHIACEAE) AND ITS RELATION WITH CLIMATE SEASONALITY

Andressa Cavalcante Meireles[2*], Ageu da Silva Monteiro Freire[3], Wagner de Melo Ferreira[4] and Rodney Haulien Oliveira Viana[4]

[1] Received on 01.02.2023 accepted for publication on 25.07.2023.
[2] Universidade Federal do Rio Grande do Norte, Programa de Pós-Graduação em Ecologia, Natal, RN - Brasil. E-mail: <andressa.meireles.075@ufrn.edu.br>.
[3] Universidade Federal do Paraná, Programa de Pós-Graduação em Engenharia Florestal, Curitiba, PR - Brasil. E-mail: <ageufreire@hotmail.com>.
[4] Universidade Federal do Tocantins, Programa de Pós-Graduação em Biodiversidade, Ecologia e Conservação, Porto Nacional, TO - Brasil . E-mail: <wmelouft@yahoo.com> and <rodney@mail.uft.edu.br>.
*Corresponding author.

ABSTRACT – Phenology is defined as the study of the timing of biological events and the biotic and abiotic factors that trigger them. This study reports a description of the phenology of *Byrsonima pachyphylla* and *B. verbascifolia* in an ecotonal area between the Cerrado and Amazonia biomes in the Brazilian state of Tocantins, to contribute to a better understanding of their autoecology in this region. Two populations of 15 adult individuals of each species, randomly selected in a Cerrado area in Porto Nacional, Tocantins, were surveyed for 12 months. Percentages were estimated of leaf flush, young, mature, and senescent leaves (vegetative phenology), flower buds, open flowers, green and ripe fruits (reproductive phenology) present in the canopy, as well as the synchrony of the reproductive phenophases. The vegetative and reproductive phenological events were seasonal and occurred mainly at the end of the dry season and during the transition from the dry to the rainy season. Considering the vegetative and reproductive phenology, *B. pachyphylla* was classified as "evergreen with continuous growth" and as a late-flowering species, whereas *B. verbascifolia* was classified as "evergreen with seasonal growth" and as an early-flowering species. The reproductive phenological activity of the species exhibited high synchrony. The results suggest that the vegetative and reproductive events are peculiar to each species and represent effective strategies for their survival in the Cerrado, which is markedly seasonal.

Keywords: Murici; Phenology; Ecotone.

SINCRONICIDADE FENOLÓGICA DE Byrsonima pachyphylla A. JUSS. E B. verbascifolia (L.) DC. (MALPIGHIACEAE) E SUA RELAÇÃO COM A SAZONALIDADE CLIMÁTICA

RESUMO – A fenologia estuda o período de ocorrência de eventos biológicos e o que os estimulam, em relação a fatores bióticos e abióticos. A presente investigação teve como objetivo descrever a fenologia de ***Byrsonima pachyphylla*** *e de* ***B. verbascifolia*** *em uma área ecotonal entre os Biomas Cerrado e Amazônia no estado do Tocantins com a finalidade contribuir para o melhor entendimento de sua autoecologia nessa região pouco estudada. Trinta indivíduos adultos de cada espécie, escolhidos aleatoriamente em área de Cerrado stricto sensu em Porto Nacional, Tocantins, foram acompanhados quinzenalmente durante doze meses. Foram estimadas as porcentagens de brotações e folhas em diferentes estágios de desenvolvimento (fenologia vegetativa), de botões florais, flores abertas, frutos verdes e maduros (fenologia reprodutiva), bem como a sincronia das fenofases reprodutivas. Os eventos fenológicos vegetativos e reprodutivos foram sazonais e ocorreram principalmente no final do período seco e início do chuvoso. A fenologia vegetativa de* ***B. pachyphylla*** *foi classificada como sempre verde com crescimento contínuo e sua floração como tardia, apresentando este evento principalmente no período seco.* ***B. verbascifolia*** *foi classificada como sempre verde com crescimento sazonal e apresentou*

produção de flores na transição entre o período seco e o chuvoso sendo considerada uma espécie de floração precoce. A atividade fenológica reprodutiva das espécies apresentou alta sincronia. Os resultados sugerem que os eventos vegetativos e reprodutivos são peculiares a cada espécie e estrategicamente eficientes para sua sobrevivência no Cerrado marcadamente sazonal.

Palavras-Chave: Fenologia; Ecótono; Murici.

1. INTRODUCTION

Phenology is defined as the study of the timing of biological events, and what stimulates them, in relation to biotic and abiotic factors, as well as the interrelationship of the phenophases characterized by these events in the same and in different species (Lieth, 1974; Grossman, 2023). There are still few works published on plant phenology for the state of Tocantins, so this article is of great importance for understanding the autoecological strategies of *Byrsonima pachyphylla* and *B. verbascifolia* in this ecotonal region between the Cerrado and Amazon biomes.

The main events considered in most studies of plant phenology are leaf sprouting, leaf fall, flowering and fruiting (Lenza and Klink, 2006; Sivéro and Lenza, 2010; Shi et al., 2015; Urbaez et al., 2015; Santos et al., 2022). Based on this information, it is possible to make predictions about the phenological strategies of the species regarding the reproductive period, deciduousness and vegetative growth cycle of the species (Grossman, 2023).

Leaf renewal in the Cerrado normally occurs in the dry season (Oliveira and Gibbs, 2000), but it can also happen in response to other environmental conditions, such as variations in relative humidity and temperature, so it can reflect the phenotypic plasticity of species. The temporal distribution of flowering and fruiting is strongly linked to the incidence of appropriate environmental conditions for flower pollination and seed dispersal, which affect the reproductive success of the species. In this context, several studies have documented flowering and fruiting patterns in different plant communities and analyzed their correlation with biotic and abiotic factors (Rathcke and Lacey, 1985).

In the case of seasonal ecosystems, there is evidence that abiotic factors have an important influence on phenological variables (Tooke and Battey, 2010). For this reason, the seasonal response of phenophases has been related to different exogenous factors, such as temperature, evaporation, radiation (Ranieri et al., 2012), photoperiod (Morellato et al., 2000) and precipitation (Belo et al., 2013).

The vast majority of studies carried out in the Cerrado have investigated the behavior of vegetation at the community level (Lenza and Klink, 2006; Silvério and Lenza, 2010). A recurrent criticism of phenological studies at this level is that these studies can fail to note the diversity of seasonal responses of phenophases at the species level (Singh and Kushwaha, 2005). For this reason, an alternative method of dealing with this problem is to divide community patterns into subsets of species that are internally homogeneous in terms of sharing common life histories (Marquet et al., 2004; Azeria et al., 2011).

Malpighiaceae, the family to which the species examined in this study belong, is monophyletic and comprises approximately 77 genera and 1,300 species, distributed in the tropics (Davis and Anderson, 2010), of which 85% are restricted to the Neotropical region (Davis et al., 2001). In Brazil, at least 150 species of the genus *Byrsonima* Rich have been found (Cronquist, 1991).

Byrsonima fruits are popularly called murici and are important as foods. They can be consumed in natura or used as a basis for the production of beverages (Aniceto et al., 2021; Souza et al., 2020), sweets (Neri-Numa et al., 2018) and cereal bars (Vinhal et al., 2022). Murici extracts are also used in the manufacture of pharmaceutical products such as medicines and cosmetics (Neri-Numa et al., 2018; Saldanha et al., 2016).

B. pachyphylla A. Juss. and *B. verbascifolia* (L.) DC., both popularly known as murici, are species native to Brazil and have life forms that vary from bushes to trees (Mamede and Francener, 2016).

Our objective is to describe the vegetative and reproductive phenology of *B. pachyphylla* and *B. verbascifolia* in order to generate information about the behavior of these two species occurring in an area of Cerrado *stricto sensu* in the municipality of Porto

Nacional, Tocantins, thus contributing to a better understanding of their autoecology.

2. MATERIALS AND METHODS

2.1 Study area

The study was carried out at the São Judas Tadeu farm, located in an area of Cerrado *stricto sensu* in the municipality of Porto Nacional, Tocantins, Brazil (10º 48'31"S and 48º 26'52"W). The soil in this area is classified as Red-Yellow Latosol, with the presence of rocky fragments. The region's climate is classified as Aw according to the Köppen scale (1928), with hot and rainy summers and cooler dry winters. The average annual rainfall in the last nine years was approximately 1,800 mm, concentrated between November and April (INMET, 2015).

2.2 Description of the studied species

Byrsonima pachyphylla is an arboreal species that has a trunk covered with thick and broken bark, peeling off in irregular plates. The leaves are single, opposed, crossed, narrow-obovate to lanceolate, leathery and/or glossy and have trichomes on the underside (Silva-Junior, 2005; Hughes, 2021).

B. verbascifolia is a shrub whose trunk is crooked, covered with thick, rough bark. The leaves are single, concentrated towards the end of the branches, short-petiolate with a tomentose-villous surface on both sides (Lorenzi, 1998).

The inflorescences of both species are composed of simple terminal racemes, with hermaphrodite flowers having five pairs of elaiophores. The color of the petals varies from yellow at the beginning of anthesis to reddish brown in the senescence period. Its fruits are of the globose drupe type, having a fleshy mesocarp with juicy and sweet pulp (Lorenzi, 1998; Lorenzi, 2006).

The species were identified in the field with the help of specialized taxonomists. Samples of botanical materials of *B. pachyphylla* and *B. verbascifolia* were deposited in the Tocantins Herbarium (HTO) of Federal University of Tocantins, under registration numbers 10,947 and 10,948, respectively.

2.3 Phenological studies

Two populations of 15 adult individuals of each species (in the reproductive phase), approximately 1.5 km apart, were studied. Individuals were marked with aluminum tags numbered from 1 to 30. Field expeditions for phenological observations were carried out at intervals of 15 days, from May 2014 to April 2015.

The presence or absence of phenophases – vegetative (budding, young, adult and senescent leaves); reproductive (flowering - presence of flower buds at any stage of development and flowers in anthesis); and fruiting (green and ripe fruits) – were recorded in field worksheets. The percentage of each phenophase in the canopy was visually estimated based on Fournier (1974) through the intensity index using a semi-quantitative scale from 0 to 4 with 25% intervals, where 0 represents total absence of the phenophase.

The species were classified into vegetative phenological groups according to Sarmiento and Monastério (1983), as modified by Lenza and Klink (2006). These are based on temporal aspects of occurrence of the phenophases of leaf fall and production, as well as the degree of deciduousness of individuals. Reproductive phenological groups were also established according to the period of the year in which flowering occurred (Sarmiento and Monastério, 1983). Classification of flowering type was performed according to Gentry (1974).

2.4 Data analysis

The phenological events were evaluated by means of circular histograms containing the percentage of individuals of each species in each month, showing the vegetative and reproductive phenophases. Using the Activity Index proposed by Bencke and Morellato (2002), the synchrony of the reproductive phenological events was estimated. Less than 20% of the individuals in the phenophase were asynchronous, 20% to 60% of the individuals were synchronous and more than 60% of the individuals were highly synchronous.

Analyses of circular distributions were performed for the phenological events in order to determine the average angle of occurrence of these events and the measures of dispersion around this angle. The average angle corresponds to the average date of occurrence of the events. The concentration (r) of the event around this date ranged from 0 to 1, related to

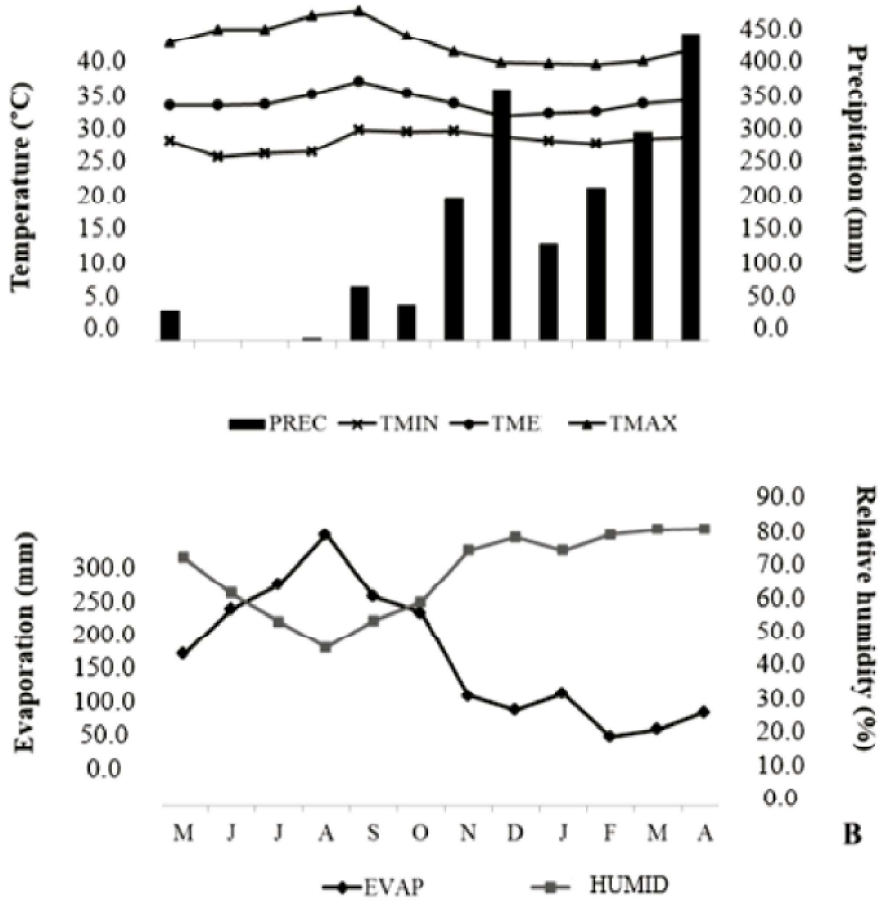

Figure 1 – Meteorological data for the municipality of Porto Nacional, Tocantins, Brazil, during the period from May 2014 to April 2015. A) Total monthly precipitation (PREC); maximum (TMAX), mean (TMED) and minimum (TMIN) monthly temperature. B) Monthly evaporation (EVAP) and average relative humidity (HUMID). Source: INMET.

***Figura 1** – Dados meteorológicos do município de Porto Nacional, Tocantins, Brasil durante o período de maio/2014 a abril/2015. A) precipitação total mensal (PREC); valores máximos (TMAX), médio (TME) e mínimo (TMIN) da temperatura mensal. B) evaporação mensal (EVAP) e umidade relativa média do ar (HUMID). Fonte: INMET.*

the length of the mean vector. The uniformity of the circular distribution of events throughout the year was evaluated using the Rayleigh (Z) test (Zar, 1999).

The Shapiro-Wilk test was performed to verify the normality of the data, and since the data had nonparametric distribution, Spearman correlations were calculated between the phenophases and the climatic variables rainfall (mm), average monthly temperature (°C), relative air humidity (%) and pitch evaporation (mm). Meteorological records were provided by the National Meteorology Institute (INMET, 2015) (Figure 1).

Circular distribution analyses were performed using the demo version of the Oriana 2.0 program. The Shapiro-Wilk test and Spearman correlation test were performed using the R version 3.0.2 software.

3. RESULTS

3.1 Reproductive and vegetative phenology

Byrsonima pachyphylla showed the phenophases of budding and young leaves almost throughout the year, with peaks in September and October. The average dates of occurrence of these phenophases were October 4th and 15th, respectively (Figures 2 A and B, Table 1). The presence of adult leaves was verified throughout the year in all individuals, with crowns being in category 4, that is, from 76 to 100% adult leaves. The average date of occurrence of this phenophase was January 30th (Figure 2 C). Senescent leaves were also observed throughout the year, with the highest amounts recorded in June. The average date of occurrence of this phenophase was August 10th (Figure 2 D). This species was classified as "evergreen with continuous growth" (Sarmiento and Monastério, 1983; Lenza and Klink, 2006), since it did not present evident deciduousness and the production of leaves occurred for a prolonged period. Of the vegetative

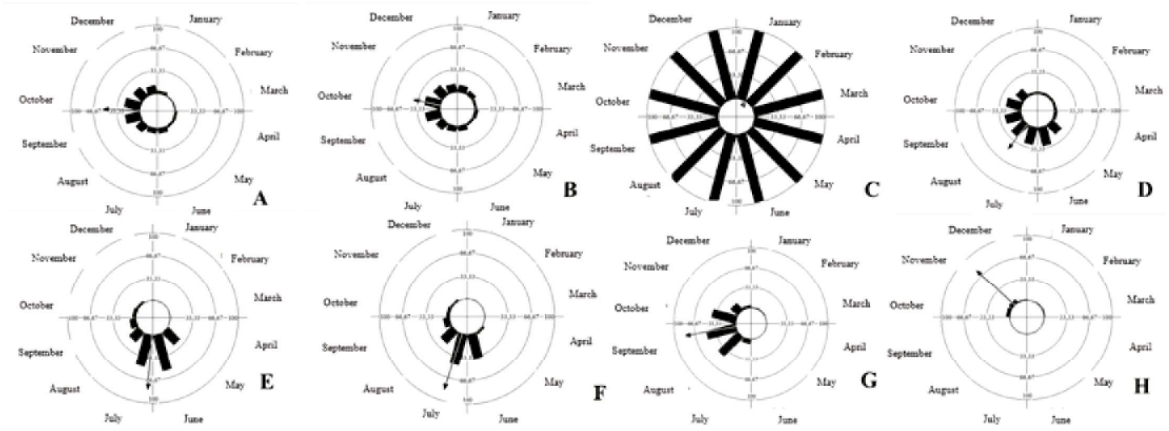

Figure 2 – Histograms of the circular distribution of vegetative and reproductive phenology of *Byrsonima pachyphylla*. A) budding; B) young leaves; C) adult leaves; D) senescent leaves; E) flower buds; F) open flowers; G) green fruits and H) ripe fruits from May 2014 to April 2015 in an area of Cerrado *stricto sensu*, Porto Nacional, Tocantins, Brazil. The vector indicates the average date of the event and the average phenological event concentration around this time.

***Figura 2** – Histogramas das distribuições circulares da fenologia vegetativa e reprodutiva de **Byrsonima pachyphylla**. A) brotação; B) folhas jovens; C) folhas adultas; D) folhas senescentes; E) botões florais; F) flores abertas; G) frutos verdes e H) frutos maduros no período de maio/2014 a abril/ 2015 em uma área de Cerrado **stricto sensu**, Porto Nacional, Tocantins, Brasil. O vetor indica a data média do evento fenológico e a concentração média do evento em torno desta data.*

Table 1 – Vegetative and reproductive phenology of *Byrsonima pachyphylla* and *Byrsonima verbascifolia* from May 2014 to April 2015 in an area of Cerrado *stricto sensu*, Porto Nacional, Tocantins, Brazil. Average angle (A), average date, number of observed occurrences of the event (N), mean vector concentration (r) Rayleigh test (Z). * P <0.0001.

***Tabela 1** – Fenologia vegetativa e reprodutiva de **Byrsonima pachyphylla** e **Byrsonima verbascifolia** no período de maio/2014 a abril/2015 em uma área de Cerrado **stricto sensu**, Porto Nacional, Tocantins, Brasil. Ângulo médio (ã), data média, número de observações da ocorrência dos eventos (N), concentração do vetor médio (r), teste de Rayleigh (Z). * p <0,0001.*

Phenophases	***Byrsonima pachyphylla***					***Byrsonima verbascifolia***				
	Ã	**Date**	**N**	***r***	***Z***	***ã***	**Date**	**N**	***r***	**Z**
Budding	271.756°	04/10/2014	116	0.53*	32.599*	329.539°	30/11/2014	157	0.622*	60.674*
Yolung leaves	282.018°	15/10/2014	133	0.399*	21.217*	337.897°	07/12/2014	233	0.567*	74.999*
Adult leaves	30°	30/01/2015	1187	0.001*	0.02*	128.312°	11/05/2014	1110	0.069*	5.341*
Senescent leaves	217.52°	10/08/2014	178	0.481*	41.356*	254.25°	17/09/2014	193	0.347*	23.195*
Floral buds	184.347°	08/07/2014	160	0.8*	102.387*	287.703°	20/10/2014	86	0.757*	49.315*
Open flowers	197.552°	20/07/2014	120	0.838*	84.349*	290.379°	23/10/2014	60	0.792*	37.598*
Green fruits	259.575°	24/09/2014	158	0.826*	107.861*	1.981°	01/01/2015	126	0.7*	63.292*
Ripe fruits	314.282°	17/11/2014	14	0.773*	8.363*	37.089°	07/02/2015	12	0.837*	8.398*

Table 2 – Spearman Correlation (rs) of Fournier intensity ratios of the different phenological phases of *Byrsonima pachyphylla* and *Byrsonima verbascifolia* with climatic variables (precipitation, temperature, relative humidity and evaporation of piche) from May / 2014 to April / 2015 in an area Cerrado *stricto sensu*, Porto Nacional, Tocantins, Brazil.

Tabela 2 *– Correlação de Spearman (rs) dos índices de intensidade de Fournier das diferentes fenofases de* ***Byrsonima pachyphylla*** *e* ***Byrsonima verbascifolia*** *com variáveis climáticas (precipitação, temperatura, umidade relativa do ar e evaporação de piche) no período de maio/2014 a abril/2015 em uma área de Cerrado* ***stricto sensu****, Porto Nacional, Tocantins, Brasil.*

Phenophases	***Byrsonima pachyphylla***								***Byrsonima verbascifolia***							
	Precipitation		Temperature		Relative Humidity		Evaporation		Precipitation		Temperature		Relative Humidity		Evaporation	
	rs	**p**	**rs**	**P**	**rs**	**p**	**rs**	**p**	**rs**	**p**	**rs**	**p**	**rs**	**p**	**rs**	**p**
Budding	-0.33	0.29	0.50	0.09	**-0.66**	**0.01**	**0.64**	**0.02**	0.46	0.12	0.03	0.91	0.21	0.50	-0.22	0.47
Yolung leaves	-0.19	0.54	0.41	0.17	-0.56	0.05	0.54	0.06	**0.58**	**0.04**	-0.03	0.90	0.35	0.25	-0.38	0.21
Adult leaves	0.39	0.20	0.03	0.91	0.28	0.37	-0.28	0.37	-0.40	0.18	-0.08	0.79	-0.13	0.66	0.19	0.55
Senescent leaves	**-0.84**	**0.05**	0.46	**0.12**	**-0.82**	**0.01**	**0.81**	**0.01**	**-0.62**	**0.02**	-0.08	0.09	**-0.89**	**0.01**	**0.86**	**0.03**
Floral buds	**-0.92**	**0.01**	0.24	0.44	**-0.81**	**0.01**	0.79	**0.02**	-0.44	0.15	0.47	0.11	**-0.64**	**0.02**	**0.61**	**0.03**
Open flowers	**-0.91**	**0.01**	0.39	0.20	**-0.90**	**0.01**	**0.88**	**0.01**	-0.27	0.39	**0.58**	**0.04**	-0.57	0.05	0.48	0.10
Green fruits	-0.24	0.44	0.50	0.09	**-0.67**	**0.01**	**0.64**	**0.02**	**0.78**	**0.02**	-0.32	0.22	**0.62**	**0.02**	**-0.65**	**0.02**
Ripe fruits	0.42	0.16	-0.03	0.99	0.30	0.33	-0.39	0.21	**0.70**	**0.01**	**-0.58**	**0.0470**	**0.77**	**0.03**	**-0.72**	**0.01**

phenological events of *B. pachyphylla*, only the presence of shoots and senescent leaves correlated significantly with relative humidity and evaporation (Figure 1, Table 2).

The emission of floral buds and flowers by *B. pachyphylla* plants occurred between May and November, with peak in July (Figures 2 E and F). The presence of unripe fruits was verified between July and December, with higher production in September (Figure 2 G). Ripe fruits were recorded between October and December (Figure 2H). The average dates of occurrence of the reproductive phenophases were July 8th and 20th for floral buds and open flowers, respectively, August 24th for unripe fruits and November 17th for ripe fruits. The flowering and fruiting pattern was annual. The synchrony between the reproductive phenophases was high, since 90% of the individuals presented the occurrence of flowering and 86.6% of the individuals exhibited fruiting in the peak season. *B. pachyphylla* was considered a late flowering species, flowering mainly in the dry period. In addition, its flowering was classified as the "big bang" type, with a single peak of short duration

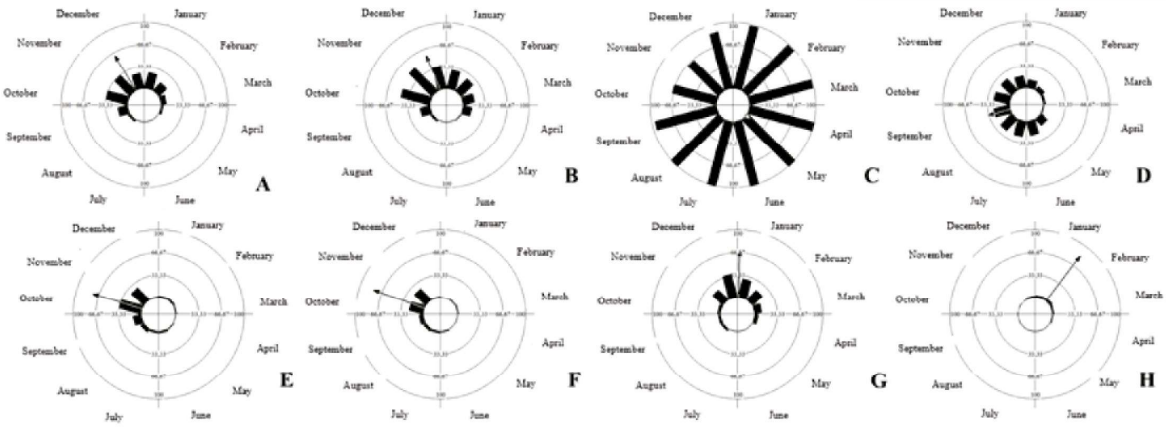

Figure 3 – Histograms of the circular distribution of vegetative and reproductive phenology of *Byrsonima verbascifolia*. A) budding; B) young leaves; C) adult leaves; D) senescent leaves; E) flower buds; F) open flowers; G) green fruits and H) ripe fruit from May 2014 to April 2015 in an area of Cerrado *stricto sensu*, Porto Nacional, Tocantins, Brazil. The vector indicates the average date of the event and the average phenological event concentration around this time.

Figura 3 *– Histogramas das distribuições circulares da fenologia vegetativa e reprodutiva de* ***Byrsonima verbascifolia****. A) brotação; B) folhas jovens; C) folhas adultas; D) folhas senescentes; E) botões florais; F) flores abertas; G) frutos verdes e H) frutos maduros no período de maio/2014 a abril/2015 em uma área de Cerrado* ***stricto sensu****, Porto Nacional, Tocantins, Brasil. O vetor indica a data média do evento fenológico e a concentração média do evento em torno desta data.*

and high synchrony between individuals (Gentry, 1974). Among the reproductive phenophases of *B. pachyphylla*, flower buds, open flowers and unripe fruits correlated positively with evaporation and negatively with relative humidity.

In *Byrsonima verbascifolia*, the phenophases of budding and young leaves occurred between August and April, with peaks being recorded on November 30th and December 7th, respectively (Figures 3 A and B). Adult and senescent leaves were observed throughout the year, without defined peaks (Figures 3 C and D). This species was classified as "evergreen with seasonal growth" (Sarmiento and Monastério, 1983; Lenza and Klink, 2006), since it showed evident leaf deciduousness and leaf production coincided with the climatic seasonality of the study area. The average dates of occurrence of these phenophases were May 11th and September 17th, respectively. Of the vegetative phenophases, only young leaves showed a positive correlation with precipitation, while senescent leaves had negative correlation with temperature.

The presence of flower buds in *B. verbascifolia* was observed between August and November, with a peak in October (Figure 3 E). Flowers were recorded between the months of July and November, with greater production in October and November (Figure 3 F). The presence of green fruits was verified between August and April, with greatest production in January (Figure 3 G). Ripe fruits were recorded from December to April (Figure 3H). The average dates of occurrence of the reproductive phenophases were October 20th and 23rd for floral buds and open flowers, respectively, January 1st for unripe fruits and February 7th for mature fruits.

The flowering and fruiting pattern of *B. verbascifolia* was annual. The synchrony of the reproductive phenophases was also considered high, with 90% of the individuals presenting flowering and 80% of the individuals exhibiting the fruiting phenophase. The production of flowers occurred in the transition between the dry and rainy seasons, so the plants were considered to have a kind of early flowering. These plants also presented a single peak of short duration and high synchrony between individuals, and thus their flowering was also classified as "big bang" (Gentry, 1974). The phenophase of flower buds of *B. verbascifolia* correlated positively with evaporation and negatively with precipitation and relative humidity; unripe and ripe fruits showed positive correlations with precipitation and relative humidity and negative correlation with evaporation.

4. DISCUSSION

The synchronicity and seasonality of the vegetative phenophases were in accordance with the tendency found in some Cerrado species to lose leaves in the dry period and later to start issuing leaf shoots (Alberton et al., 2014; Souza et al., 2015). Similar results were also recorded in phenological studies of *Byrsonima crassifolia* and *B. coccolobifolia* (Barbosa et al., 2012), *B. intermedia* and *B. pachyphylla* (Boas et al., 2013), and even *B. verbascifolia* (Araújo et al., 2014).

The presence of adult leaves recorded in both species throughout the study period is common in evergreen species (Franco et al., 2005), and is considered a strategy extensively used by species to combat various environmental constraints (Lenza and Klink, 2006) that can be caused by the climatic seasonality of the Cerrado biome.

Leaf senescence, followed by abscission in the dry period, recorded in the species studied, can be considered an adaptation to the decrease in water availability, as a mechanism for saving and efficiently using water by plants to increase their survival during these unfavorable periods (Lenza and Klink, 2006; Grossman, 2023). There may also be translocation of nutrients during the senescence period or even a reduction in transpiration caused by leaf abscission (Mantovani and Martins, 1988).

Cerrado species have shown variations in their vegetative phenological behavior depending on the region studied (Franco et al., 2005; Lenza and Klink, 2006). When studying the phenology of *B. pachyphylla* in a Cerrado area in the state of Mato Grosso, Silvério and Lenza (2010) classified this species as "always green with seasonal growth", characterized by leaf fall and budding at the end of the dry period and beginning of the rainy season, a result different from that observed by us. Lenza and Klink (2006), investigating the vegetative phenological behavior of *B. verbascifolia* in the Federal District, classified the species as "brevi-deciduous", also differing from our observation.

The most striking characteristics observed by these authors were the complete replacement of the crown during the dry period and the fact that during this

period the plants had only a few leaves in the process of formation and senescence. These differences may be related to the strong phenotypic plasticity of Cerrado species resulting from the diversity of biotic and abiotic factors found in this biome.

Regarding the reproductive dynamics, marked seasonality was also verified in both species studied (flowering in periods of greater evaporation and temperature [dry season] and fruiting in periods of greater relative humidity and precipitation [rainy season]). This is in accordance with the behavior recorded in other studies for several other Cerrado species (Lenza and Klink, 2006; Silvério and Lenza, 2010; Araújo et al., 2014).

Peak flowering in the dry season and fruiting in the wet season by *B. pachyphylla* have also been recorded in other studies in Cerrado areas, namely in Nova Xavantina, Mato Grosso (Silvério and Lenza, 2010), and in Campo Grande, Mato Grosso do Sul (Boas et al., 2013). The reproductive phenology of *B. verbascifolia* observed in the present study was similar to that recorded in a Cerrado area in Brasília, Federal District (Lenza and Klink, 2006) and in an area of Tabuleiro in Maceió, Alagoas (Araújo et al., 2014). This seasonality was found in other species of the genus studied in Cerrado areas: *B. coccolobaefolia*, *B. sericea* and *B. verbascifolia* in the Araripe National Forest in the municipality of Barbalha, Ceará (Costa et al., 2004); *B. rotunda* in Urbano Santos, Maranhão (Mendes et al., 2011) and also in *B. crassifolia* (L.) and *B. coccolobifolia* in Boa Vista, Roraima (Barbosa et al., 2012).

The high synchrony of the flowering phenophase registered in the studied species can be considered a strategy to guarantee reproductive success. This pattern is common in entomophilous species (Primack, 1980), and may increase the attraction of pollinating agents that promote cross-pollination, thus contributing to increased gene flow between different individuals, and consequently ensuring greater fruit production.

The occurrence of flowering in the dry season observed in the studied species has advantages, such as coincidence with the period of greatest activity of pollinators and the decrease in florivory (Rathcke and Lacey, 1985), in addition to the reduction of mechanical damage to flowers that can be caused by rain (Fernandes et al., 2012).

The ripening of zoochoric fruits during the rainy season (as observed in the studied species) is important for the maintenance of these fruits, as their attractiveness can remain for a longer period, thus increasing the chances of dispersion (Mantovani and Martins, 1988; Batalha and Mantovani, 2000; Grossman, 2023). This seasonal fruiting pattern was recorded in other studies with different woody species in Cerrado areas (Batalha and Mantovani, 2000).

5. CONCLUSION

The vegetative and reproductive phenological events of *Byrsonima pachyphylla* and *B. verbascifolia* are peculiar to each of these species, which makes them strategically synchronic and efficient for their survival in the ecotone between the Cerrado and Amazon biomes, which is markedly seasonal. In addition, there was no overlap between the peaks of the reproductive phenophases of the species, a possible way to avoid the sharing of pollinators and seed dispersers at the interspecific level, thus increasing the reproductive success and consequently the maintenance of the species.

AUTHOR CONTRIBUTIONS

Andressa Cavalcante Meireles wrote the paper obtained and discussed the statistical, experimental, and estimated data. Ageu da Silva Monteiro Freire, Wagner de Melo Ferreira and Rodney Haulien Oliveira Viana supported the writing of the paper.

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7. REFERENCES

Alberton B, Almeida J, Helm R, Torres RS, Menzel A, Morellato LPC. Using phenological cameras to track the green up in a cerrado savanna and its on-the-ground validation. Ecological Informatics. 2014; 19: 62-70. doi: 10.1016/j.ecoinf.2013.12.011

Aniceto A, Montenegro J, Cadena RDS, Teodoro

AJ. Physicochemical characterization, antioxidant capacity, and sensory properties of murici (*Byrsonima crassifolia* (L.) kunth) and taperebá (*Spondias mombin* L.) beverages. Molecules. 2021; 26 (2): 332. doi: 10.3390/molecules26020332

Araújo RR, Santos ED, Lemos EEP. Fenologia do muricizeiro *Byrsonima verbascifolia* (L.) RICH em Zona de Tabuleiro Costeiro do Nordeste Brasileiro. Ciência Agrícola. 2014; 12(1): 1-8. doi: 10.28998/rca.v12i1.905

Azeria ET, Bouchard M, Pothier D, Fortin D, Hébert C. Using biodiversity deconstruction to disentangle assembly and diversity dynamics of understorey plants along post-fire succession in boreal forest. Global Ecology and Biogeography. 2011; 20: 119-133. doi: 10.1111/j.1466-8238.2010.00580.x

Barbosa RI, Mourão JRM, Casadio GML, Silva SJR. Reproductive phenology of the main tree species in the Roraima savanna, Brazilian Amazon. Ecotropica. 2012; 18(2): 81-91.

Batalha MA, Mantovani W. Reproductive phenological patterns of cerrado plant species at the Pé-de-Gigante Reserve (Santa Rita do Passa Quatro, SP, Brazil): a comparison between the herbaceous and a woody floras. Revista Brasileira de Biologia. 2000; 60(1):129-145. doi: 10.1590/S0034-71082000000100016

Belo RM, Negreiros D, Fernandes W, Silveira FAO, Ranieri BD, Morelato LPC. Fenologia reprodutiva e vegetativa de arbustos endêmicos de campo rupestre na Serra do Cipó, Sudeste do Brasil. Rodriguésia. 2013; 64(4): 817-828. doi: 10.1590/S2175-78602013000400011

Bencke CSC, Morellato LPC. Comparação de dois métodos de avaliação da fenologia de plantas, sua interpretação e representação. Revista Brasileira de Botânica. 2002; 25(3): 269-275. doi: 10.1590/S0100-84042002000300003

Boas JCV, Fava WS, Laroca S, Sigrist MR. Two sympatric *Byrsonima* species (Malpighiaceae) differ in phenological and reproductive patterns. Flora. 2013; 208: 360–369. 2013. doi: 10.1016/j.flora.2013.05.003

Costa IR, Araújo FS, Lima-Verde LW. Flora e aspectos auto-ecológicos de um encrave de cerrado na chapada do Araripe, Nordeste do Brasil. Acta Botanica Brasilica. 2004, 18(4): 759-770. doi:10.1590/S0102-33062004000400006

Cronquist A. An integrated system of classification of flowering plants. New York, Columbia University. 1991.

Davis CC, Anderson WRA. Complete generic phylogeny of Malpighiaceae inferred from nucleotide sequence data and morphology. American Journal of Botany. 2010; 97(12): 2031–2048. doi: 10.3732/ajb.1000146

Davis CC, Anderson WR, Donoghue MJ. Phylogeny of Malpighiaceae: evidence from chloroplast ndhF and trnl-F nucleotide sequences. American Journal of Botany. 2001; 88(10): 1830–1846. doi: 10.2307/3558360

Fernandes GW, Oki Y, Sá CEM, Sales NM, Quintino AV, Mendes CFA, et al. Impact of the hailstorm across plant taxa: leaf fall in a mountain environment. Neotropical Biology and Conservation. 2012; 7(1): 8-15. doi: 10.4013/nbc.2012.71.02

Fournier LA. Un método cuantitativo para lamedición de características fenológicas enárboles. Turrialba. 1974; 24(4): 422-423.

Franco AC, Bustamante M, Caldas LS, Goldstein G, Meinzer FC, Kozovits AR, et al. Leaf functional traits of Neotropical savanna trees in relation to seasonal water deficit. Trees. 2005; 19: 326-335. doi: 10.1007/s00468-004-0394-z

Gentry AH. Flowering phenology and diversity in tropical Bignoniaceae. Biotropica, 1974, 6:64–68. doi: 10.2307/2989698

Grossman JJ. Phenological physiology: seasonal patterns of plant stress tolerance in a changing climate. New Phytologist. 2023; 237(1): 1508-1524. doi: 10.1111/nph.18617

Hughes FM. Reciprocal intercompatibility between Byrsonima Rich. ex Kunth species (Malpighiaceae), in an urban ecotonal fragment of semi-deciduous seasonal forest and Cerrado. Anales de Biología. 2021; 43:211-221. doi: 10.6018/analesbio.43.20

Instituto Nacional de Metereologia – INMET. Banco de dados meteorológicos para ensino e pesquisa.

INMET. Avaiable from: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep. Acesso em: 15 de julho de 2015.

Köppen W, Geiger R. Klimate der Erde. Gotha: Verlag Justus Perthes. 1928.

Lenza E, Klink CA. Comportamento fenológico de espécies lenhosas em um cerrado sentido restrito de Brasília, DF. Revista Brasileira de Botânica. 2006, 29(4): 627-638. doi: 10.1590/S0100-84042006000400013

Lieth H. Introduction to phenology and the modeling of seasonality. Phenology and seasonality modeling. In Ecological Studies 8. (H. Lieth, ed.). Springer-Verlag, Berlin, 1974. p.3-19.

Lorenzi H. Árvores brasileiras - Manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa, SP, Editora Plantarum, 1998. V.2

Lorenzi H, Bacher L, Lacerda M, Sartori S. Frutas brasileiras e exóticas cultivadas (de consumo *in natura*). São Paulo: Instituto Plantarum de Estudos da Flora, 2006, p. 157- 158.

Mamede MCH, Francener A. *Byrsonima* in Lista de Espécies da Flora do Brasil. Jardim Botânico do Rio de Janeiro. Disponível em: <http://www.reflora.jbrj.gov.br/jabot/floradobrasil/FB19425>. Acesso em: 26 Janeiro de 2016.

Mantovani W, Martins FR. Variações fenológicas das espécies do cerrado da Reserva Biológica de Moji-Guaçu, Estado de São Paulo. Revista Brasileira de Botânica. 1988; 11: 101-112.

Marquet PA, Fernandez M, Navarrete SA, Valdovinos C. Diversity emerging: towards a deconstruction of biodiversity patterns. In Frontiers of Biogeography: New directions in the geography of nature. Edited byM. Lomolino and L. Heaney. Cambridge University Press. 2004. p. 191–209.

Mendes FN, Rêgo MMC, Alburquerque PMC. Fenologia e biologia reprodutiva de duas espécies de *Byrsonima* Rich. (Malpighiaceae) em área de Cerrado no Nordeste do Brasil. Biota Neotropica. 2011; 11(4): 103-115. doi: 10.1590/S1676-06032011000400011

Morellato LPC, Talora DC, Takahasi A, Bencke CC, Romera EC, Zipparro VB. Phenology of Atlantic rain forest trees: A comparative study. Biotropica. 2000; 32(4b): 811-823. doi: 10.1111/j.1744-7429.2000.tb00620.x

Neri-Numa IA, Sancho RAS, Pereira APA, Pastore GM. Small Brazilian wild fruits: Nutrients, bioactive compounds, health-promotion properties and commercial interest Food. Research International. 2018; 103:345-360. doi: 10.1016/j.foodres.2017.10.053

Oliveira PE, Gibbs PE. Reproductive biology of woody plants in a cerrado community of the central Brazil. Flora. 2000; 195(4): 311-329. doi: 10.1016/S0367-2530(17)30990-8

Primack RB. Phenological variation within natural populations: flowering in New Zealand montane shrubs. Journal of Ecology. 1980; 68(3): 849-862. doi: 10.2307/2259460

Ranieri BD, Negreiros D, Lana TC, Pezzini FF, Fernandes GW. Fenologia reprodutiva, sazonalidade e germinação de *Kielmeyera regalis* Saddi (Clusiaceae), espécie endêmica dos campos rupestres da Cadeia do Espinhaço, Brasil. Acta Botanica Brasilica. 2012; 26(3): 632–641. doi: 10.1590/S0102-33062012000300012

Rathcke BJ, Lacey EP. Phenological patterns of terrestrial plants. Annual Review of Ecology and Systematics. 1985; 16: 179-214. doi: 10.1146/annurev.es.16.110185.001143

Saldanha AA, Carmo LF, Nascimento SB, Matos NA, Veloso CC, Castro AHF, De Vos RCH, Klein A, Siqueira JMD, Carollo CA, Nascimento TVD,. Toffoli-Kadri MC, Soares AC. Chemical composition and anti-inflammatory activity of the leaves of *Byrsonima verbascifolia*. Journal of Natural Medicines. 2016; 70:760-768

Santos MO, Almeida BV, Campos NB, Macedo JGF, Macêdo MJF, Ribeiro DA, et al. Vegetative and reproductive phenology of *Copaifera langsdorffii* Desf. in different phytophysiognomies. Research, Society and Development. 2022; 11(4): 1-27. doi: 10.33448/rsd-v11i4.27288.

Sarmiento G, Monasterio M. Life forms and phenology. In Ecosystems of the World: tropical savannas (F. Bouliere, ed.). Elsevier: Amsterdan, 1983. p.79-108.

Shi SY, Li WC, Zhang HN, Liu LQ, Shu B, Liang QZ, et al. Application of extended Biologische Bundesantalt, Bundessortenamt and Chemische Industrie scale for phenological studies in longan (*Dimocarpuslongan*). Annals of Applied Biology. 2015; 167: 127–134. doi: 10.1111/aab.12214

SILVA-JUNIOR MC, SANTOS GC, NOGUEIRA PE, MUNHOZ CAR, RAMOS AE. 100 Árvores do cerrado: guia de campo. Brasília: Rede de Sementes do Cerrado. 2005. 304p.

Silvério DV, Lenza E. Fenologia de espécies lenhosas em um cerrado típico no Parque Municipal do Bacaba, Nova Xavantina, Mato Grosso, Brasil. Biota Neotrópica. 2010; 10(3): 205-216. doi: 10.1590/S1676-06032010000300024

Singh KP, Kushwaha CP. Emerging paradigms of tree phenology in dry tropics. Current Science. 2005; 89(6): 964–975.

Souza VR, Aniceto A, Abreu JP, Montenegro J, Boquimpani B, Jesuz VA, Teodoro AJ. Fruit-based drink sensory, physicochemical, and antioxidant properties in the Amazon region: Murici (Byrsonima crassifolia (L.) Kunth and verbascifolia (L.) DC) and tapereba (Spondia mombin). Food science & Nutrition. 2020; 8 (5): 2341-2347. doi: 10.1002/fsn3.1520

Souza MC, Bueno PCP, Morellato LPC, Habermann G. Ecological strategies of Al-accumulating and non-accumulating functional groups from the Cerrado *sensu stricto*. Anais da Academia Brasileira de Ciências. 2015; 87(2): 813-823. doi: 10.1590/0001-3765201520140222

Tooke F, Battey NH. Temperate flowering phenology. Journal of Experimental Botany. 2010; 61(11): 2853–2862. doi: 10.1093/jxb/erq165

Urbaez MC, Silva-Acuña R, Natera JRM, Padilla SM. Fenología de la floración del cafeto var. Catuaí Rojo em el município Caripedel estado Monagas, Venezuela. Idesia. 2015; 33(1): 59-67. doi: 10.4067/S0718-34292015000100007

Vinhal GLRRB, Sanches MAR, Barcia MT, Rodrigues D, Pertuzatti P.B. Murici (*Byrsonima verbascifolia*): a high bioactive potential fruit for application in cereal bars. LWT-Food Science and Technology. 2022; 160: 1-9. doi: 10.1016/j.lwt.2022.113279

Zar JH. Biostatistical analysis. 4ªed. New Jersey, Prentice-Hall, Inc., 1999. 663p.