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ORIGINAL ARTICLE

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Phenology of *Dipteryx odorata* and *Dipteryx punctata* in agroforestry systems in the eastern Amazon

Fenologia de Dipteryx odorata e Dipteryx punctata em sistemas agroflorestais na Amazônia oriental

ABSTRACT: The phenology of trees in agroforestry systems is important for predicting the management and collection of timber and nontimber resources. This study describes the phenological stages of *Dipteryx odorata* and *Dipteryx punctata* in agroforestry systems, assessing meteorological factors that may affect the phenophases of the species. The study was conducted in plantations in Mojuí dos Campos city, Pará State, Brazil. In each area, 45 trees were monitored, totaling 90 individuals. Observations lasted 25 months (Oct/2015 to Dec/2017). The phenophases evaluated monthly were flowering, fruiting, new leaves, and leaf fall. Data were collected for dendrometric characterization of the trees, as well as meteorological variables including rainfall, temperature, humidity, and insolation for the period. For the analysis of phenological data, the intensity, frequency, synchrony, and duration of phenophases were described for each species. The influence of meteorological factors on the phenophases was analyzed through multivariate principal component analysis aiming to select the essential variables for phenological studies in the species plantations, as well as to identify correlations. The results indicate phenological seasonality for the two species under study. Species *Dipteryx odorata* has low synchrony for phenological events. For *Dipteryx punctata*, the phenophases are synchronous. High correlations between phenological and meteorological variables must be evaluated individually for each species, as they have different periods of phenophase manifestation.

RESUMO: *A fenologia de árvores em sistemas agroflorestais é importante para previsão de manejo e coleta de recursos madeireiros e não-madeireiros. O objetivo deste estudo foi analisar os padrões fenológicos de Dipteryx odorata e Dipteryx punctata em sistemas agroflorestais e avaliar as variáveis meteorológicas que afetam as fenofases das espécies. O estudo foi desenvolvido em dois plantios situados no município de Mojuí dos Campos, Pará. Em cada área, foram monitoradas 45 árvores, totalizando 90 indivíduos, observados durante 25 meses (out/2015 a dez/2017). As fenofases mensalmente avaliadas foram: floração, frutificação, folhas novas e queda foliar. Foram coletados dados para caracterização dendrométrica do porte das árvores, e variáveis meteorológicas de precipitação, temperatura média, umidade do ar e insolação do período. Para análise dos dados fenológicos foi descrito para cada espécie a intensidade, frequência, sincronia e duração. A influência dos fatores climáticos nas fenofases foi analisada por meio de análises multivariadas de componentes principais para selecionar as variáveis essenciais para estudos fenológicos nos plantios, e identificar correlações. Os resultados indicam que há sazonalidade fenológica para as duas espécies analisadas. Para Dipteryx odorata há baixa sincronia para os eventos fenológicos. Para Dipteryx punctata as fenofases são sincrônicas. Altas correlações entre variáveis fenológicas e meteorológicas devem ser avaliadas individualmente para cada espécie pois possuem épocas distintas de manifestação de fenofases.*

1 Introduction

Agroforestry systems (AFSs) can provide different environmental services through the interactions between their components. These systems and interactions depend on the dynamics, ecology, and management of natural resources that diversify and sustain production through the integration of trees on the property and the agricultural landscape. Agroforestry generates greater social, economic, and environmental benefits for those who use the soil at different scales (Miccolis *et al.*, 2019).

Simple intercropping and crop-livestock-forest integration systems, as well as complex stratified systems (or agroforests), contribute to broad rural development, environmental protection, and social and ecosystem protection policies (Fernandes *et al.*, 2020). Noteworthy, the choice of species is a primordial characteristic in AFSs. Whether they are arboreal or not, they must be selected according to the objective of the producer. Traditional knowledge on the species, considering their available resources and lifetime, influence quality of life and the market and food diversification of agroforestry producers (Ewert *et al.*, 2016).

D. odorata (Aubl.) Forsyth f. and *D. punctata* (S.F.Blake) Amshoff, known in Brazil as '*cumaru*', are trees of the family Fabaceae, genus *Dipteryx*. These trees are native to the Amazon, whose potential has been intensively exploited in recent decades due to the international demand for wood of the species. They have high economic value, high density, and resistance to air humidity and pest attack (Portela & Pauletto, 2020).

Pará State, in the Amazon, has accounted for 79.0% of the extraction of '*cumaru*' fruits and seeds in Brazil, a percentage concerning all commercialized species of the genus (IBGE, 2018). In addition to wood, one of the main products sold are the seeds of the species. These seeds are known internationally as '*tonka*', with an increasing use in the perfume, flavoring, and medicine industries, currently being used also for gastronomic purposes (Mabberley, 2017; Rêgo *et al.*, 2017).

Cultivation of '*cumaru*' in AFSs has become a viable alternative due to the multiple use of the species (Rêgo *et al.*, 2017). According to Silva *et al.* (2018), the most economically profitable AFSs in the western region of Pará State present in their arrangement the species *D. odorata*, of common occurrence in the Amazon region. This may be due to the increasing commercialization value of dry almond in the region. In 2012, the price of dry almond in the country was US$ 3.89/kg. In 2017, the amount paid per kilogram of dry almond reached US$ 8.36/kg (Rêgo *et al.*, 2017; Silva *et al.*, 2018). Another fundamental point for choosing the species is the fact that - unlike most tree species - it starts producing fruit early, around four years of age (Pinto *et al.*, 2008).

In this scenario, research on the ecology, management, and reproduction of the species is necessary to ensure sustainable production of resources. Another necessity is the elaboration of detailed calendars on the time of application of inputs, the time for pruning, and the time for harvesting the natural resources of the species in plantations.

In natural forests, an important tool to understand the dynamics and functioning of ecosystems is the phenology of trees. Phenology is the study of the occurrence of vegetative and reproductive events of species throughout the year, as well as its relationships with environmental and biotic factors (Dantas *et al.*, 2016; Semensato *et al.*, 2020). Phenological information applies to the knowledge of species biology, supporting research on physiology, germination, genetics, breeding, management, and forestry (Freitas *et al.*, 2010).

Factors such as rainfall, average air temperature, day length, seed dispersal mode, and pollinator activity can influence reproductive phenology patterns (Oliveira & Rech, 2018). In tropical environments, especially those with high seasonal variation in rainfall, the dry season usually determines phenological patterns, changing the reproductive cycles of species as a means of adaptation and resource use efficiency (Dantas *et al.*, 2016).

The phenological patterns of trees in AFSs are important, especially for species of economic interest at national and international level (Portela & Pauletto, 2020). The literature lacks information on the phenology of *D. punctata*. On the other hand, several studies addressed the species *D. odorata* in recent years. These studies were decisive for the growing use of the latter species in agroforestry arrangements in the Amazon (Cysneiros *et al.*, 2018; Freitas *et al.*, 2010).

Therefore, knowledge of the reproductive patterns of species inserted in agroforestry plantations is important for the success of the project planned by the producer. In this context, the present study describes the phenological patterns of *Dipteryx odorata* and *Dipteryx punctata* in agroforestry systems, assessing meteorological variables that may affect the phenophases of the species.

2 Materials and Methods

The study was conducted in agroforestry plantations installed on two properties in Mojuí dos Campos city, Pará State, Brazil (2° 41' 5" S latitude, 54° 38' 35" W longitude). These plantations consisted of: a crop-livestock-forest integration system with *D. odorata* intercropped with annual and forage crops, with rotational cattle grazing; and a planting with species *D. punctata* intercropped with orange (*Citrus sinensis* L. Osbeck.) and annual crops such as cassava (*Manihot esculenta* Crantz.). The species in this study are duly registered in the National System for the Management of Genetic Heritage and Associated Traditional Knowledge (SisGen), in accordance with Law N°. 13,123, of May 20, 2015, regarding the use of Brazilian genetic heritage in experimental research.

The predominant soil in the city is Dystrophic Yellow Latosol with clayey texture. According to the Köppen classification, the climate is Am (tropical monsoon). The region has an average monthly temperature between 25 and 28 °C, and annual rainfall of 1920 mm, with higher rainfall in the months of December to May. The months from July to August characterize the dry period of the region (Silva & Fadini, 2017).

Forty-five trees were sampled in each system, totaling 90 individuals. The phenotypic selection criteria adopted for selecting and marking the individuals were good phytosanitary conditions and good formation of the stem and crowns. *D. odorata* trees were 5 years old at the beginning of monitoring (2015), being distributed in a 1 hectare plot containing 285 trees, with a spacing of 5 x 7 m between plants. *D. punctata* trees were 6 years old at the beginning of monitoring, being distributed in a 0.5 hectare plot containing 156 trees, with a spacing of 4 x 8 m between plants.

Phenological monitoring took place during 25 months of observation, between October 2015 and December 2017. The following vegetative and reproductive phenophases were recorded monthly: flowering, fruiting (immature and mature fruits), new leaves, and leaf fall. Pollinators of the species occurred simultaneously with the registration of phenophases.

The germplasm of *D. odorata* and *D. punctata*, used in their respective plantations, were donated by Embrapa Amazônia Oriental (Santarém/PA unit) and by the Technical Assistance and Rural Extension Company of Pará State (Belterra unit), respectively. Botanical samples of *D. odorata* (voucher: ALBC 128838, ALBC 128839, and ALBC 188840) and *D. punctata* (voucher: ALBC 128832, ALBC 128834, ALBC 128835, ALBC 128836, and ALBC 128837) were deposited at the Alexandre Leal Costa Herbarium (ALCB).

To characterize the size of the trees, in August 2016, the authors collected punctual data in each system, namely: stem diameter at 1.30 m from the ground (DBH), total height (m), and crown diameter (m). Stem diameter was measured with a diametric tape; total height was measured with a measuring rod of up to 10 meters, with the height of larger trees being estimated from the limit of the rod; and crown diameter was calculated through measurements from two crown diameters in the fixed north-south and east-west directions.

Meteorological variables were extracted from the Santarém meteorological station (A250/82246 Station; 2° 50' 26" S latitude; 54° 72' 03" W longitude), being provided by the National Institute of Meteorology (NIMET). Geographically, this is the closest meteorological station to Mojuí dos Campos city. The variables extracted were: rainfall (mm), maximum temperature (°C), minimum temperature (°C), relative humidity (%), and insolation (W/m²).

For data analysis, the number of individuals manifesting the vegetative and reproductive phases in each system was calculated as a percentage. The frequency of phenophases – number of cycles per year – was recorded as annual if the event occurred only once a year, and as biannual if the time elapsed between two phenological events was less than one year over the two years of observation. The duration of the phenological phase was classified as short (< 2 months), intermediate (2-5 months), or extended (> 5 months) based on the average number of months in which the phenophase occurred (Luna-Nieves *et al.*, 2017).

The synchrony of the vegetative and reproductive phases was evaluated using the index proposed by Fournier (1974), adapted by Bencke & Morellato (2002). The index indicates whether the peak intensity of a given phenophase completely coincides or not in all individuals of a population, so values < 0.20% mean that the trees in the system had an asynchronous reproductive event, values between 0.21 and 0.60% indicate that an event had low synchrony, and values > 0.60% denote a synchronous event.

To select the most pertinent variables for phenological studies in *D. odorata* and *D. punctata* plantations, we used exploratory multivariate statistical techniques applied through Principal Component Analysis (PCA). The PCA matrix was constructed over 25 months of observation (rows), being linked to the monthly averages of the phenological and meteorological data for that period (columns) in each plantation. To avoid the influence of high data collinearity in the construction of the PCA, the meteorological variables relative humidity and minimum temperature were removed from the PCA after the Pearson correlation (r) analysis showing values greater than r = 0.90 with the other meteorological variables. The data did not show normal distribution by the Shapiro-Wilk test ($p < 0.05$), except for the variable maximum temperature ($p = 0.495$). However, multivariate analyses were performed after standardizing all variables, each with a mean of 0 and variance of 1.

The interpretation of the PCA included the analysis of elementary statistics (means, deviations, covariances, and correlations between the variables), as well as of the eigenvalues and percentages of variation explained individually by the principal components (PCs). Finally, the structure of the variables was analyzed based on their correlations with the main axes, and the distribution of individuals based on their coordinates on the PCA axes. Analyses were processed using the experimental statistical softwares Genes and Past®.

Circular statistical analyses were performed to determine whether vegetative and reproductive phenophases were evenly distributed throughout the year. For this purpose, the months were converted into angles at 30° intervals (October/2015, 0°; November/2015, 30°; December/2015, 60°; etc.); then, the following were calculated: mean angle (μ), circular concentration (r), and circular standard deviation (SD). In these calculations, μ indicates the time of the year (month) in which the greatest number of individuals of a given species presented phenophase, and r indicates the degree of dispersion or concentration of observations (Luna-Nieves *et al.*, 2017). To determine the significance of the angle, a Rayleigh (z) test was used; a significant mean angle ($p < 0.01$) means that the phenophase is seasonal. Circular concentration intensity (r) values range from 0 (phenological activity evenly distributed throughout the year) to 1 (phenological activity concentrated in a certain period of the year). The program Oriana 4 was used for these analyses.

3 Results and Discussion

The meteorological variables for the study period indicate that the month of March 2016 had the highest rainfall (334 mm). The lowest rainfall (zero) occurred in the months of November 2015 and December 2015, and again in November 2017 (Figure 1). The maximum temperature (35 °C) occurred in November 2015 and November 2017. March 2017 accounted for the highest relative humidity (92%), and August 2016 for the highest insolation (269 W/m²). Thus, the months of October/2015 to February/2016 and July/2017 to November/2017 correspond to the dry period, and the months of March/2016 to June/2016 and December/2016 to June/2017 correspond to the rainy period.

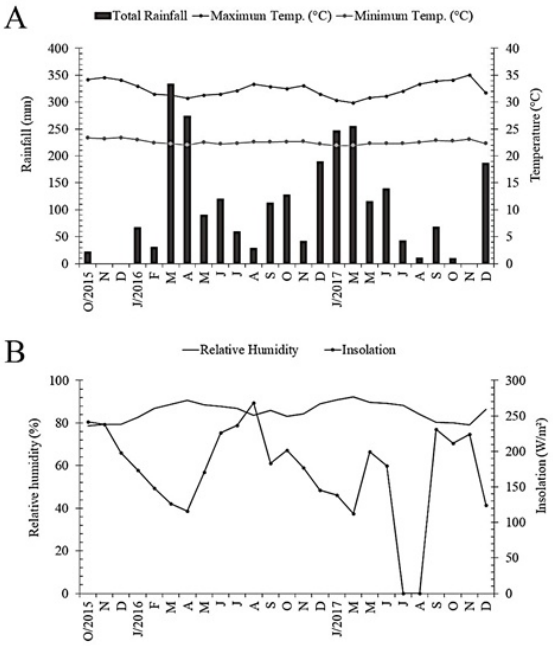

Figure 1. Monthly distribution of average rainfall; minimum, mean, and maximum temperature (A); relative humidity; and insolation (B) between October 2015 and December 2017 in Mojuí dos Campos city, Pará State, Brazil.

Figura 1. Distribuição mensal dos níveis médios de precipitação, temperatura máxima média e mínima (A), umidade relativa e insolação (B) entre outubro de 2015 e dezembro de 2017 em Mojuí dos Campos, Pará, Brasil.

Regarding the dendrometric characterization of trees, *D. odorata* specimens have average stem diameter of 12.3 ± 1.3 cm (max = 15.7; min = 9.5), average total height of 8.8 ± 1.0 m (max = 11.0; min = 6.3), and average crown diameter of 4.7 ± 0.7 m (max = 5.8; min = 3.4). *D. punctata* trees have average stem diameter of 10.3 ± 1.9 cm (max = 15.7; min = 6.7), average total height of 6.2 ± 0.8 m (max = 7.4; min = 4.5), and average crown diameter of 5.1 ± 1.0 m (max = 7.2; min = 2.7).

The authors of the present study assessed average synchronicity for the months in which the trees showed phenophases in each plantation considering the synchronicity index proposed by Fournier (1974), adapted by Bencke & Morellato (2002). For the planting of *D. odorata*, the phenophases flowering and new leaves had low synchrony over the years, averaging 22% and 37%, respectively. Moreover, the phenophases leaf fall and fruiting were asynchronous, averaging 20% and 16%, respectively (Figure 2). For *D. punctata*, the phenophases fruiting, new leaves, and leaf fall had low synchrony, averaging 49%, 34%, and 47% respectively. For this species, only the flowering phenophase occurred asynchronously, with an average value of 20% of trees manifesting the phase throughout the study period.

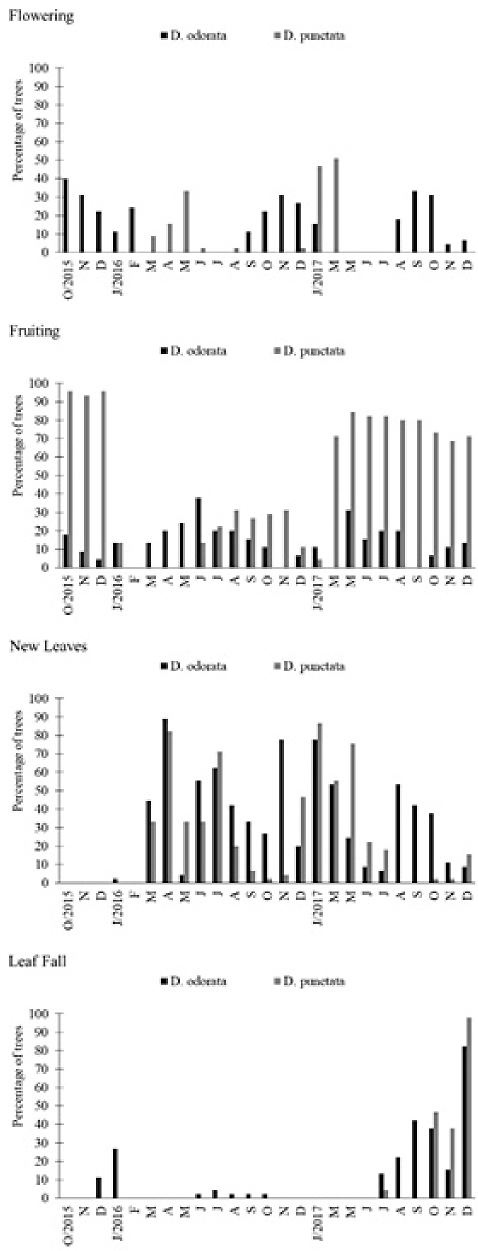

Figure 2. Percentage of *Dipteryx odorata* and *Dipteryx punctata* trees showing vegetative and reproductive phases for two years in agroforestry systems in Pará State, Brazil.

Figura 2. Percentual de árvores de *Dipteryx odorata* e *Dipteryx punctata* manifestando fases vegetativas e reprodutivas durante dois anos em sistemas agroflorestais no Pará, Brasil.

The flowering phenophase of *D. odorata* has intermediate duration, with low synchrony between trees (Table 1; Figure 2). The phase occurred in the two years of observation. Its most expressive peak occurred in the first year, in October 2015 (40% of the trees), followed by the peak occurring in September 2017 (33%). Both these peaks occurred in the dry period. *D. punctata* also showed intermediate flowering with low synchrony (Table 1; Figure 2). For this species, the highest intensities occurred in May 2016 (33%) and March 2017 (51%), both in the rainy season.

Regarding native trees in the forest, in central Amazon, *D. odorata* produced flowers in the dry season, with some events occurring in the dry-rainy transition period (Pinto *et al.*, 2008). In agroforestry plantations, *D. odorata* showed flower production in the rainy season (Freitas *et al.*, 2010), contrary to the present study with the same species. Although the periods of occurrence of flowers for *D. odorata* differ from region to region, the adverse conditions caused by El Niño in 2015-2016 may have triggered the manifestation of this phase. In the months following the event (Nov./Dec. 2015), developing flower buds presented dehydration aspect and were aborted. This may have been due to the high temperatures caused by the phenomenon, whose intensity accounted for the period without rainfall in the region (Figure 1). According to Jiménez-Muñoz *et al.* (2016), the El Niño of the year 2015 in eastern Amazon surpassed the anomalies observed in 2005 and 2010. Among the impacts are the intense mortality of trees, decreased biomass growth, and fires in forest areas in the Amazon.

Table 1. Pattern of cycles per year, duration, and synchrony of the phenophases of *Dipteryx odorata* and *Dipteryx punctata* over two years in agroforestry systems in Pará.

Tabela 1. Padrão de ciclos por ano, duração e sincronia das fenofases de *Dipteryx odorata* e *Dipteryx punctata* avaliados durante dois anos em sistemas agroflorestais no Pará.

Phase	Species	Pattern of cycles	¹Phase duration (Months)	²Synchrony
Flowering	*D. odorata*	Biannual	5	Low
	D. punctata	Annual	3	Low
Fruiting	*D. odorata*	Biannual	9-11	Low
	D. punctata	Biannual	8-12	Synchronous
New Leaves	*D. odorata*	Biannual	7-12	Synchronous
	D. punctata	Biannual	6	Synchronous
Leaf Fall	*D. odorata*	Biannual	6	Low
	D. punctata	Annual	3	Synchronous

¹Assessment proposed by Luna-Nieves et al. (2017); ²Index proposed by Fournier (1974), adapted by Bencke & Morellato (2002).

¹Avaliação proposta por Luna-Nieves et al. (2017); ²Índice proposto Fournier (1974), adaptado por Bencke & Morellato (2002).

The literature lacks reports indicating the flowering period of *D. punctata*. Therefore, this study consists of the first evidence that the species blooms in the rainy season. It is also worth mentioning the presence of pollinators (bees and wasps) during flowering, indicating pollination by entomophilia. In the study by Bentos *et al.* (2008), most flowering of tree species in central Amazon occurred during the dry-rainy season transition, which intensified insect pollination. These results disagree with those of the present study for *D. punctata* in plantations in eastern Amazon. Despite the different results, it is acceptable that species modify their metabolism in plantations given the available resources, water, light, and nutrients, depending on fertilizer management and pruning. These conditions can trigger favorable conditions for the manifestation of reproductive stages, attracting the attention of pollinators. Noteworthy, the flowers of this species exude a strong sweet aroma, attracting the most common visitors of the species of the genus in the field, which are bees of the family *Apidae*.

The fruiting phenophase for *D. odorata* is extended and with low synchrony between trees (Table 1; Figure 2). Two annual peaks occurred. The first peak occurred in June 2016 (38% of the trees), and the second peak occurred in May 2017 (31%), both in the rainy season (Figure 1 and 2). For *D. punctata*, fruiting is an extended event with synchronous peaks (Table 1; Figure 2). Its highest fruiting peak occurred in October 2015 and December 2015 (96%), in the dry season; and its second highest fruiting peak occurred in May 2017 (84%), at the end of the rainy season (Figure 1 and 2).

The occurrence of fruiting preferentially during dry periods, as in the present study for *D. punctata*, corroborates evidence from other phenological studies with other tree species in plantations and natural forest areas (Felsemburgh *et al.*, 2016; Dantas *et al.*, 2016). Higher fruiting intensities in the dry period can guarantee the physiological maturity of seeds by reducing seed water content, a key aspect for survival and post-dispersal germination (Felsemburgh *et al.*, 2016).

The new leaves phenophase of *D. odorata* showed extended duration, with synchronous peaks between trees (Table 1; Figure 2). Two peaks occurred: the first in April 2016 (89% of the trees) and the second in January 2017 (78%). For *D. punctata*, leaf budding is an extended and synchronous event (Table 1). Two budding peaks occurred: the first in April 2016 (82%) and the second in January 2017 (87%). Both species had new leaves in the rainy season. According to Andreacci *et al.* (2017), metabolic stimuli that trigger leaf budding occur from the rehydration of plant tissues after the dry period.

Leaf fall has extended duration in *D. odorata* (Table 1). The peaks of this phenophase occurred in the two years of observation, the first one in January 2016 (27% of the trees), with low synchrony; and the second one in December 2017 (82%), with high synchrony between the trees. Both these events occurred in the dry season of the study years. For *D. punctata*, leaf fall has intermediate duration and is synchronous (Table 1). The leaves of this species did not fall in the first year; however, leaf fall occurred in the second year, in December 2017 (98%), corresponding to the dry period.

Researchers consider leaf fall in the dry season to be an adaptation against eventual water loss. It occurs when soil moisture becomes limiting and there is an increase in evaporative rates, allowing leafless branches to be rehydrated through water obtained from deeper reserves in the soil profile (Pires *et al.*, 2016; Felsemburgh *et al.*, 2016). Water deficit is a likely inducer of defoliation, but may also correlate with biotic and abiotic influences, or occur due to the action of strong winds, causing premature rupture of leaf abscission zones (Sánchez-Salguero *et al.*, 2017; Oliveira & Rech, 2018).

Studies with Amazonian species show leaf fall in the dry period (Pires *et al.*, 2016; Felsemburgh *et al.*, 2016). These results corroborate those of the present study, although '*cumaru*' species are evergreen, not having their crowns completely defoliated. Leaf fall in the dry season can also be a strategy of plants for maximizing carbon gain from the increase in assimilation rates when the first rains begin. Furthermore, nutrient content increases during the dry season, with these nutrients being translocated to new expanding leaves during senescence (Felsemburgh *et al.*, 2016; Semensato *et al.*, 2020).

The Principal Component Analysis (PCA) in the phenological study of *D. odorata* and *D. punctata* assumes a preponderant role in the search for meteorological variables that most influence the phenology of trees in agroforestry plantations. From the obtainment of eigenvectors, it is possible to determine the scores or loads of the most representative variables for the construction of the PCA (Table 2).

This study considered the first two components (PC 1 and PC 2) of the PCA since they retain a sufficient amount of the total information contained in the set of original variables for each agroforestry plantation (Figure 3). In PCA, the greater the vector of the variable in relation to the axes, the greater the influence of the variable in the discrimination of data within each principal component. In addition, the more grouped the variables, the greater the direct correlation between them (Pires *et al.*, 2016).

In this scenario, for *D. odorata*, the two main components explained 57.9% of the data variance (Table 3). The first component explained 39.3% (PC 1) of the total variance, with more representative loads for the variables maximum temperature, rainfall, and flowering (Tables 2 and 3). The second principal component explained 18.6% (PC2) of the total variance, and presented more representative loads for the variables fruiting, insolation, and flowering. The graphic construction of the principal axes of the PCA for *D. odorata* highlighted the largest vectors and smallest angles in relation to the principal axes between the variables fruiting - insolation, leaf fall - insolation, and flowering - temperature, representing the variables with the greatest dependencies and correlations with each other (Figure 3).

For *D. punctata*, the two principal components explained 65.2% of the data variance (Table 3). The first component explained 48.5% (PC 1) of the total variance, with loads with greater influence on the construction of the PC for the variables temperature, rainfall, and new leaves (Tables 2 and 3). The second principal component explained 16.7% (PC 2) of the data variance and presented the most important loads for the variables leaf fall, insolation, and fruiting. The graphic construction of principal axes of the PCA for *D. punctata* highlighted the largest vectors and smallest angles in relation to the axes for the variables: temperature, in relation to all phenophases, except for leaf fall; rainfall, in relation to all phenophases; and insolation - leaf fall, representing the variables with the greatest dependencies and correlations with each other (Figure 3).

Table 2. Contributions (loads) of the phenological and meteorological variables of species *Dipteryx odorata* and *Dipteryx punctata* for the construction of the principal components PC1 and PC2.

Tabela 2. Contribuições (cargas) das variáveis fenológicas e meteorológicas de *Dipteryx odorata* e *Dipteryx punctata* para construção dos planos principais CP1 e CP2.

Dipteryx odorata		
Variable	PC 1	PC 2
New Leaves	-0.52	-0.22
Leaf Fall	0.29	-0.39
Flowering	0.75	-0.40
Fruiting	-0.42	0.76
Rainfall (mm)	-0.81	-0.34
Maximum temperature (ºC)	0.90	0.14
Insolation (W/m²)	0.45	0.48
Dipteryx punctata		
Variable	PC 1	PC 2
New Leaves	0.45	-0.09
Leaf Fall	-0.12	0.69
Flowering	0.41	0.03
Fruiting	-0.32	0.39
Rainfall (mm)	0.47	0.14
Maximum temperature (ºC)	-0.50	-0.10
Insolation (W/m²)	-0.21	-0.58

Table 3. Estimates of eigenvalues obtained from the analysis of principal components, percentage of importance or variance, accumulated variance, and prominent variables in the construction of the matrix.

Tabela 3. Estimativas de autovalores obtidos a partir da análise de componentes principais, percentual de importância ou variância, variância acumulada e variável de destaque na construção da matriz.

Dipteryx odorata				
PC	Eigenvalue	Importance (%)	Accumulated Variance (%)	Variable
1	2.751	39.3	39.3	Temperature
2	1.305	18.6	57.9	Fruiting
3	1.115	15.9	73.8	Leaf Fall
4	0.745	10.6	84.5	New Leaves
5	0.618	8.8	93.3	Insolation
6	0.303	4.3	97.6	Flowering
7	0.167	2.4	100.0	Temperature
Dipteryx punctata				
PC	Eigenvalue	Importance (%)	Accumulated Variance (%)	Variable
1	3.392	48.5	48.5	Temperature
2	1.166	16.7	65.2	Fruiting
3	0.850	12.1	77.3	Leaf Fall
4	0.698	10.0	87.3	New Leaves
5	0.453	6.5	93.7	Insolation
6	0.276	3.9	97.7	Flowering
7	0.161	2.3	100.0	Temperature

Due to the presence of high correlations between phenological and meteorological variables in the PCA, one can infer that the dependence between these events is a significant result. For the present study, it provides adequate information, redirecting them mainly to the management of '*cumaru*' plantations. High correlations allow satisfactory indirect gains and serve to help producers plan favorable strategies for the survival of the planting under various environmental conditions. In addition, phenological monitoring of the planting can help develop phenological calendars aiming to identify changes in the manifestation of phenophases. This allows efficient system management, with satisfactory gains in the desired direction.

Freitas *et al.* (2010) also found high correlations between phenophases and meteorological variables in agroforestry planting of *D. odorata* in Amapá State. Although the correlations are inverse to those of the present study with the same species, they were decisive for the planning of seed and fruit collection, as well as for the selection of a favorable time for pruning with a view to restructure the plantation. Luna-Nieves *et al.* (2017) state that phenological patterns must be explained as a result of a general context of tree development, which is determined by a set of factors involved in the evaluation (climatic, edaphic, and biotic aspects).

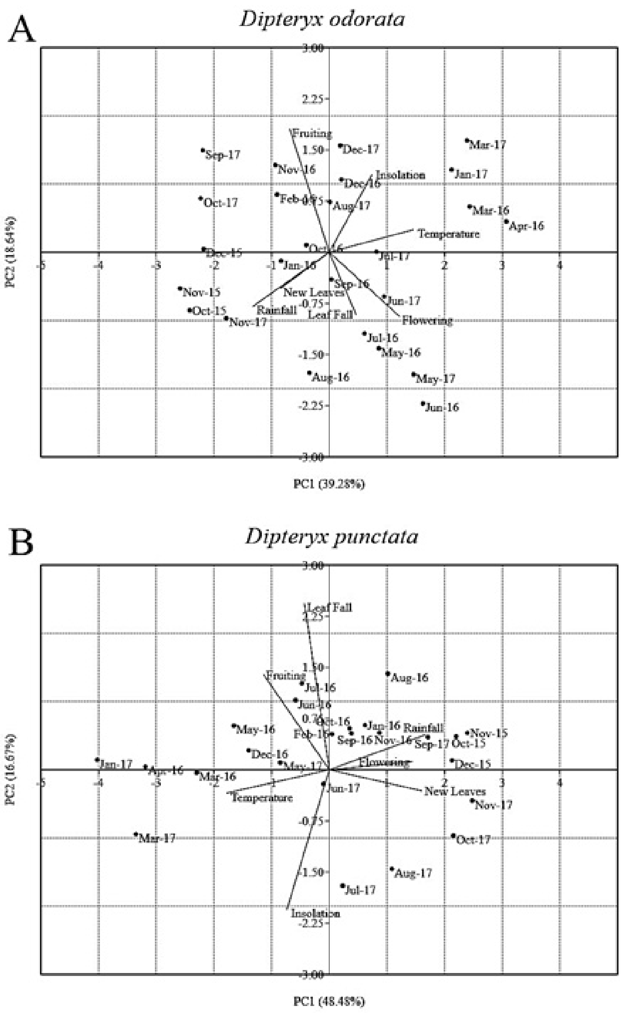

Figure 3. Distribution of the 25 months of observations, and means of the phenological variables of *Dipteryx odorata* (A) and *Dipteryx punctata* (B) trees and climatic variables from October 2015 to December 2017 in the two main axes of the PCA.

Figura 3. Distribuição dos 25 meses de observações, e médias das variáveis fenológicas das árvores de *Dipteryx odorata* (A) e *Dipteryx punctata* (B) e climáticas do período de outubro de 2015 a dezembro de 2017 nos dois eixos principais da ACP.

Regarding the seasonality of phenophases, for the planting of *D. odorata*, the mean vector angle (μ) was significant for all phenological variables in the two years of observation, indicating that the phases are seasonal (Table 4). Notwithstanding, the vector (r) indicated the highest concentration of observations for the phenophases flowering and leaf fall in the two years, and for the new leaves phenophase only in the first year.

Table 4. Results of the circular statistical analysis of the phenological variables of *Dipteryx odorata* and *Dipteryx punctata* over two years in agroforestry systems in Pará.

Tabela 4. Resultados da análise estatística circular das variáveis fenológicas de *Dipteryx odorata* e *Dipteryx punctata* avaliados durante dois anos em sistemas agroflorestais no Pará.

D. odorata		Phenological Variable			
	Year	Flowering	Fruiting	New Leaves	Leaf Fall
Observations (N)	1	63	88	150	22
	2	58	56	162	67
Mean vector angle (μ)	1	40.22°	252.60°	233.13°	76.32°
	2	5.72°	263.42°	35.06°	353.09°
Average length of the mean vector (r)	1	0.70	0.33	0.53	0.57
	2	0.69	0.34	0.23	0.65
Average Date	1	11/Nov.	13/Jun.	23/May	16/Dec.
	2	6/Oct.	25/Jun.	6/Nov.	24/Sep.
Circular standard deviation	1	48.65°	85.33°	64.58°	60.86°
	2	49.73°	84.41°	97.88°	53.17°
Rayleigh Uniformity Test (z)	1	< 0.01	< 0.01	< 0.01	< 0.01
	2	< 0.01	< 0.01	< 0.01	< 0.01
D. punctata		Phenological Variable			
	Year	Flowering	Fruiting	New Leaves	Leaf Fall
Observations (N)	1	28	176	126	0
	2	45	283	133	44
Mean vector angle (μ)	1	197.86°	16.06°	221.26°	***
	2	121.15°	284.00°	147.03°	36.91°
Average length of the mean vector (r)	1	0.88	0.68	0.66	***
	2	0.87	0.33	0.43	0.84
Average Date	1	21/Apr.	16/Oct.	14/May	***
	2	31/Jan.	19/Jul.	27/Feb.	07/Nov.
Circular standard deviation	1	29.65°	50.43°	52.45°	***
	2	30.69°	85.56°	74.46°	34.40°
Rayleigh Uniformity Test (z)	1	< 0.01	< 0.01	< 0.01	***
	2	< 0.01	< 0.01	< 0.01	< 0.01

*** indicates lack of data for the calculation

***indica que não houve dados para o cálculo

Phenophases are also seasonal in the planting of *D. punctata*, although with greater dispersion of data for the phenophases fruiting and new leaves in the second year of observation, with lower (r) values (Table 4). For both species, circular analysis allowed to establish the probable average date when trees were synchronously manifesting the phenophases (Table 4). This is particularly important for the elaboration of phenological calendars of the species in the plantations.

Phenophase seasonality in a plantation is valuable information for drivers of agroforestry systems in the Amazon (Pires *et al.*, 2016; Ewert *et al.*, 2016; Freitas *et al.*, 2010). Although this information is preliminary, it can be used to compare *D. odorata* and *D. punctata* in other types of plantations, to evaluate the behavior of the species, and to establish the most appropriate treatment for each one with a view to obtain greater productivity from the resources.

4 Conclusion

The species under study showed phenological seasonality and were strongly influenced by the maximum temperature. The phenological events of *D. odorata* have low synchronicity. For *D. punctata*, phenophases are mostly synchronous.

High correlations between phenological and meteorological variables must be analyzed individually for each species, as they have different periods of phenophase manifestation.

Circular analysis is useful for the construction of a phenological calendar for both species, as it allowed to establish a probable average date of greater phenological synchronicity of the trees in the plantations.

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