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Notes and Comments

A long fruiting series of *Myrcia neoregeliana* (Myrtaceae) shows the maintenance of seasonal resource supplies for dispersal by birds

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The availability of food resources for frugivores in tropical forests is crucial to the maintenance of bird species (Silva, 2022) that, in turn, strongly modulate the continuous fruiting patterns observed at plant community levels in humid tropical forests (Chiarello, 1995; Staggemeier et al., 2010; Costa et al., 2017; Silva et al., 2021). Myrtaceae species, largely demonstrating seasonally flowering in neotropical forests, are especially influenced by photoperiod and temperature (Staggemeier et al., 2010; Orellana et al., 2020; Pereira et al., 2022). Fruiting within the Myrtaceae community, however, does not exhibit any obvious seasonality, as it is influenced by the time required for flowering sequences and fruit maturation at the community level, with fruits being continuously available to seed dispersers (Staggemeier et al., 2010; Orellana et al., 2020; Santos et al., 2023).

Here, we report a study of fruiting seasonality of *Myrcia neoregeliana* E.Lucas & C.E.Wilson in the Chapada Diamantina mountains in northeastern Brazil, based on a 50-month time series, as well as aspects of dispersal processes by birds. We addressed the following questions: are there interannual differences among the average dates of fruiting? What environmental factors are related to fruiting?

Myrcia neoregeliana is endemic to Brazil, and distributed throughout the Atlantic Forest domain (Santos et al., 2020). The present study was conducted in the gallery forest along the Lençóis River (12°33'S - 41°24'W, at 400m a.s.l.) in northeastern Brazil (Funch et al., 2002), and used phenological datasets for *M. neoregeliana* accumulated over many years by our research group. The region experiences a moderately humid tropical climate (type Aw according to the Köppen system), with a rainy season concentrated in the austral summer (between December and April) followed by a dry winter season (between July and August) (Alvares et al., 2014). Monthly observations of 10 tagged individuals were carried out during the years 2005-2006, 2012-2013 and of 8 individuals in 2017, that qualitatively evaluated the presence of immature fruits (green) and mature fruits (black).

In February 2017, both frugivory and seed dispersal were accompanied, noting the presence of visitors, the removal of fruits, as well as fruit characterization. We undertook 98 hours of focal diurnal observations distributed among different days and different times (between 06:00 and 17:00) to identify dispersal agents and their behaviors in relation to fruit consumption. During observations we recorded visiting hours, visiting species, numbers of individuals, total visiting time, numbers of fruits consumed, eating behaviors (mashed the fruit and regurgitated it; mashed the fruit and swallowed it; swallowed it straight; pecked the fruit; carried the fruit), and post-visitation behaviors (flew close to the observed trees; flew away from the trees). We evaluated a random sample (N = 100 total) of fruits from five trees of *Myrcia neoregeliana* (not those considered in the focal observations) and described fruit diameters and weights, as well as the number of seeds per mature fruit. Data on total monthly precipitation, average monthly temperatures, average monthly relative air humidity, average monthly solar radiation, and average monthly photoperiod were acquired from the meteorological station in Lençóis - BA, located 1.8 km from the study site. The seasonality of the phenological fruiting data was evaluated using circular statistics (Morellato et al., 2010), considering the following parameters: the average angle, the length of the *r* vector (with high values of $r > 0.5$ indicating seasonality); the Rayleigh test (z) (Zar, 2010). The circular analysis and the Mardia-Watson-Wheeler test were performed using R software, with the addition of the "circular" package version 4.0.3 (R Core Team, 2020). The relationships between the proportions of immature and mature fruits with monthly precipitation and temperature were analyzed using the Generalized Linear Model (GLM), with a binomial error and logit link function, with the addition of the "car" package (Fox and Weisberg, 2019), using R software version 4.0.3 (R Core Team, 2020). We excluded from the analyses

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the variables average monthly relative humidity, average monthly insolation, and average monthly photoperiod, to avoid multicollinearity effects, as they exhibited correlation values greater than 0.7 (r > 0.7). The Kruskal-Wallis H test was used to verify whether the number of frugivore visits differed among the observation periods; the feeding behaviors and post-visit data of the frugivores, as well as the analysis of fruit and seed biometry were calculated using Past software (Hammer et al., 2001).

Myrcia neoregeliana demonstrated seasonal fruiting (Figure 1) at the end of the rainy period, with the average angles of immature fruits in January and mature fruits in January and February (Table 1). Significant differences were observed among the average dates of mature fruits when comparing the years 2013 x 2017 (W= 6.29, p= 0.03) and 2005 x 2006 x 2012 x 2013 x 2017 (W= 5.4, p= 0.002). The percentage of immature fruits was positively correlated only with temperature (β 0.783, *z* 5.105, *p* 0.001), while the percentage of mature fruits was positively correlated with both temperature (β 1.065, *z* 4.963, *p* 0.001) and rainfall (β 0.734, *z* 4.314, *p* 0.001).

Different from our findings, some Myrteae species do not exhibit pronounced fruiting seasonalities in neotropical forests (Staggemeier et al., 2010) due to the times required for their flowering sequences and fruit maturation – resulting in continuous fruit availability. This pattern contributes to maintaining the regular presence of seed dispersers (Orellana et al., 2020). The mean dates of fruit maturation in *M. neoregeliana* during the years 2005-2006 and 2012-2013 were in the first half of January, while in 2017, maturation occurred at the end of January – with a significant delay of approximately 15 days in relation to the previous dates. Phenological changes such as those could lead to incompatibilities in terms of plant-animal interactions (Rafferty et al., 2015) as fruit maturation, for example, could occur either before or after the initiation of disperser activities (e.g., Warren II et al., 2011). The availability of *M. neoregeliana* fruits

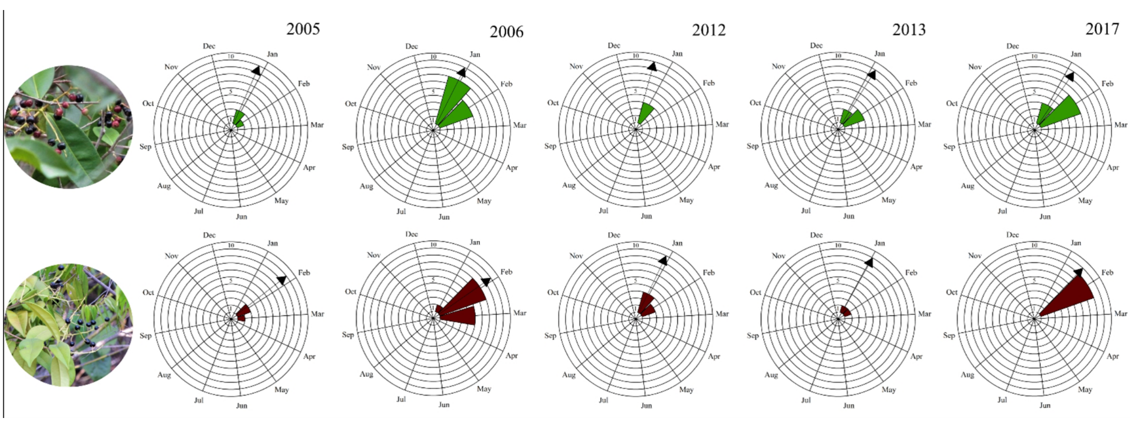

Figure 1. Circular histograms of the fruiting phenology of *M. neoregeliana* E.Lucas & C.E.Wilson (Myrtaceae), in a gallery forest, Chapada Diamantina, Bahia, Brazil. Green: Immature fruit; Red: Mature fruit.

Table 1. Circular statistics of the fruiting of *Myrcia neoregeliana* E.Lucas & C.E.Wilson (Myrtaceae) in a gallery forest, Chapada Diamantina, Bahia, Brazil.

Study Years	Phenophase	Phenophase frequency	Mean Angle	Mean date	Mean Vector Length (*r*)	Angular Standard Deviation	Rayleigh Test (*p*)
2005	Immature fruit	03	9.89	10/Jan	0.97	14.1°	< 0.04
	Mature fruit	03	39.89°	09/Feb	0.97	14.1°	< 0.04
2006	Immature fruit	12	12.44°	13/Jan	0.96	14.8°	< 0.001
	Mature fruit	12	42.44°	12/Feb	0.97	14.8°	< 0.001
2012	Immature fruit	03	0°	01/Jan	1	61.8°	< 0.03
	Mature fruit	05	11.9°	12/Jan	0.96	14.7°	< 0.002
2013	Immature fruit	05	18°	19/Jan	0.96	14.7º	< 0.002
	Mature fruit	02	15°	16/Jan	0.96	15.08°	0.1
2017	Immature fruit	09	20.1º	21/Jan	0.96	14.1º	< 0.001
	Mature fruit	08	30°	31/Jan	1	0°	< 0.001

during periods of high precipitation is closely linked to their fleshy structure, corroborating data of other Atlantic Forest species (such as Melastomataceae) with similarly fleshy fruits (Brito et al., 2017; Sierra and López, 2021). Species with fleshy fruits have been found to primarily produce them during the rainy season when humidity levels increase, and they play crucial roles in providing resources for bird species those environments (Morellato et al., 2000; Cardoso et al., 2012; Sierra and López, 2021). A decrease (or absence) of rainfall would therefore impact fruit production by *M. neoregeliana* and decrease food sources available to disperser birds.

The individual fruits produced from one to two seeds, with fruit lengths ranging from 6.53 to 10.16 mm and widths ranging from 7.61 to 12.47 mm; fruit weight varied from 0.2978 to 0.9449 g; seed length varied from 3.56 to 5.58 mm, their widths from 3.45 to 6.78 mm, and seed weight from 0.0408 to 0.1119 g. The smaller fruits of *Myrcia neoregeliana* are most appropriate for small birds to eat or carry. Fruit size and shape affect frugivore preferences and limit how many fruits/seeds they can manipulate (Ragusa-Netto, 2002; Orellana et al., 2020; Rojas et al., 2021).

We recorded 11 bird species, visiting *M. neoregeliana* fruits (Table 2), with a total of 118 visits to fruiting *M. neoregeliana*. *Turdus leucomelas* (Figure 2C), and *Dacnis cayana* (Figures 2A and 2B) made the highest percentages of visits (28.8% and 23.7% respectively). The highest fruit consumption observed was by *Turdus leucomelas* (116 fruits), representing 29.4% of the consumed fruits, followed by *Dacnis cayana* (75 fruits; 24.8%). Visiting duration times ranged from 30 seconds to 20 minutes, with *Turdus leucomelas* and *Euphonia chlorotica* staying the longest (110 minutes and 32.5 minutes respectively) (Table 1). No differences were observed in terms of post-visit behaviors between the species in the early morning; in the afternoon, most visitors flew away from the visited plant (Table 1).

We have shown in a 50-month non-continuous time series that *M. neoregeliana* fruiting is seasonal, always occurring at the end of the rainy season and associated with increased temperature and rainfall during the austral summer, and that fruiting plants attract many bird species. *Turdus leucomelas* and *Dacnis cayana* appear as potential dispersers of *M. neoregeliana*, ensuring that its fruits and seeds are dispersed in the area around the parent plant and in the forests of Chapada Diamantina and are able to colonize new habitats and enhance genetic diversity. The birds in question are generalists and consume *M. neoregeliana* fruits for their high energy contents; additionally some Myrteae species, including *Eugenia punicifolia* (Kunth) DC., contain beneficial bioactive compounds such as lycopene (Braga et al., 2023). Understanding the dispersal processes associated with fruiting rhythms is crucial for the conservation of this species, which, although not being considered threatened, it is important for maintaining ecosystem services and supports overall effective forest management.

Table 2. List of bird species and the behaviors of frugivores observed in *Myrcia neoregeliana* trees (Myrtaceae) during the 98 hours of diurnal observations (morning and afternoon) in a gallery forest in the Chapada Diamantina, Brazil.

Táxon	Shift	NV	Time (Minutes)	Fruits consumed	Feeding behavior	Behavior after a visit
Fringillidae						
Euphonia chlorotica, Linnaeus, 1766	M/A	M3/A1	32.5	25	PF	FA/FC
Pipridae						
Manacus manacus, Linnaeus, 1766	M	M2	1	20	PF	FA/FC
Antilophia galeata, Lichtenstein, 1823	M	M1	0	2	S	FA
Thraupidae						
Dacnis cayana, Linnaeus, 1766	M/A	M13/A11	23.6	75	MS/S/ PF/U	FA/FC
Tangara cayana, Linnaeus, 1766	M/A	M1/A3	2	23	MS/S	FA
Coereba flaveola Linnaeus, 1758	A	M1	1	3	PF	FA
Tyrannidae						
Camptostoma obsoletum, Temminck, 1824	M	M1	5	1	PF	FC
Pitangus sulphuratus, Linnaeus, 1766	A	M1	1.5	2	S	FA
Turdidae						
Turdus leucomelas, Vieillot, 1818	M/A	M10/A10	110	116	MS/S/ PF/U	FA/FC
Turdus rufiventris, Vieillot, 1818	M/A	M1/A2	8.5	17	S/CF/U	FA/FC

Shift = M: Morning, A: Afternoon. **NV**: Number of visitors (M: Morning, A: Afternoon). **Feeding behavior** = S: Swallowed, MR: Mash and Regurgitates, MS: Mash and Swallowed, CF: Carried the fruit, PF: Pecks the fruit, and U: Unidentified. **Behavior after a visit** = FA: Flies away and FC: Flies close, and UB: Unidentified Behavior.

Figure 2. *Myrcia neoregeliana* seed dispersal by birds in a gallery forest, Chapada Diamantina, Bahia, Brazil. **(A)** *Dacnis cayana* perching on a *M. neoregeliana* individual **(B)** A *Dacnis cayana* with a *M. neoregeliana* berry in its beak. **(C)** *Turdus leucomelas* is seen here on the plant holding a fruit in its beak before eating it.

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