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Special Supplement: *Cerrado* **[Brazilian Savanna]**

Yield and diametric structure of *Dimorphandra mollis* Benth.[1]

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ABSTRACT

Dimorphandra mollis is native to the Brazilian Savanna and has social, economic and environmental importance. This study aimed to evaluate the yield and diametric distribution of *Dimorphandra mollis* Benth. in the Pandeiros River Environmental Protection Area, in Bonito de Minas, Minas Gerais state, Brazil. Five areas were assessed, totaling five hectares (50 plots of 1,000 m^2). The total number of plants, yield per plant (2018, 2019 and 2020) and diameter at breast height were recorded, considering all trees from the plots in diametric classes. The average diameter at breast height of all plants was 6.05 ± 3.07 cm, and that of the plants that produced in at least one of the evaluated years was 7.46 ± 3.15 cm. The diametric distribution showed classes with no individuals, indicating imbalance, as well as a trend to inverted "J" shape. The maximum annual yield was 8.08 kg ha^{-1} of dry fruits (2019), the minimum 0.42 kg ha^{-1} (2018), and the average 2.74 kg ha^{-1}, with biennial characteristic.

KEYWORDS: Fava-d'anta, forest species, Brazilian Savanna, phytosociology.

RESUMO

Produtividade e estrutura
diamétrica de *Dimorphandra mollis* Benth.

Dimorphandra mollis é nativa do Cerrado e possui importância social, econômica e ambiental. Objetivou-se avaliar a produtividade e distribuição diamétrica de *Dimorphandra mollis* Benth. na Área de Proteção Ambiental do Rio Pandeiros, em Bonito de Minas, Minas Gerais. Foram avaliadas cinco áreas, totalizando cinco hectares (50 parcelas de 1.000 m^2). O número total de plantas, produtividade por planta (2018, 2019 e 2020) e diâmetro à altura do peito foram registrados, considerando-se todas as árvores das parcelas em classes diamétricas. O diâmetro médio à altura do peito de todas as plantas foi de 6,05 ± 3,07 cm, e o das plantas que tiveram produção em pelo menos um dos anos avaliados foi de 7,46 ± 3,15 cm. A distribuição diamétrica apresentou classes sem indivíduos, indicando desequilíbrio, bem como tendência ao formato de "J" invertido. A produtividade anual máxima foi de 8,08 kg ha^{-1} de frutos secos (2019), a mínima de 0,42 kg ha^{-1} (2018) e a média de 2,74 kg ha^{-1}, com característica de bienalidade.

PALAVRAS-CHAVE: Fava-d'anta, espécie florestal, Cerrado, fitossociologia.

INTRODUCTION

Cerrado (Brazilian Savanna) is regarded as a global biodiversity hotspot, due to its large number of endemic species. Such diversity and endemism make it the richest Savanna in the world (Myers et al. 2000). According to Machado et al. (2004), 55 % of the Cerrado areas had already been lost in 2002, showing that part of the native species of this biome is being threatened by burning and illegal deforestation.

Created in 1995, the Pandeiros River Environmental Protection Area (EPA) is located in the northern Minas Gerais state, Brazil, and encompasses the municipalities of Januária, Bonito de Minas and Cônego Marinho, with a total area of 396,060.407 ha. The area has two vegetal physiognomies (Caatinga and Cerrado), characterizing itself as a transitional area, where phytophysiognomies with very particular adaptations and, therefore, of extreme biological importance, coexist and are favored for conservation and scientific research (Nunes et al. 2009).

Dimorphandra mollis Benth. is a species with bioactive potential native to the Cerrado, being

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present in more than 74 % of this biome (Ratter et al. 2003).

Popularly known as fava-d'anta or favela, it has social and economic relevance in the regions where it occurs, mainly due to the bioflavonoids rutin and quercetin present in its fruits (Filizola 2013), and was listed as a native species of the Brazilian flora with current or potential economic value (Brasil 2016).

Between 2011 and 2020, 1,808.50 t of rutin and its derivatives were exported at an average price of US$ 32.49 kg^{-1} (Brasil 2020). This commercial interest is due to the therapeutic effects of this metabolite, such as neuroprotective action (Javed et al. 2012) and blood vessels protection (Diwan et al. 2017).

D. mollis fruits commercialized for rutin extraction are obtained exclusively in Cerrado extraction areas (Filizola 2013). Extractive activities, when carried out without adequate management criteria for the species, that is, disregarding their conservation and sustainable use, may cause an imbalance in native populations and, consequently, yield losses (Filizola 2013). Thus, the diametric distribution is one of the possible ways of evaluating the regeneration of the species in naturally occurring areas, as well as assessing the equilibrium status of the population (Carvalho 1984).

Since it is a native species that depends on extractivist practices to obtain its raw material, the production chain of *D. mollis* presents bottlenecks; for example, oscillation in the quantity of fruits made available to the market (Silva & Egito 2005). That said, knowing the yield of the species in Cerrado areas over time is essential for the production chain to be organized and work in the best way. Hence, this study aimed to evaluate the fruit yield of *Dimorphandra mollis* Benth., along three years, as well as to characterize the diametric distribution of individuals in *stricto sensu* Cerrado areas located in the Pandeiros River Basin, in the northern Minas Gerais state, Brazil.

MATERIAL AND METHODS

The study was conducted at the Pandeiros River Environmental Protection Area (EPA), in the municipalities of Bonito de Minas and Januária. The field research had four stages: 1) selection of areas in the EPA; 2) virtual demarcation of the plots; 3) localization and determination of plant diameter; 4) harvest of fruits.

The areas selected and made available for the study were named A1 (-15.226S; -44.915W), A2 (-15.477S; -44,726W), A3 (-15.258S; -44.979W), A4 (-15.190S; -44.766W) and A5 (-15.201S; -44.788W), with a current history of extractivism for A1 and A3, and no recent history of it for A2, A4 and A5, regarding *D. mollis*. A total of 10 plots were virtually demarcated in each area, with the aid of the TrackMaker PRO™ software, in which 20 m wide and 50 m long rectangles (plots) were drawn, separated by a distance of 20 m and distributed along a central axis, totaling 1 ha per area and a total of 5 ha in the EPA. All areas had Quartzarenic Neosols (Santos et al. 2018), Arenosols (FAO 2015) or Quartzipsamments (USA 2014).

The first stage took place in the first year of evaluation (2018). The Garmin™ 60CSX GPS receiver was used to view the position of the plots virtually demarcated and to record the geographical coordinates of each plant, allowing the location of the same plants in subsequent harvests. The walk was carried out within the plots and all individuals were located and had their diameter at breast height (DBH = 1.3 m) collected with the help of a tree caliper. All individuals with a DBH greater than or equal to 3 cm were considered in the evaluation of the diametric distribution, performed only in this first year of the evaluation. The representativeness and sampling sufficiency, due to the variance in the number of plants per plot, was calculated for each area (A1, A2, A3, A4 and A5) also considering the general data. Infinite degrees of freedom were considered and a 95 % probability.

The fruit harvest was carried out in three consecutive years (2018, 2019 and 2020) to assess the annual yield, with the help of a pruner, keeping a corymb with fruits (Nunes et al. 2012) to guarantee the food dispersion for animals and maintain the seed bank. After harvesting, the fruits were immediately weighed in the field, using a digital scale, to determine the yield (kg of fresh fruit per hectare), and the samples were taken to the laboratory, where biometric data such as width and length were determined with the aid of a digital caliper and a ruler graduated in centimeters, in addition to the dry matter weight, after drying in a forced air circulation oven (65 ºC). The biometric data were evaluated using analysis of variance and the Tukey test at 5 % of probability.

In 2020, the areas were flown over by a Mavic Pro (Dji) drone with pre-programmed flight plan from the Dronedeploy app. The flight height was 100 m, with frontal and lateral overlaps of 75 and 65 %, respectively. The same parameters were used for all areas. The images were processed using the Pix4DMapper software and the maps with the Normalized Difference Vegetation Index (NDVI), according to Costa et al. (2020), in order to verify the existence of degradation in the areas.

The individuals were distributed in diameter classes according to Meira et al. (2016). The interval between classes (IC) was calculated according to the Sturges formula: IC = A/NC, where A is the amplitude between diameters and NC the number of classes [NC = 1 + 3.3 * log (n), with n being the number of individuals]. After obtaining the frequency (*fi*), the D'Liocourt quotient 'q' was obtained, being the ratio of the number of trees among successive diameter classes from the formula: q = Ni/Ni + 1, in which Ni is the number of trees of the nth diameter class, and Ni + 1 is the number of trees of the nth diameter class plus a subsequent diameter class (Felfili & Rezende 2003). In order to make the calculation feasible, with no existence of individuals in any of the classes, the number 1 was added as a constant to all classes. The total basal area (G) was obtained from the sum of the basal area of trees with DBH greater than or equal to 3 cm , in which: G (m^2 ha^{-1}) = (π x d^2)/40,000, where d is the DBH in cm.

The distribution pattern of individuals in the areas was assessed using the Morisita dispersion index (Id), based on the following formula: Id = n ($\sum z^2$)/[N x (N - 1)], where n is the total number of plots sampled, N the total number of individuals of the species and z^2 the square of the number of individuals of the species by plots (Estigarribia et al. 2017, Silva et al. 2019, Souza et al. 2020a). Id = 1 indicates a random distribution pattern, Id < 1 a uniform pattern and Id > 1 an aggregate pattern. The Id confirmation was tested by the chi-square test (χ^2), where χ^2 = [(n x $\sum z^2$)/N] - N. The calculated χ^2 was compared to the tabulated χ^2, at 5 % of significance ($p < 0.05$), for degrees of freedom df = n - 1. The chi-square interpretations were based on the criterion in which, when the calculated χ^2 is greater than the tabulated χ^2, the distribution pattern is assumed to be random (Id = 1); otherwise, Id is ≠ 1, and, therefore, the distribution pattern is aggregated or uniform.

The trees diameter (DBH) and yield data were used to estimate the probability of production of the trees as a function of the diameter, using the Rstudio software (RStudio Team 2015). The yield data were used to build a binary matrix, with "one" (1) being assigned to the tree that showed production and "zero" (0) to fruitless trees. From that matrix, the generalized linear model was used to determine the probability of production for the *D. mollis* trees depending on their diameter (DBH), according to the following equation: $(y/x) = [\exp(ß_0 + ß_1 X + ß_2 X^2)]/1 + [\exp(ß_0 + ß_1 X + ß_2 X^2)]$, where y/x is the probability of the tree being productive depending on its DBH, x the value corresponding to the trees DBH, $ß_0$ the point of intersection and $ß_1$ and $ß_2$ the coefficients (Hartzel et al. 2001). Also based on the DBH data, it was verified whether or not there was a correlation between the dry matter of the fruits produced (kg) and the diameter of the respective trees. The Spearman's correlation was used to examine that.

RESULTS AND DISCUSSION

In the evaluated areas, there was a predominance of individuals in the first diametric classes, which include the lowest DBH values (Figure 1). The presence of the largest number of plants in the smallest diameter classes is common for Cerrado areas, indicating that the species is regenerating (Santos et al. 2017, Souza et al. 2020).

There were diametric classes without individuals in the areas A2 and A4, even though these areas are among those with the highest degree of conservation and with no current history of extractivism. The lack of individuals in intermediate diametric classes in part of the assessed areas and the abrupt variations in the D'Liocourt quotient 'q' indicate that some kind of disturbance occurred in the species population. Among all areas, considering the observation of the researchers, A2 and A5 are the ones with the most dense vegetation. The D'Liocourt quotient 'q' was not constant among the diametric classes, although the distribution tends to the inverted "J" shape. The data representativeness and sampling sufficiency can be seen in Table 1.

Although the study areas are inside an environmental preservation area, while the evaluations were conducted, it was observed that, in all areas, there were indications of human intervention, such as burning, tree cutting and/or presence of cattle.

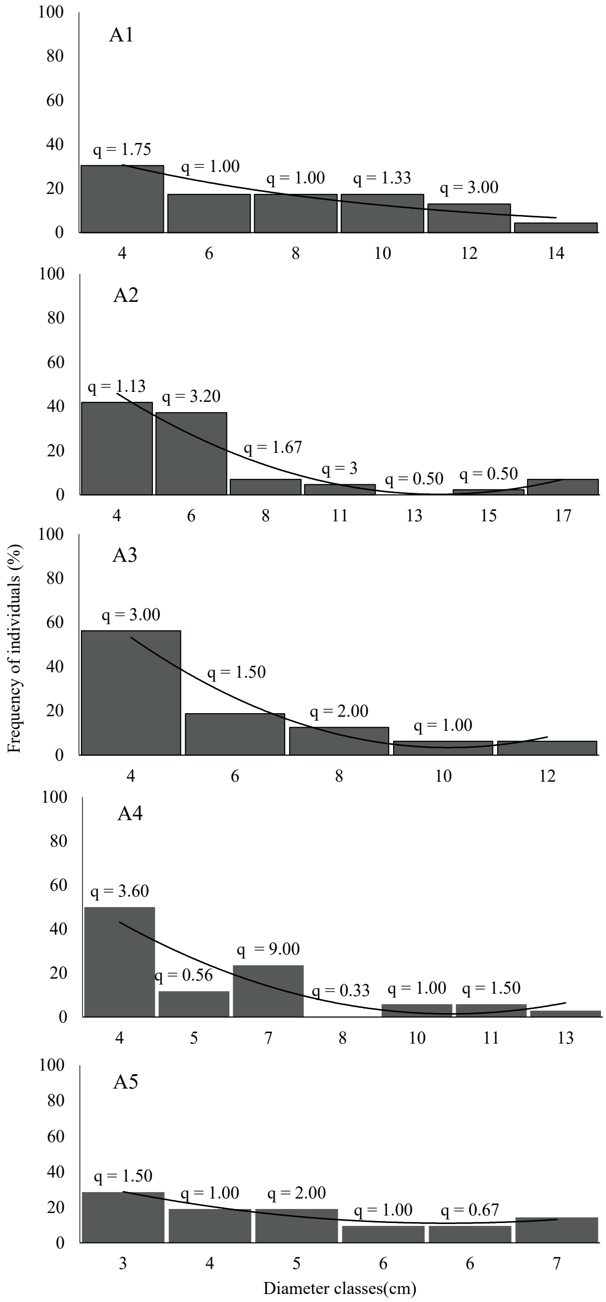

Figure 1. Distribution in diameter classes and D'Liocourt quotient 'q' of individuals from *Dimorphandra mollis* Benth., in five Cerrado areas (A1, A2, A3, A4 and A5) located in the Pandeiros River Environmental Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil.

The presence or absence of vegetation cover in a specific area can be measured from aerial images. The Normalized Difference Vegetation Index (NDVI) can be obtained based on the assessment of the set of pixels from the images; the closer it is to zero that indicates absence of vegetation (Costa et al. 2020).

Table 1. Data referring to the sampling sufficiency of the survey carried out with *Dimorphandra mollis* Benth. plants, in five areas located in the Pandeiros River Environmental Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil.

Area	Sampling sufficiency	Average standard deviation	Error (%)
A1	178.32	0.50	0.42
A2	268.02	1.14	0.52
A3	284.56	0.49	0.53
A4	230.41	0.83	0.48
A5	299.08	0.59	0.55
All areas*	300.86	0.35	0.30

* Analysis considering data from all areas in the same data set.

The analysis of aerial images captured by drone shows that all areas present absence of vegetation to some degree. The areas A1 and A3, which have a recent history of extractivism, are the ones that visually showed the highest degree of degradation by NDVI. This corroborates what was observed *in locu* (Figure 2).

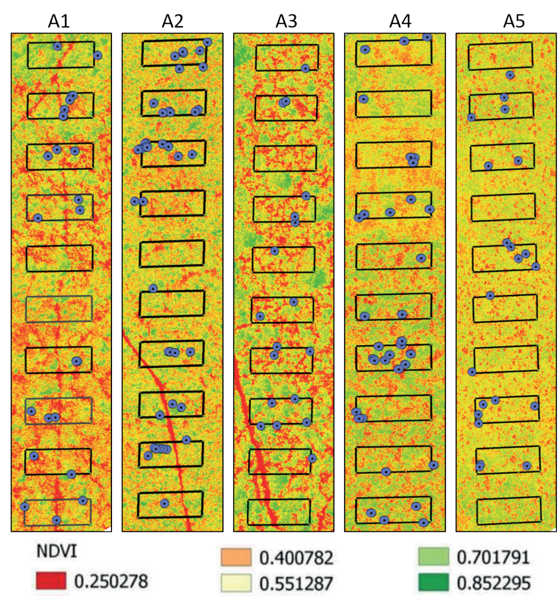

Figure 2. Occurrence of *Dimorphandra mollis* Beth. plants in plots distributed in five areas (A1, A2, A3, A4 and A5) located in the Pandeiros River Permanent Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil. The picture was obtained based on Normalized Difference Vegetation Index maps generated from images taken by drone flying over the evaluated areas. * The closer the pixel is to 0 (red in the image), that indicates absence of vegetation. ** The black lines represent the delimitation of the plots. *** The blue circles represent the location of all plants that have been observed.

The areas had a total number of plants ha^{-1} equal to 24, 43, 18, 34 and 21, respectively for areas A1, A2, A3, A4 and A5. The number of *D. mollis* plants ha^{-1} commonly varies along Cerrado areas, according to results presented by Rocha et al. (2014), Lehn et al. (2008) and Carielo et al. (2012), who found 200, 73 and 15 plants ha^{-1} of *D. mollis*, respectively. The distribution of the species shows an aggregate distribution pattern (Id > 1) for all the assessed areas (Table 2). This distribution pattern of the species is due to one of its forms of dispersion, *barocoria*, in which the fruits are dispersed by gravity, favoring the increase of the population by recruiting individuals close to the matrix plant (Bezerra et al. 2020).

Areas with the largest number of plants ha^{-1} are expected to be the most productive ones. Nonetheless, as shown in Table 3, where the annual yields and number of productive plants per year of assessment are presented, this was not the standard observed for *D. mollis*, as the area with the highest number of plants ha^{-1} (A2) did not correspond to the area with the highest average yield in the three years of evaluation (A4).

Table 2. Density and distribution pattern of *Dimorphandra mollis* Benth., in the Pandeiros River Environmental Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil.

Area	TN	NP	G (m² ha^{-1})	Id	Calculated χ^2	Tabulated χ^2
A1	24	23	0.12	1.03	9.61	3.33
A2	43	43	0.19	1.43	27.00	3.33
A3	18	16	0.05	1.17	11.50	3.33
A4	34	34	0.09	1.28	18.35	3.33
A5	21	21	0.04	1.29	14.71	3.33

* TN: total number of plants; NP: number of plants with diameter at breast height (DBH) greater than or equal to 3 cm; G: occupation of *Dimorphandra mollis* in forest stand considering its DBH; Id: Morisite index to determine the aggregate distribution pattern (> 1).

Table 3. Yield of *Dimorphandra mollis* Benth., from 2018 to 2020, in the Pandeiros River Environmental Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil.

Area	Yield* (kg ha^{-1})			Average yield (kg ha^{-1})	Producing plants (plants ha^{-1})		
	2018	2019	2020		2018	2019	2020
A1	2.35	1.81	5.33	3.17 ± 4.45	7	7	7
A2	0.94	3.49	1.11	1.85 ± 0.99	2	4	7
A3	3.28	8.07	0.46	3.94 ± 3.10	5	8	3
A4	2.49	4.02	5.64	4.05 ± 0.75	9	13	9
A5	0.42	0.69	1.56	0.89 ± 0.37	4	6	8
Average	1.90 ± 1.18	3.62 ± 2.82	2.82 ± 2.46	2.78 ± 2.15	5.4 ± 2.70	7.6 ± 3.3	6.8 ± 2.28

* The yield (kg ha^{-1} of dry fruits) based on dry weight was obtained for a yield of 45.6 % of dry matter.

Table 4. Biometry of *Dimorphandra mollis* Benth. fruits harvested in the Pandeiros River Environmental Preservation Area, in Bonito de Minas, Minas Gerais state, Brazil.

Area	Thickness (mm)	Length (cm)	Dry matter (g)
A1	8.75 a*	14.23 a	16.09 a
A2	7.60 a	15.23 a	11.95 a
A3	7.03 a	16.35 a	15.15 a
A4	11.45 a	17.13 a	22.23 a
A5	7.80 a	15.68 a	14.21 a
Average	8.73 ± 2.3	15.73 ± 2.1	15.93 ± 5.5

* Avarages followed by the same letter in the column do not differ by the Tukey test at 5 % of probability.

The fruits from the five areas showed no statistical differences, regarding the biometrics (Table 4), with thickness and average length of 8.73 ± 2.3 mm and 15.73 ± 2.1 cm, respectively. The dry mass of the fruits also showed no statistical difference among the areas (15.93 ± 5.5 g).

The number of productive plants was higher in the second year of evaluation, which also showed a higher average yield. The variation observed along the years shows that *D. mollis* has a biennial production pattern. The data in this study confirm the trend reported by Caldeira Júnior et al. (2008), on the phenology of *D. mollis* plants.

Silva (2007) reported that, for *D. gardneriana*, the number of plants ha^{-1} varied from 39 to 120, with yield of approximately 186.4 kg ha^{-1} $year^{-1}$ in 2005 and 430.8 kg ha^{-1} $year^{-1}$ in 2006, also demonstrating a biennial production trend. This author also presented that the largest number of plants had DBH between 5 and 15 cm. Considering the observed interval for *D. gardneriana*, a similar behavior was observed for *D. mollis* in this study, in relation to the DBH; however, the *D. mollis* yield was lower than that of *D. gardneriana*. The biennial production pattern has impacts on the availability of fruits for the industries, which must adapt the processing chain according to the perspective of fruit production.

The higher yield in areas where *D. mollis* occurs depends, for example, on the increase in the number of plants per area. The population structure of this species will also influence the yield over a longer period. The binary logistic regression analysis showed that trees with DBH between 8.20 and 14.40 cm are more than 70 % likely to be reproducing (Figure 3). The general average DBH of all monitored plants was equal to 6.05 ± 3.07 cm.

The summation of the production from the three years of evaluation showed a significant positive correlation with the DBH of the trees [r = 0.46**; yield (kg) = 0.36** x DBH (cm) - 0.98]. This shows that there is a tendency that the higher the DBH, the greater is the *D. mollis* production over time. However, the presence of plants in the larger diameter classes is reduced. Human actions such as burning and deforestation directly impact on the species population structure, and, with that, there is a reduction in the number of larger plants. The entire Pandeiros River EPA has a previous record of deforestation for charcoal production (Nunes et al. 2009, Magalhães & Cunha 2011, Dias et al. 2017), and this is reflected in what was observed in the present study, a reduced number of plants with larger diameters, with greater probability of production.

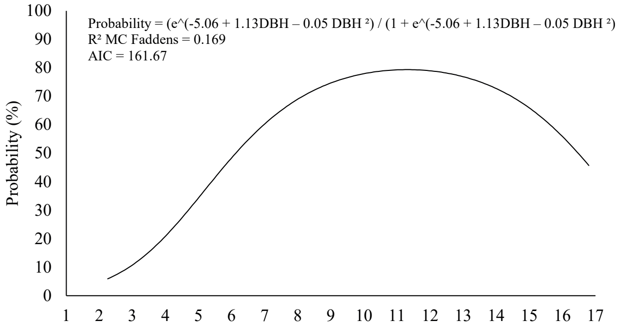

Figure 3. Probability of *Dimorphandra mollis* Benth. trees presenting fruit yield according to the diameter at breast height (DBH = 1.30 m).

From the results observed in this study, it is possible to say that 2.70 ha of Cerrado are necessary to produce 7.3 kg of dried fruits of *D. mollis*, in order to produce 1 kg of rutin, considering that the dry matter yield is 45.6 % and the rutin content in dried fruits is 13.8 %.

CONCLUSION

Dimorphandra mollis Benth. presents an average annual yield of 2.74 kg ha^{-1} of dry fruits, varying along the years, with a biennial production characteristic. Its diametric distribution presents a pattern with a tendency to an inverted "J" shape, with a distribution pattern of individuals being the aggregate one.

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