Acta Botanica Brasilica - 34(2): 401-408. April-June 2020.
doi: 10.1590/0102-33062019abb0408

Structural assessment of a population of *Anacardium humile* subjected to fire during different periods of the year

Diego Guimarães de Sousa[1*] and Hélida Ferreira da Cunha[2]

Received: December 23, 2019
Accepted: April 2, 2020

ABSTRACT

Understanding how fire affects the plant biota of the Cerrado is essential for formulating conservational strategies. We evaluated the effects of fires during different periods of the year on the populational structure of *Anacardium humile*. The research was carried out in areas of typical cerrado *stricto sensu* in the territory of the Kalunga, state of Goiás, Brazil. These areas, which comprise the same population, were submitted to the following treatments: unburned (control), burned in May 2016 (early fire - EF), and burned in September 2016 (late fire - LF). In July 2018, we delimited two contiguous transects of 100 x 20 m, subdivided into 10 plots of 20 x 20 m, in each area. Fire stimulated the development of branches from basal regrowth in EF and LF. No differences were found in height and diameter of individuals among LF, EF, and the control area. Individuals of EF had size patterns similar to the control individuals, indicating a lesser effect of early fire. The greatest differences regarding all significant parameters were found between LF and control individuals. Early prescribed fires, depending on periodicity, may be less harmful to *A. humile*.

Keywords: Anacardiaceae, burning, Cerrado, fire, impact, regimes

Introduction

Fire can change the structure, dynamics, and phenological behavior of Cerrado plant communities and populations (Medeiros & Miranda 2005; Libano & Felfili 2006). For at least 10 million years, the Cerrado coexists with fire (Simon *et al*. 2009), which resulted in the adaptation of plants (Coutinho 1990; Eiten 1994). Natural fires are caused by lightning and are more frequent at the end of the dry season and during the rainy season (Ramos-Neto & Pivello 2000). However, about 35,000 years ago, the occurrence of fires started to change due to human actions (Watanabe *et al*. 2003). In recent history, these anthropogenic fires have been increasingly frequent and concentrated in the dry season (Fidelis & Pivello 2011), becoming one of the main threats to the Cerrado biodiversity (Durigan *et al*. 2007).

Consecutive fires affect the reproduction and phenology of Cerrado plants (Whelan 1995). The success of regrowth is higher in wood and shrub species in savanna-like phytophysiognomies (Coutinho 1990; Ramos 1990; Hoffman 1998; Felfili *et al*. 1999). However, for other species, such as monocotyledons that occupy the lower strata, sexual reproduction is stimulated through post-fire flowering (Maitre & Midgley 1992; Abrahamson 1999; Munhoz & Felfili 2005; 2007; Miola *et al*. 2010).

The timing and frequency of fires can affect flowering and fruiting (Miranda 1995; Sanaiotti & Magnusson 1995; Miola *et. al*. 2010; Palermo & Miranda 2012; Françoso *et al*. 2014; Deus *et al*. 2016; Sousa & Cunha 2018b), seed banks and dispersal (Cirne & Miranda 2008; Xavier 2011),

1 Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis, 74605-090, Goiânia, GO, Brazil
2 Unidade Universitária, Universidade Estadual de Goiás, 75132-903, Anápolis, GO, Brazil

* Corresponding author: diegoagro97@hotmail.com

recruitment and mortality rates of many species (Medeiros & Miranda 2005; Bouchartdet *et al.* 2015), and the size and distribution of regrowth (Silva *et al.* 2009; Dodonov *et al.* 2014), especially in dryer months (Sato 2003). The short intervals between fires prevent seedling development and recruitment, and successive regrowth results in depletion of storage organs (Whelan 1995; Medeiros 2002). This changes the population structure of species, and as a consequence, the entire plant community (Whelan 1995; Sano *et al.* 2008).

How fire negatively affects the reproduction of Cerrado plants depends on spatial and temporal variations of the fire, edaphoclimatic factors, as well as flame height, speed, and intensity (Miranda *et al.* 2010). Besides, it depends on the inherent attributes of each species such as size, architecture, phenology, reproductive success, mechanisms of seed protection, and seedling resprouting (García-Núñez *et al.* 2001; Bouchartdet *et al.* 2015; Lucena *et al.* 2015; Gawryszewski *et al.* 2019). Furthermore, the amount and moisture of plant fuel and the structure and organization of plant communities influence the fire behavior (Castro & Kauffman 1998; Rissi *et al.* 2017).

Anthropogenic forest fires occurring during the dry season usually have higher coverage and intensity (França *et al.* 2007). In this sense, there are ongoing discussions to approve a national policy to prevent and fight forest fires by using prescribed fires as a conservation tool in public and private areas (Durigan & Ratter 2016; Fidelis & Pivello 2011). In this case, the use of prescribed fires at the end of the rainy season or beginning of the dry season (early fires) may reduce the amount of dead fuel that accumulates during the dry season. This would mitigate the risk of large-scale and intense fires (Pivello *et al.* 2010; Fidelis & Pivello 2011), cited as having the greatest impact on Cerrado biodiversity.

In the cerrado *stricto sensu*, early fires tend to be less intense and to have lower temperatures in comparison to mid (August, when most anthropogenic fires occur) and late fires (September, the end of the dry season), because of the lower amount of dry biomass, mainly grasses. This results in lower mortality, less damage to woody stems (Ramos-Neto & Pivello 2000; Sato 2003; Miranda *et al.* 2006; Miranda *et al.* 2009), and therefore, lower greenhouse gas emissions in the other periods (Russell-Smith *et al.* 2009). Moreover, mid and late fires occur during the period of significant phenological activity for many species of the Cerrado that lose leaves and bear fruit during the dry season (Oliveira 2008; Pirani *et al.* 2009; Silvério & Lenza 2010; Lucena *et al.* 2015). Thus, these fires can limit regrowth since part of the carbohydrate and nutrient reserves were spent on the vegetative and reproductive phenological activity of the plants (Hoffmann & Solbrig 2003; Pirani *et al.* 2009; Françoso *et al.* 2014; Dodonov *et al.* 2018).

However, there are still many gaps regarding the effect of these fires in the Cerrado biota, which requires more research to support public policies that favor the adequate use of this conservation tool (Medeiros & Fiedler 2004; Durigan & Ratter 2016). Therefore, in this study, we aim to assess the effect of fires during different periods of the year (early and late dry season) on the population structure of *Anacardium humile* in typical cerrado *scricto sensu* areas. Changes in populations - as addressed in the present study - depend on individual characteristics (Bond & Wilgen 1996) that are essential to recognize the ecosystem responses to fire. These individual characteristics can be observed in a shorter period than those related to the effect of the season and frequency of fires on communities and ecosystems (Giroldo 2016).

Anacardium humile is a small shrub and subshrub species, abundant in the territory of the Kalunga, in the state of Goiás (Sousa & Cunha 2018a), and it is subject to damage directly caused by high- or low- intensity fires (Carvalho *et al.* 2005), which influenced its choice as model species for this experiment. We hypothesize that there will be differences in the population structure of *A. humile* among areas subjected to fires during different periods of the year. Moreover, we expect individuals subjected to early fire (May) to have a population structure more similar to those in the control area than to individuals subjected to late fire (September). In this case, the early fire would have less impact on the population of *A. humile*, reinforcing the use of this tool for forest fire prevention and species conservation.

Material and methods

Study area

The study was carried out in a cerrado *stricto sensu* area within the territory of the Kalunga community, municipality of Cavalcante, north region of the state of Goiás, Brazil (13º36'09" S and 47º27'26" W). Climate is tropical Aw (Köppen-Geiger classification) with two defined seasons, a rainy season between October and April and a dry season between May and September. The mean precipitation is around 1300 and 1500 mm and the mean temperature is 25 ºC (Fundação Grupo Boticário 2011). The population of *A. humile* is found in altitudes varying between 950 and 1052 m. The soil is sandy with rocky outcrops and gravel, classified as litholic dystrophic Neossolo (EMBRAPA - Solos 2006; Fundação Grupo Boticário 2011).

Studied specie

Anacardium humile A.St.-Hil. (Anacardiaceae), commonly named cajuí or caju-do-campo, is a heliophyte and melliferous plant (Almeida *et al.* 1998) that often occurs in *campo rupestre* and cerrado *stricto sensu* phytophysiognomies (Agostini-Costa *et al.* 2016). The species is widely distributed in the Brazilian Cerrado and can also be found in Bolivia and Paraguay (Agostini-Costa *et al.* 2016). It reaches 30 to 150 cm height and has a shrubby and subshrubby habit with an underground stem (Almeida *et al.* 1998; Silveira *et al.*

2009). This small size makes the species more susceptible to anthropogenic land use and fire damage (Carvalho *et al*. 2005). On the other hand, it has deep roots, and the largest portion of its stem biomass is underground. The presence of xylopodium provides protection and resistance to fire and drought (Agostini-Costa *et al*. 2016), which makes it frequent in burned environments (Loiola *et al*. 2010). In the territory of the Kalunga, the flowering occurs between May and September, with fruiting occurring from July to September (Sousa & Cunha 2018b). The high ratio of 4:1 between male and hermaphrodite flowers (Almeida *et al*. 1998), the inability of some hermaphrodite flowers to turn into fruits, the tendency of stamen pollen grains to remain attached to the anther after dehiscence, and the existence of only one fertile stamen in the staminate flowers are mentioned as reasons for its poor pollination (Ferrão 1995). The true fruit is reniform, with hard and dry pericarp, brown in color, reaching its final size before the pedicel thickens and modifies to a berry shape (Barroso *et al*. 1999). False fruits and true fruits are valued locally as a food source (Almeida *et al*. 1998).

Experimental design and inventory

In 2015, the Centro Nacional de Prevenção e Combate aos Incêndios Florestais (PREVFOGO) of the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) started to perform prescribed fires in the territory of the Kalunga. In 2016, in agreement with the actions of IBAMA/PREVFOGO, we subdivided an area without fire records for at least five years, which comprises the same population of *A. humile*, into two areas. The first area, with about three hectares, was subjected to prescribed fire on May 14th, 2016 (beginning of the dry season), and became the experimental area 1, hereafter called early fire - EF. The second area, with just over 30 hectares and adjacent to the burned area, remained protected from fire and became our control area. However, in September 2016 (end of the dry season), a fire occurred in the control area and consumed approximately five hectares. This area was then used as the experimental area 3, hereafter called late fire - LF. The flames in the EF area were, on average, 0.33 m height, with average fire spread of 0.019 m/s, and in the LF area, the flames were, on average, 2.86 m height, with average fire spread of 0.11 m/s.

In July 2018, we delimited two contiguous transects of 100 x 20 m, subdivided into 10 plots of 20 x 20 m, totalizing a sampling surface of 4,000 m^2 in each experimental area. We performed a census of all individuals within each plot. For each surveyed specimen, we collected the geographic location within the plot (latitude and longitude) and the number of branches. We also recorded the total height (from ground level to the stem apex) and basal diameter at the ground level of the main branch (the one with the highest total height) of each plant. Finally, we measured the crown area of each individual from the crown projections in N, S, E, and W directions, starting with the main branch.

Statistical analysis

For analysis and understanding of the results found, we emphasize that the entire area comprising the population of *A. humile* is rich in rocky outcrops. All the transects contained rocky outcrops, but the transects located in the LF (late fire) treatment had the largest area with outcrops. Since the late fire was caused by an unexpected fire, it was not possible to relocate the transects to other areas because the objective was to inventory the individuals under that condition.

Rocky outcrop areas influence the community structure because they have few and small spaces for plants, shallow soils with low water storage capacity, constant organic matter accumulation, and great daily thermal amplitude and high insolation, besides undergoing long periods of water deficit and short periods with excessive water and floods (Harley 1995; Conceição & Giulietti 2002; Conceição & Pirani 2005; Conceição 2006). These characteristics also influence the fire behavior since the lower amount of fuel in the exposed rock limits the fire progression and contributes to the formation of a mosaic of burned areas, with vegetation islands not directedly affect by the fire (Conceição & Pirani 2005; Neves & Conceição 2010).

Considering the influence that rocky outcrops have on the abundance of *A. humile*, and the need to evaluate the effect of fires on the post-fire species abundance, the local species density before the fire events was adopted as a parameter of comparison. These species density data were published by Sousa & Cunha (2018a). The density of *A. humile* before the fire events was 104.25 ind ha^{-1}(± 60.35), with an amplitude of 46 to 189 ind ha^{-1}. The greater the number of rocky outcrops within the plot, the greater the abundance of *A. humile*, which can be up to 70 % greater than in areas without rocky outcrops.

Statistical analyses were performed using non-parametric tests because of the non-normal distribution of data. Median values of abundance, total height, basal diameter, number of branches, and crown area of individuals in the different experimental areas were compared using a Kruskal-Wallis test (H test; α=0.05) and a Student-Newman-Keuls as post-hoc test. We generated histograms of total height and basal diameter and compared them using the G-test (α=0.05) to assess the differences in the population structure of *A. humile* among the experimental areas. Class intervals were defined by the formula *A/K*, where *A* represents the amplitude of mean values (height and basal diameter) and *K*, the number of class intervals defined by the Sturges' formula: $K = 1 + 3.3 \times \text{Log}(N)$, where N is the number of individuals (Paixão 1993).

Descriptive statistics and the G-test were performed in the Biostat program version 5.0 (Ayres *et al*. 2007) and the

H-tests were performed in the R software (R Development Core Team 2018), using the *vegan* (Oksanen *et al.* 2018) and *agricolae* (Mendiburu 2019) packages, respectively.

Results

We surveyed 120 individuals of *A. humile*, where 24 were in the control area, 22 in EF, and 74 in LF areas. The abundance of individuals were different among the areas (H = 9.1792, p = 0.0102). The number of plants were greater in LF than in control (H = 9.9000, p = 0.0119) and EF (H = 10.5000, p = 0.0077) areas. The abundance of individuals showed no difference between the control and EF (H = 0.6000, p = 0.8789) areas. The estimated density was 60 ind. ha^{-1} in the control area, 55 ind. ha-1 in the EF area, and 185 ind. ha^{-1} in the LF area.

Although the control area showed the highest amplitude of total height and basal diameter, we found no significant difference in the median values between the studied areas (Total height: H = 1.838, p = 0.3989; Basal diameter: H = 3.460, p = 0.177) (Tab. 1). The median number of branches per individual was significantly higher in the EF (5.50 branches $ind.^{-1}$) and LF (4.50 branches $ind.^{-1}$) areas than in the control area (2.00 branches $ind.^{-1}$) (H = 14.377, p = 0.0008). The total amplitude of the number of branches per individual was also higher in the burned areas (EF and LF) than in the control area (Tab. 2). We found no significant difference in the median values of crown areas among the experimental areas (H = 2.102, p = 0.349). The crown area showed a high coefficient of variation in all areas studied (Tab. 2).

Regarding the distribution of individuals by height classes, we found significant differences only between the control and LF (G = 12.215, p = 0.03) areas. The individuals in the control area reached the 165 to 198 cm in height class, while in the LF area, the individuals only reached the 99 to 132 cm class. In all areas, the class with the largest number of individuals was 66 to 99 cm in total height. Individuals taller than 165 cm were observed only in the control area. We found no individuals with a total height above 132 cm in the LF area, and in the EF area, the individuals found did not exceed the class of 132 to 165 cm (Fig. 1).

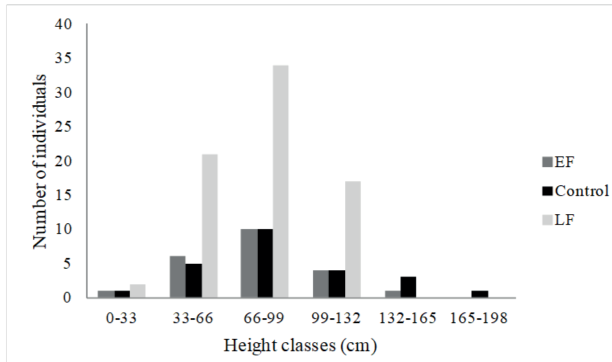

Figure 1. Height classes of *Anacardium humile* individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

Table 1. Descriptive statistics of total height and basal diameter of *Anacardium humile* A. ST.-Hill individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

	EF (N= 22)		Control (N= 24)		LF (N= 74)	
	Total height (cm)	Basal diameter (cm)	Total height (cm)	Basal diameter (cm)	Total height (cm)	Basal diameter (cm)
Minimum	33.00	0.50	24.00	0.30	25.00	0.40
Maximum	140.00	2.00	208.00	3.40	132.00	2.00
Total amplitude	107.00	1.50	184.00	3.10	107.00	1.60
Median	73.50 a	1.00 a	84.50 a	1.20 a	79.50 a	1.00 a
Mean	79.14	1.08	92.17	1.33	78.27	1.01
Standard deviation	28.23	0.40	40.17	0.74	24.60	0.33
Coefficient of variation (%)	35.00	36.00	43.00	55.00	31.00	32.00

Table 2. Descriptive statistics of the number of branches and crown area of *Anacardium humile* A. ST.-Hill individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control) and with late fire (LF), in the municipality of Cavalcante, Goiás, Brazil.

	EF (N= 22)		Control (N= 24)		LF (N= 74)	
	Branches (unid.)	Crown area (m^2)	Branches (unid.)	Crown area (m^2)	Branches (unid.)	Crown area (m^2)
Minimum	1.00	0.18	1.00	0.09	1.00	0.08
Maximum	29.00	7.60	12.00	8.44	30.00	5.18
Total amplitude	28.00	7.42	11.00	8.35	29.00	5.10
Median	5.50 b	1.16 a	2.00 a	0.49 a	4.50 b	0.63 a
Mean	8.73	1.64	3.37	1.33	5.81	1.03
Standard deviation	7.28	1.89	3.05	1.86	4.76	1.06
Coefficient of variation (%)	83	115	90.00	139	82	103

We found significant differences in the distribution of basal diameter classes only between the control and LF areas (G = 11.571, p = 0.041). In the control area, the individuals reached the basal diameter class of 2.80 to 3.36 cm, while in the LF area, the individuals were limited to the class of 1.68 to 2.24 cm. Most of the surveyed individuals in all areas were distributed in the basal diameter class of 0.56 to 1.12 cm. The LF area had the largest number of individuals in the first basal diameter class (Fig. 2).

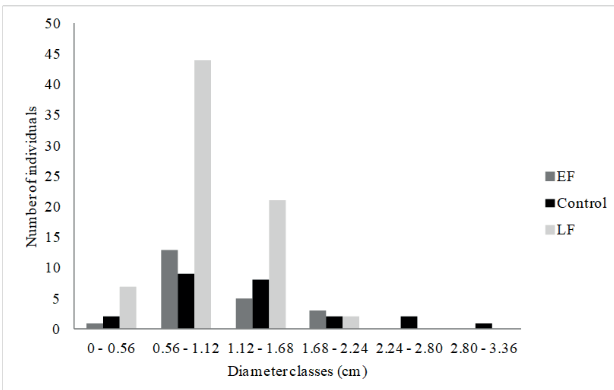

Figure 2. Basal diameter classes of *Anacardium humile* individuals surveyed in the cerrado *stricto sensu* areas with early fire (EF), without fire record for seven years (Control), and with late fire (LF), in the municipality of Cavalcante, state of Goiás, Brazil.

Discussion

The abundance of individuals was not different between the control and EF areas, and the higher abundance in the LF area may be related to the large number of rocky outcrops observed within the plots. Although the rocky area within the plots was not calculated, the LF area had a higher number of rocky outcrops than the other areas. As a result, about 60 % of the LF individuals were in rocky outcrop sites, which are preferred environments of the local population of *A. humile* (Sousa & Cunha 2018a). In this case, the fire had no influence on the abundance of individuals in the EF and LF areas.

Anacardium humile has a low potential for sexual reproduction (Carvalho *et al.* 2005). In 2016, the fruit production by the studied population was low (Sousa & Cunha 2018b). Therefore, we believe that natural regeneration had a low contribution to the abundance observed in the LF area. Nevertheless, the species germinates and develops well in sandy soils (Rodrigues *et al.* 2016; Zuffo 2018), and have high growth rates and increased leaf numbers in fire-disturbed environments (Fernandes 2012).

The fire stimulated underground or basal regrowth in individuals located in the EF and LF areas because the number of branches per individual in these areas was significantly higher than in the control area. Vegetative reproduction or branch regrowth occurs in response to events such as fires and are common in woody plants of the Cerrado (Coutinho 1990; Muramaki & Klink 1996; Hoffmann 1998; 1999; Hoffmann & Solbrig 2003; Sato 2003; Ribeiro *et al.* 2012). Plants with heights between 1.0 and 1.5 m have higher rates of topkill and subsequent regrowth in the epigeal part of gemmiparous roots or basal stem, as a measure of rapid post-fire recovery (Miranda & Sato 2005; Vale & Lopes 2010; Ribeiro *et al.* 2012). In the specific case of *A. humile*, after losing the aerial parts due to fires, the plagiotropic shoots reactivate, reversing the growth direction. This differentiation is rapid and occurs before the grass and herbaceous regenerative organs cover the soil surface (López-Naranjo & Pernía 1990).

The median values of total height and basal diameter were not different among the areas, probably because this species is a fast-growing shrub after a fire disturbance (López-Naranjo & Pernía 1990; Fernandes 2012; Sousa & Cunha 2018a). Thus, after about two years of the fire disturbance in the areas, the individuals had similar height and basal diameter. This occurred due to the rapid growth from natural regeneration through sexual reproduction, and especially, regrowth through asexual reproduction. Considering the small size of *A. humile* individuals and the great post-fire regrowth, we found that for a single fire event, regardless of the season (early or late fire) and in at least two years, both the height and the diameter are not decisive parameters for the species survival. This pattern is likely to apply mainly to species with underground reproductive structures such as *Coccoloba cereifera* (Furst *et al.* 2017). Considering the fire recurrence, experiments have demonstrated that the diameter and regrowth capacity of individuals are key factors for their survival (Hoffmann 1998; 1999; Medeiros & Miranda 2005; Miranda & Sato 2005). In these circumstances, woody species, such as *Guapira graciliflora* and *Guapira noxia*, with low regrowth capacity, show lower survival rates (Rios *et al.* 2019) than species with underground reproductive structures (gemmiparous roots, xylopodia, and rhizophores), such as *Rourea induta*, *Myrsine guianensis*, and *Piptocarpha rotundifolia* (Hayashi 2003; Hoffmann & Solbrig 2003; Diniz & Franceschinelli 2014).

The fire regime and behavior (higher flame height and spread rate in the LF area) explain the differences observed in the distribution of individuals in the diameter and height classes between the control and LF areas. We did not find these differences between the control and EF areas, and EF and LF areas. Individuals in the highest height and diameter classes were found almost exclusively in the control area and were absent from the LF area. This shows the mass topkill effect in the LF area, which eliminated the structures with larger diameter and height. The process was followed by intense basal regrowth of *A. humile* individuals, which after a little more than two years of the fire occurrence, demonstrated smaller amplitudes.

The late fire had higher flame height (mean of 2.86 m) and spread rate (0.11 m/s) than the early fire (mean flame height: 0.33 m; spread rate: 0.019 m/s). Considering the average height of individuals in the control area (92.17 cm), which represent the size of those within the burned areas at the time of fire spread, the flames in the LF area exceeded the size of the plants over 2 m, thus, with a great damage potential to *A. humile* individuals. Individuals in this area were more vulnerable to mass topkill, different from the EF area, where the flames had an average height of 0.33 m, lower than the average height of their individuals.

The lower values of flame height and spread rate in the EF area indicate less fire intensity. The less intense early fire resulted in a lower impact on *A. humile* individuals that showed intermediate size structures, and thus, not significantly different from those located in the control and LF areas. It is important to emphasize that, considering at least two years after the early and late fires, the fire did not threaten the local existence of the species in both EF and LF areas. This result highlights the evolutionary behavior of this species regarding fire events. One of the survival strategies of this species consists of regrowth and emission of post-fire branches in both low- and high-severity fires. Similar results were found by Dodonov *et al.* (2014) for the shrub species *Miconia albicans*.

Conclusion

Fire changed the population structure of *A. humile* individuals subjected to fires during different periods of the year, by stimulating the production of sprouts and reducing the diameter and height of their individuals. The most significant differences occurred between the LF and control areas, evidencing the effect of the higher fire intensity. As expected, individuals of the EF area evidenced an intermediate pattern between the control and LF areas. This result suggests that, depending on the periodicity, fires at the beginning of the dry season are more suitable to reduce the surface fuel of the Cerrado and to maintain the *A. humile* populations feasibly conserved.

Height and diameter parameters should not be considered as limiting factors for the survival of *A. humile*, and this pattern is related to the presence of underground reproductive structures. The regrowth capacity and rapid post-fire growth of *A. humile* individuals stand out for their ability to reproduce sexually, and they are likely the main resilience mechanisms of this species in the Cerrado. Studies assessing the effect of fire frequency and periodicity on *A. humile* populations may indicate the limit of species resilience (exhaustion of regrowth capacity) and collaborate with strategies for its conservation.

Acknowledgements

We thank the Kalunga fire brigade of IBAMA/PREVFOGO and Damião Moreira dos Santos for support in fieldwork. We dedicate this study to the memory of Augusto Avelino de Araújo, former coordinator of PREVFOGO/IBAMA in Goiás, a pioneer in the use of fire for the Cerrado conservation. H.F.C thanks CNPq for the CNPq research productivity fellowships (Process n. 302198/2015-6).

References

Abrahamson WG. 1999. Episodic reproduction in two fire-prone palms, *Serenoa repens* and *Sabal etonia* (Palmae). Ecology 80: 100-115.

Agostini-Costa TS, Faria JP, Naves RV, Vieira RF. 2016. *Anacardium* spp.: caju-do-cerrado. In: Vieira RF, Camilo J, Coradin L. (eds.) Espécies nativas da flora brasileira de valor econômico atual ou potencial: Plantas para o Futuro: Região Centro-Oeste. Brasília, Ministério do Meio Ambiente. p. 138-149.

Almeida SP, Proença CEB, Sano SM, Ribeiro JF. 1998. Cerrado: espécies vegetais úteis. Planaltina, Embrapa-CPAC.

Ayres M, Ayres Júnior M, Ayres DL, Santos AA. 2007. BIOESTAT – Aplicações estatísticas nas áreas das ciências bio-médicas. Belém, Instituto Mamirauá.

Barroso GM, Morim MP, Peixoto AL, Ichaso CLF. 1999. Frutos e sementes: morfologia aplicada à sistemática de dicotiledôneas. Viçosa, Editora UFV.

Bond WJ, Wilgen BW. 1996. Fire and Plants. Dordrecht, Springer Netherlands.

Bouchartdet DA, Ribeiro IM, Souza NA, Aires SS, Miranda HS. 2015. Efeito de altas temperaturas na germinação de sementes de *Plathymenia reticulata* Benth. e *Dalbergia miscolobium* Benth. Revista Árvore 39: 697- 705.

Carvalho MP, Santana DG, Ranal MA. 2005. Emergência de plântulas de *Anacardium humile* A. St.-Hil. (Anacardiaceae) avaliada por meio de amostras pequenas. Brazilian Journal of Botany 28: 627-633.

Castro EA, Kauffman JB. 1998. Ecosystem structure in the Brazilian Cerrado: a vegetation gradient of aboveground biomass, root mass and consumption by fire. Journal of Tropical Ecology 14: 263-284.

Cirne P, Miranda HS. 2008. Effects of prescribed fires on the survival and release of seeds of *Kielmeyera coriacea* (Spr.) Mart. (Clusiaceae) in savannas of Central Brazil. Brazilian Journal of Plant Physiology 20: 197-204.

Conceição AA, Giulietti AM. 2002. Composição florística e aspectos estruturais de campo rupestre em dois platôs do Morro do Pai Inácio, Chapada Diamantina, Bahia, Brasil. Hoehnea 29: 37-48.

Conceição AA, Pirani JR. 2005. Delimitação de habitats em campos rupestres na Chapada Diamantina: substratos, composição florística e aspectos estruturais. Boletim de Botânica da Universidade de São Paulo 23: 85-111.

Conceição AA. 2006. Plant ecology in 'campos rupestres' of the Chapada Diamantina, Bahia. In: Queiroz LP, Rapini A, Giulietti AM. (eds.) Towards greater knowledge of the brazilian semi-arid biodiversity. Brasília, Ministério da Ciência e Tecnologia. p 63-67.

Coutinho LM. 1990. Fire in the Ecology of Brazilian Cerrado. In: Goldammer JG. (ed.) Fire in the tropical biota: Ecological processes and global challenges. Berling, Springer-Verlag. p. 82- 105

Deus FF, Oliveira PM. 2016. Changes in floristic composition and pollination systems in a "Cerrado" community after 20 years of fire suppression. Brazilian Journal of Botany 39: 1051-1063.

Diniz VSS, Franceschinelli EV. 2014. Estrutura populacional e brotamento de três espécies nativas do cerrado em diferentes regimes de queimada. Revista de Biologia Neotropical 11: 107-115.

Dodonov P, Xavier RO, Tiberio FCS, Lucena IC, Zanelli CB, Matos DMS. 2014. Driving factors of small-scale variability in a savanna plant population after a fire. Acta Oecologica 56: 47-55.

Dodonov P, Zanelli CB, Silva-Matos DM. 2018. Effects of an accidental dry-season fire on the reproductive phenology of two Neotropical savanna shrubs. Brazilian Journal of Biology: 78: 564-573.

Durigan G, Siqueira MF, Franco GADC. 2007. Threats to the Cerrado remnants of the state of São Paulo, Brazil. Scientia Agricola 64: 355-363.

Durigan G, Ratter JA. 2016. The need for a consistent fire policy for Cerrado conservation. Journal of Applied Ecology 53: 11-15.

Eiten G. 1994. Vegetação do Cerrado. In: Pinto MN. (ed.) Cerrado: caracterização, ocupação e perspectivas. Brasília, Edunb/SEMATEC. p. 17-73.

EMBRAPA - Solos. 2006. Sistema Brasileiro de Classificação de Solos. 5th. edn. Brasília, Embrapa Solos.

Felfili JM, Silva-Junior MC, Dias BJ, Rezende AV. 1999. Estudo fenológico de *Stryphnodendron adstringens* (Mart.) Coville no cerrado *sensu stricto* da Fazenda Água Limpa no Distrito Federal, Brasil. Brazilian Journal of Botany 22: 83-90.

Fernandes TA. 2012. Sobrevivência e crescimento inicial de espécies de cerrado após perturbação por fogo. MSc Thesis, Universidade Federal do Tocantins, Porto Nacional.

Ferrão JEM. 1995. O cajueiro (*Anacardium occidentale* L.). Lisboa, Instituto de Investigação Cientifica Tropical.

Fidelis A, Pivello VR. 2011. Deve-se usar o fogo como instrumento de manejo no Cerrado e Campos Sulinos? Biodiversidade Brasileira 2: 12-25.

França H, Ramos-Neto MB, Setzer A. 2007. O fogo no Parque Nacional das Emas. Brasília, Ministério do Meio Ambiente.

Françoso R, Guaraldo AC, Prada M, Paiva AO, Mota EH, Pinto JRR. 2014. Fenologia e produção de frutos de *Caryocar brasiliense* Cambess. e *Enterolobium gummiferum* (Mart.) J.F.Macbr. em diferentes regimes de queima. Revista Árvore 38: 579-590.

Fundação Grupo Boticário. 2011. Plano de Manejo da Reserva Natural Serra do Tombador. Gatti GA, Curitiba, Brasil. 2011. http://www.icmbio.gov.br/portal/images/stories/docs-planos-de-manejo/pm_Serra_do_Tombador2.pdf.

Furst H, Silva RP, Fernandes GW, *et al.* 2017. Rebrotamento pós-fogo em arbusto ameaçado e microendêmico dos campos rupestres da Serra do Cipó, sudeste do Brasil. Neotropical Biology & Conservation 12: 143-149.

García-Núñez C, Azócar A, Silva JF. 2001. Seed production and soil seed bank in three evergreen woody species from a neotropical savanna. Journal of Tropical Ecology 17: 563-576.

Gawryszewski FM, Sato MN, Miranda HS. 2019. Frequent fires alter tree architecture and impair reproduction of a common fire-tolerant savanna tree. Plant Biology 22: 106-112.

Giroldo PZ. 2016. Efeitos da época de queima em um campo sujo de Cerrado. PhD Thesis, Universidade de São Paulo, São Paulo.

Harley RM. 1995. Introduction. In: Stannard BL. (ed.) Flora of the Pico das Almas, Chapada Diamantina, Brazil. Kew, Royal Botanic Gardens Kew. p. 1-42.

Hayashi AH. 2003. Morfo-anatomia de sistemas subterrâneos de espécies herbáceo-subarbustivas e arbóreas, enfatizando a origem das gemas caulinares. PhD Thesis, Universidade Estadual de Campinas, Campinas.

Hoffmann WA, Solbrig OT. 2003. The role of topkill in the differential response of savanna woody species to fire. Forest Ecology and Management 180: 273-286.

Hoffmann WA. 1998. Post-burn reproduction of woody plants in a neotropical savanna: the relative importance of sexual and vegetative reproduction. Journal of Applied Ecology 35: 422-433.

Hoffmann WA. 1999. Fire and population dynamics of woody plants in a neotropical savanna: matrix model projections. Ecology 80: 1354-1369.

Libano AM, Felfili JM. 2006. Mudanças temporais na composição florística e na diversidade de um cerrado sensu stricto do Brasil Central em um período de 18 anos (1985-2003). Acta Botanica Brasilica 20: 927-936.

Loiola PD, Cianciaruso MV, Silva IA, Batalha MA. 2010. Functional diversity of herbaceous species under different fire frequencies in Brazilian savannas. Flora-Morphology, Distribution, Functional Ecology of Plants 205: 674-681.

López-Naranjo H, Pernía NE. 1990. Anatomia y ecologia de los organos subterraneos de *Anacardium humile* A. St.-Hil. (Anacardiaceae). Revista Forestal Venezolana 24: 55-76.

Lucena IC, Leite MB, Matos DMS. 2015. A deciduidade foliar indica a vulnerabilidade de espécies lenhosas ao fogo. Revista Árvore 39: 59-68.

Maitre DC, Midgley JJ. 1992. Plant Reproductive Ecology. In: Cowling RM. (ed.) The ecology of Fynbos: nutrients, fire and diversity. Cape Town, Oxford University Press. p. 135-174

Medeiros MB, Fiedler NC. 2004. Incêndios florestais no Parque Nacional da Serra da Canastra: desafios para a conservação da biodiversidade. Ciência Florestal 14: 157-168.

Medeiros MB, Miranda HS. 2005. Mortalidade pós-fogo em espécies lenhosas de campo sujo submetidas a três queimadas prescritas anuais. Acta Botanica Brasilica 19: 493-500.

Medeiros MB. 2002. Efeitos do fogo nos padrões de rebrotamento de plantas lenhosas, em campo sujo, após queimadas prescritas. PhD Thesis Universidade de Brasília, Brasília.

Mendiburu O. 2019. Agricolae: Statistical Procedures for Agricultural Research. R package version 1.3-1. 2019. https://CRAN.R-project.org/package=agricolae. 01 May 2019.

Miola DTB, Correia HVL, Fernandes GW, Negreiro D. 2010. Efeito do fogo na fenologia de *Syagrus glaucescens* Glaz. ex Becc. (Arecaceae). Neotropical Biology & Conservation 5: 146-153.

Miranda HS, Nascimento Neto W, Neves BMC. 2010. Caracterização das queimadas no Cerrado. In: Miranda HS. (ed.) Efeitos do regime do fogo sobre a estrutura de comunidade de Cerrado: Projeto fogo. Brasília, IBAMA. p. 23-33

Miranda HS, Sato MN, Neto WN, Aires FS. 2009. Fires in the Cerrado, the Brazilian savanna. In: Cochrane MA (ed.) Tropical Fire Ecology: Climate Change, Land Use and Ecosystem Dynamics. Chichester, Springer Praxis Publishing. p. 427-450.

Miranda HS, Sato MN, Santos JRD, Almeida CAD, Krug T, Andrade SMA, Sano EE, *et al*. 2006. Emissões de gases de efeito estufa da queima de biomassa no cerrado não-antrópico utilizando dados orbitais: relatórios de referência: primeiro inventário brasileiro de emissões e remoções antrópicas de gases de efeito estufa. Brasília, Ministério de Ciência e Tecnologia (MCT).

Miranda HS, Sato MN. 2005. Efeitos do fogo na vegetação lenhosa do Cerrado. In: Scariot A, Sousa-Silva JC, Felfili JM. (eds.) Cerrado: Ecologia, Biodiversidade e Conservação. Brasília, Ministério do Meio Ambiente. p. 93-105.

Miranda IS. 1995. Fenologia do estrato arbóreo de uma comunidade de cerrado em Alter-do-Chão, Pará. Revista Brasileira de Botânica 18: 235-240.

Munhoz CBR, Felfili JM. 2005. Fenologia do estrato herbáceo-subarbustivo de uma comunidade de campo sujo na Fazenda Água Limpa no Distrito Federal, Brasil. Acta Botanica Brasilica 19: 979-988.

Munhoz CBR, Felfili JM. 2007. Reproductive phenology of an herbaceous-subshrub layer of a Savannah (Campo Sujo) in the cerrado biosphere reserve I, Brazil. Brazilian Journal of Biology 67: 299-307.

Muramaki EA, Klink A. 1996. Efeito do fogo na dinâmica de crescimento e reprodução de *Echinolaena inflexa* (Poiret) Chase (Poaceae). In: Miranda HS, Saito CH, Dias BFS. (eds.) Impactos de queimadas em áreas de cerrado e restinga. Brasília, Universidade de Brasilia. p. 53-60.

Neves SPS, Conceição AA. 2010. Campo rupestre recém-queimado na Chapada Diamantina, Bahia, Brasil: plantas de rebrota e semente, com espécies endêmicas na rocha. Acta Botanica Brasilica 24: 697-707.

Oksanen J, Blanchet FG, Kindt R, *et al.* 2018. Vegan: Community Ecology Package. R package version 2.5-3. 2018. http://CRAN.R-project.org/package=vegan .18 Jan. 2019.

Oliveira PEAM. 2008. Fenologia e biologia reprodutiva das espécies de Cerrado. In: Sano SM, Almeida SP. (eds.) Cerrado: ambiente e flora. Planaltina, EMBRAPA-Cerrados. p.169-188.

Paixão ILSC. 1993. Estrutura e dinâmica de populações de espécies arbustivo-arbóreas das vertentes norte e sul do Morro da Boa Vista, Maciço da Tijuca – RJ. PhD Thesis, Universidade Estadual de Campinas, Campinas.

Palermo AC, Miranda HS. 2012. Efeito do fogo na produção de frutos de *Qualea parviflora* MART. (Vochysiaceae) em Cerrado *sensu stricto*. Revista Árvore 36: 685-693.

Pirani FR, Sanchez M, Pedroni F. 2009. Fenologia de uma comunidade arbórea em cerrado sentido restrito, Barra do Garças, MT, Brasil. Acta Botanica Brasilica 23: 1096-1110.

Pivello VR, Oliveras I, Miranda HS, Haridasan M, Sato MN, Meirelles ST. 2010. Effect of fires on soil nutrient availability in an open savanna in Central Brazil. Plant and Soil 337: 111-123.

R Development Core Team. 2018. R: A language and environment for statistical computing, R Foundatiton for Statistical Computing, Vienna, Austria. https://www.R-project.org/. 22 May 2019.
Ramos AE. 1990. O efeito de queima sobre a vegetação lenhosa do Cerrado. MSc Thesis, Universidade de Brasília, Brasília.
Ramos-Neto MB, Pivello VR. 2000. Lightning Fires in a Brazilian Savanna National Park: Rethinking Management Strategies. Environmental Management 26: 675-684.
Ribeiro MC, Sanchez M, Pedroni F, Peixoto KS. 2012. Fogo e dinâmica da comunidade lenhosa em cerrado sentido restrito, Barra do Garças, Mato Grosso. Acta Botanica Brasilica 26: 203-217.
Rios MNS, Silva JCS, Meirelles ML. 2019. Dinâmica pós-fogo da vegetação arbóreo-arbustiva em cerrado sentido restrito no Distrito Federal. Biodiversidade 18: 1-17.
Rissi MN, Baeza MJ, Gorgone-Barbosa E, Zupo T, Fidelis A. 2017. Does season affect fire behaviour in the Cerrado? International Journal of Wildland Fire 26: 427-433.
Rodrigues F, Pereira CL, Mrojinski F, Silva MA, Mendes RC. 2016. Comportamento inicial de mudas de *Anacardium humile* A. St.-Hil. sob diferentes substratos. Revista Agrotecnologia 7:1-9.
Russell-Smith J, Murphy BP, Meyer CP, *et al.* 2009. Improving estimates of savanna burning emissions for greenhouse accounting in northern Australia: limitations, challenges, application. International Journal of Wildland Fire 18: 1-18.
Sanaiotti TM, Magnusson WE. 1995. Effects of annual fires on the production of fleshy fruits eaten by birds in a Brazilian Amazonian savanna. Journal of Tropical Ecology 11: 53-65.
Sano SM, Almeida SPA, Ribeiro JF. 2008. Cerrado: ecologia e flora. Brasília, Embrapa Informações Tecnológicas.
Sato MN. 2003. Efeito a longo prazo de queimadas na estrutura da comunidade de lenhosas da vegetação do cerrado *sensu stricto*. PhD Thesis, Universidade de Brasília, Brasília.
Silva IA, Valenti MW, Silva-Matos DM. 2009. Fire effects on the population structure of *Zanthoxylum rhoifolium* Lam (Rutaceae) in a Brazilian savanna. Brazilian Journal of Biology 69: 813-818.
Silveira EP, Costa RB, Felfili JM. 2009. Florística da vegetação remanescente de Cerrado *stricto sensu* em terra indígena no noroeste de Mato Grosso, Brasil. Revista de Biologia Neotropical / Journal of Neotropical Biology 6: 15-25.
Silvério DV, Lenza E. 2010. Fenologia de espécies lenhosas em um cerrado típico no Parque Municipal do Bacaba, Nova Xavantina, Mato Grosso, Brasil. Biota Neotropica 10: 205-216.
Simon MF, Grether R, Queiroz de LP, Skema C, Pennington RT, Hughes CE. 2009. Recent assembly of the Cerrado, a neotropical plant diversity hotspot, by in situ evolution of adaptations to fire. Proceedings of the National Academy of Sciences of the United States of America 106: 20359-20364. https://doi.org/10.1073/pnas.0903410106
Sousa DG, Cunha HF. 2018a. Population structure, spatial distribution and phenology of *Anacardium humile* A. St.-Hil. (Anacardiaceae) in cerrado *stricto sensu*. Hoehnea 45: 450-467.
Sousa DG, Cunha HF. 2018b. Effect of fire on flowering and fruiting of *Anacardium humile* (Anacardiaceae) in cerrado *stricto sensu*. Revista Árvore 42: p. e420605. https://dx.doi.org/10.1590/1806-90882018000600005
Vale VS, Lopes SF. 2010. Efeitos do fogo na estrutura populacional de quatro espécies de cerrado. Revista Nordestina de Biologia 19: 45-53.
Watanabe S, Ayta WEF, Hamaguchi H, *et al.* 2003. Some evidence of a date of first humans to arrive in Brazil. Journal of Archaeological Science 30: 351-354.
Whelan RJ. 1995. The ecology of fire. Cambridge, Cambridge University Press.
Xavier RO. 2011. Influência do fogo no banco de sementes de áreas de cerrado com diferentes históricos de incêndio. MSc Thesis, Universidade Federal de São Carlos, São Carlos.
Zuffo AM. 2018. Biometria do hipocarpo, fruto e semente e desenvolvimento das plântulas de *Anacardium humile* A. St.-Hil. (Anacardiaceae). Revista de Ciências Agrárias 41: 191-200.