



## Effects of different prescribed burning seasons on *Hancornia speciosa* Gomes trees

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**Keywords:** Integrated fire management; native fruits; traditional knowledge; tropical savanna.

**ABSTRACT** – The *Hancornia speciosa* Gomes (Apocynaceae), locally known as “mangabeira”, is a common tree in the central South American savannas. It is an important species, especially because of its fruits, which are consumed by wild animals and local human populations, driving a significant economic chain. In Brazil, *H. speciosa* occurs in abundance in the Cerrado biome, where protected areas have been subjected to management changes. The implementation of integrated fire management in these areas has drastically changed the prevailing fire regimes, from fire exclusion interspersed with large wildfires to prescribed burnings. In Indigenous Lands, technical recommendations for the use of fire were based on traditional knowledge and cover a long fire window, which goes from the late rainy season to the middle dry season. The objective of this work was to evaluate the effects of these different prescribed burning seasons on *H. speciosa*. The methodology involved data collection by local fire brigade members and statistical analysis using the Tukey Test ( $p < 0.05$ ). In all prescribed burning seasons, tree mortality rates were low. Prescribed burnings during the late rainy season were the most severe one. Prescribed burnings during the early dry season were the least severe ones and the trees presented higher reproduction and fruit production rates. Prescribed burnings during the middle dry season presented more reproductive structures losses. These results indicate that early dry season prescribed burnings can be the most appropriate for *H. speciosa*. However, considering the variability of responses and the relatively positive



results in all treatments, we conclude that prescribed burning can be carried out during all seasons studied, providing a wide fire window that facilitates large scale management, and probably benefits species diversity.

### Efeitos de diferentes épocas de queima prescrita em árvores de *Hancornia speciosa* Gomes

**Palavras-chave:** Manejo integrado do fogo; conhecimento tradicional; frutas nativas; savana tropical.

**RESUMO** – A *Hancornia speciosa* Gomes (Apocynaceae), conhecida como mangabeira, é uma árvore comum nas savanas centro-sul-americanas. A espécie é importante, especialmente por seus frutos, que são consumidos pelos animais nativos e comunidades locais, impulsionando uma cadeia econômica significativa. No Brasil, *H. speciosa* ocorre em abundância no bioma Cerrado, onde as áreas protegidas foram submetidas a mudanças de gestão. A implementação do manejo integrado do fogo alterou os regimes de fogo predominantes, da exclusão do fogo intercalada por grandes incêndios para o manejo com queimas prescritas. Nas Terras Indígenas, as recomendações técnicas são baseadas no conhecimento tradicional e cobrem uma ampla janela de fogo, que vai do final da estação chuvosa até a metade da estação seca. O objetivo deste trabalho foi avaliar os efeitos de diferentes épocas de queima prescrita na *H. speciosa*. A metodologia envolveu coleta de dados por brigadistas locais e análise estatística usando o Teste de Tukey ( $p < 0,05$ ). Em todas as épocas avaliadas, as taxas de mortalidade foram baixas. As queimas prescritas durante o final da estação chuvosa foram mais severas. As queimas prescritas durante o início da estação seca apresentaram menor severidade e as maiores taxas de reprodução e de produção de frutos. As queimas prescritas no meio da estação seca apresentaram as maiores perdas de estruturas reprodutivas. Esses resultados indicam que as queimas prescritas no início da estação seca podem ser mais apropriadas para a *H. speciosa*. No entanto, considerando a variabilidade das respostas e os resultados relativamente positivos em todos os tratamentos, concluímos que as queimas prescritas podem ser realizadas durante todas as épocas avaliadas, proporcionando uma ampla janela de fogo que facilita o manejo em larga e beneficia a diversidade de espécies.

### Efectos de diferentes temporadas de quema prescrita en árboles de *Hancornia speciosa* Gomes

**Palabras clave:** Manejo integrado del fuego; conocimiento tradicional; frutos nativos; sabana tropical.

**RESUMEN** – *Hancornia speciosa* Gomes (Apocynaceae), conocida localmente como mangabeira, es un árbol común en las sabanas de América Central y del Sur. La especie es importante, especialmente por sus frutos, que son consumidos por animales nativos y comunidades locales, impulsando una importante cadena económica. En Brasil, *H. speciosa* ocurre abundantemente en el bioma Cerrado, donde las áreas protegidas han experimentado cambios de gestión. La implementación del manejo integrado del fuego en estas áreas ha cambiado los regímenes del fuego, de la exclusión del fuego intercalada con grandes incendios, hasta las quemadas prescritas. En Tierras Indígenas, las recomendaciones técnicas se basaron en el conocimiento tradicional y cubren una amplia ventana, que va desde el final de la temporada de lluvias hasta la mitad de la temporada seca. El objetivo de este trabajo fue evaluar los efectos de diferentes temporadas de quemadas prescritas en la *H. speciosa*. La metodología implicó la recopilación de datos por parte de brigadistas locales y el análisis estadístico mediante la prueba de Tukey ( $p < 0,05$ ). Las tasas de mortalidad de los árboles fueron bajas en todas las temporadas de quema prescrita. Las quemadas prescritas realizadas al final de la temporada de lluvias fueron las más severas. Las quemadas prescritas realizadas al inicio de la temporada seca presentaron la menor severidad y las mayores tasas de reproducción y producción de frutos. Las quemadas prescritas realizadas en la mitad de la temporada seca presentaron la mayor pérdida de estructuras reproductivas. Estos resultados indican que las quemadas en el inicio de la temporada

seca deben ser más apropiadas para *H. speciosa*. Sin embargo, considerando la variabilidad de las respuestas y los resultados relativamente positivos en todos los tratamientos, concluimos que la quema prescrita puede realizarse durante todas las temporadas evaluadas, lo que proporciona una amplia ventana que facilita el manejo a gran escala y beneficia la diversidad de especies.

## Introduction

Fire is a key element for biodiversity conservation in fire-prone ecosystems, such as Brazilian tropical savannas [1][2]. Despite this, protection strategies based on zero-fire policies have been implemented in several Brazilian protected areas in the last decades [3][4][5][6]. Recently, fire ban policies have been successfully replaced by new approaches based on integrated fire management – IFM [7][8] [9]. This changed the prevailing fire regimes. Areas that were subjected to fire exclusion for several years, interspersed with large-scale late-dry season wildfires, are now managed with prescribed burnings (PB) [10] [11].

In Indigenous Lands, technical recommendations for fire use were mainly based on traditional knowledge. The recommended period to perform PB covers a very long interval, extending from the late rainy season to the middle dry season [12][13]. An assessment of the fire effects on native species over this period is essential to help achieving management objectives, especially when it comes to species of socio-environmental importance [7][13].

*Hancornia speciosa* is one of the most important native plants for Brazilian traditional communities [14][15][16][17]. The species is used in popular medicine, as it has pharmacological properties that are being studied [18][19][20]. But the most consumed product is its fruit, which is very popular in various regions of the country. In addition to being consumed directly, the fruits can be transformed into sweets, jellies and pulp. The annual production recorded in the northeastern Brazil was 2,560 tons in 2023, which corresponded to R\$ 6,954,000 in marketing, approximately USD 1,188,311 [21]. However, these values are quite underestimated, since its production is predominantly from native tree harvesting and its marketing is informal, promoted by local/regional arrangements [16][19].

Spread across different regions of the country, *H. speciosa* is common in marginal soils for agriculture. In the Cerrado biome, the species occurs mainly on

rocky slopes, in open vegetations, with an aggregate distribution pattern, often called “native orchards”, which facilitate their gathering [15][17]. Its adult trees are usually between 4 and 6 meters tall, with a wide and spread canopy of deciduous characteristics, changing the foliage during the driest period of the year (July to September). During the rainy season, the leaves sprout, and flowers and fruits emerge. The species has low phenological synchronization and two flowering and fruiting peaks per year, with the flowers produced in one harvest being responsible for the fruits of the next one. The first peak occurs between April and June, called “flower harvest”, resulting in low productivity and lower quality fruits, called “precocious”. The second peak occurs between October and December, called “button harvest”, resulting in higher productivity and fruit quality [14] [16][22][23]. In addition to facilitating seed dispersal, this wide distribution of flowers and fruits benefits wild animals that depend on *H. speciosa*, since it provides food resources distributed throughout the year [24][25].

Native *H. speciosa* orchards of the Cerrado biome are subjected to a range of fire regimes. In some protected areas, they may have been under fire exclusion for many years. But this management strategy has been replaced, as it has negative consequences for biodiversity conservation and reduces the provision of environmental services [5] [26][27]. Furthermore, fire exclusion for several years tends to result in large wildfires due to fine fuel accumulation, with several deleterious consequences [10][11][28]. In tropical savannas around the planet, these wildfires generally occur from the end dry season to the early rainy season, are highly intense due to the accumulation of fine fuel [5][10][29][30] [31][32] and can harm even the fire-resistant tree species [33][34].

As it is for other Cerrado species, it is possible that the best strategy for protecting *H. speciosa* is with the application of PB [5][12][13][35]. In addition to preventing the damages caused by large late-dry season wildfires, the PB can make nutrients available

to the soil and stimulate the flowering and fruiting [12][13][35][36][37].

Since 2014, the main Brazilian federal environmental agencies, the Brazilian Institute of the Environment and Renewable Natural Resources (Ibama) and the Chico Mendes Institute for Biodiversity Conservation (ICMbio), began to implement management programs based on the principles of IFM and use of low intensity PB to achieve conservation goals [3][7][8][11][38]. However, there were no specific studies on the effects of the use of fire on several fruit trees species that are important to traditional and indigenous communities, such as *H. speciosa*.

On the other hand, the indigenous communities that inhabit the Cerrado have vast traditional ecological knowledge related to fire use to stimulate the production of natural resources [39][40][41]. According to indigenous peoples' reports, the Cerrado fruit trees need fire to stay healthy and productive. However, when fire occurs at the "wrong time", in the reproductive period of many plants, the damage caused to the trees is higher and the flowers and unripe fruits get burned, reducing the fruit production. Although, if fire occurs at the "right time", the damage is lower, and the trees are stimulated to produce more fruits [12][13][35]. Similar descriptions of the use of fire to protect or stimulate the production of native fruits have already been recorded for the Brazilian [42][43] and other tropical savannas [44].

Hence, Prevfogo, Ibama's Fire National Center, chose to incorporate traditional knowledge to make management decisions in Indigenous Lands-ILs and Quilombola (maroon) Territories-QTs covered by the Federal Brigades Program-BRIFs [8][38]. The recording and systematization of this knowledge was carried out through a work called "Recovering Traditional Knowledge Over the Use of Fire" [12]. Based on the objectives and fire regimes described by the communities, together with the application of new technologies and technical/scientific recommendations, the PB were planned and executed in the savannas of 31 traditional territories, covering 10,462,418.9 hectares (ha) of the Cerrado, Pantanal and Amazonia biomes [38].

Since then, the prevailing fire regime in these areas, fire exclusion interspersed with wildfires [4][8], has been replaced by a frequent low-intensity burning regime, based on prescribed burns [9][11][38]. Between 2015 and 2018, 3,386 PB were

registered during the period between February and July, which resulted in a temporal and spatial mosaic of fire regimes and a unique opportunity to assess their effects in the savanna ecosystems.

However, this management season is considered very broad and there may be significant differences in the effects of fire during these time frames. This work aimed to evaluate the results of these different PB seasons in adult *H. speciosa* trees. Furthermore, their field assessments help to understand what happens when management is implemented on a large scale, forming a broad mosaic of fire behaviors and histories [38][45].

These assessments conducted here are part of a broader program to monitor the implementation of IFM by the BRIFs Program of Ibama/Prevfogo in Brazilian Indigenous Lands and QTs. Through them, it was possible to evaluate the effects of different fire regimes and periods of prescribed burning on culturally important species of flora and fauna [13][35][38]. Combined with other studies, they can contribute with technical management recommendations, in addition to evaluating whether the environmental agency's decisions are being efficient for the conservation of ethnobiodiversity and environmental services provided by traditional peoples.

## Materials and Methods

One of the main objectives of the work was to enable the monitoring of integrated fire management (IFM) to be carried out by local fire brigades. To this end, we developed protocols in a participatory manner to allow indigenous and quilombola brigades to collect data and evaluate the effects of fire regimes in their territories, following the principles of "Citizen Science" [46].

### Study area and treatments

Our study involved 18 traditional territories, 17 ILs and 01 QT, where prescribed burns - PB were implemented and the species *H. speciosa* occurred widely (Table 1 and Figure 1). All of them are located in the Cerrado biome, except the ILs Xingu and Pequizar do Naruvôtu, that are in the Amazon biome but were included in the study because they are in the transition zone between the biomes and present Cerrado ecosystems [47].

The seasons for carrying out PB were divided into three treatments: late rainy season-LRS, early dry season-EDS and middle dry season-MDS. The

area managed with prescribed burns in each of the seasons [48] is presented in Table 1.

Table 1 – Name of the traditional territory, total area, number of burning plans registered and accumulated burnt area between 2015 and 2018 (LRS = late rainy season; EDS = early dry season; and MDS = middle dry season).

Traditional territories <sup>1</sup>	Total area (ha)	Number of burning plans	Burned area (ha)		
			LRS	EDS	MDS
Kalunga QT	261,827.4	106	0.0	3,449.0	910.4
Avá-Canoeiro IL	38,000.0	11	0.0	0.0	4,271.5
Bakairi IL	61,405.5	66	0.0	3,143.2	5,953.6
Juininha IL	70,537.5	51	753.7	4,012.0	3,056.3
Paresi/Formoso ILS	583,336.0	140	4,299.5	90,940.9	120,985.3
Utiariti IL	412,304.2	43	550.7	25,531.4	9,074.8
Xerente/Funil ILS	183,245.9	554	0.0	3,233.8	10,001.4
Krahôlândia IL	302,533.4	285	0.0	844.4	12,815.5
Apinajé IL	82,432.5	104	0.0	0.0	5,629.5
Araguaia IL	1,358,499.5	1,263	1,651.3	16,794.7	410,009.0
Xingu/Pequiza Naruvôtu ILS	2,642,003.0	469	15,814.8	11,758.1	53,887.1
Porquinhos IL	79,520.3	88	0.0	51,893.8	13,476.1
Governador/Krikati ILS	186,419.5	119	0.0	2,512.8	3,196.4
Araribóia IL	413,288.0	87	0.0	2,774.9	10,827.6
<b>Total</b>	<b>6,675,352.6</b>	<b>3,386</b>	<b>23,070.0</b>	<b>216,889.0</b>	<b>664,094.5</b>

<sup>1</sup> Some territories were grouped together because the burning plans were recorded together.

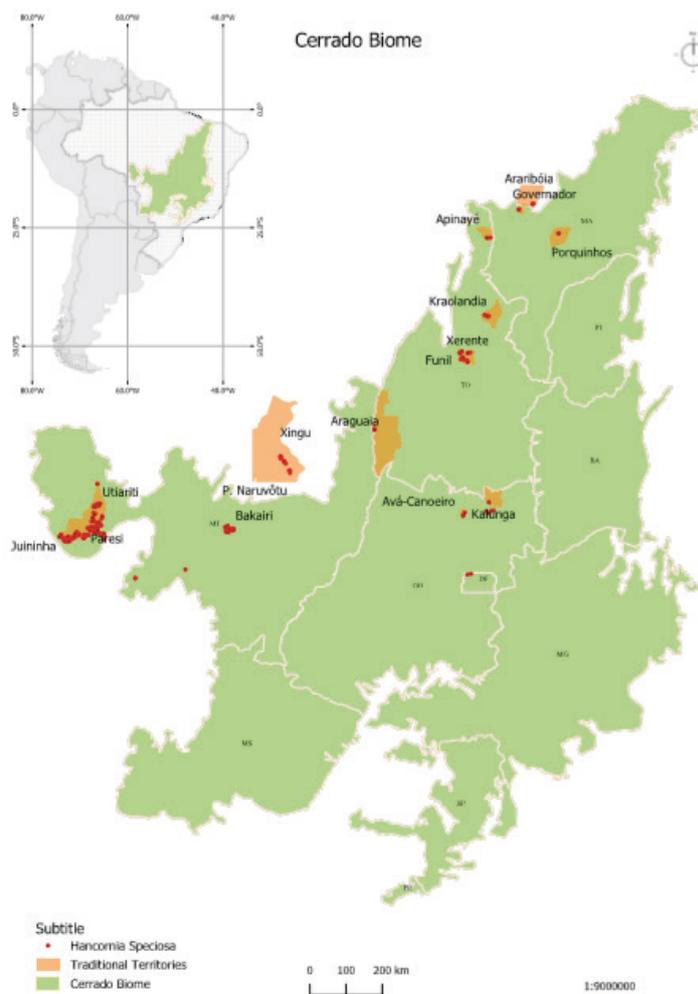


Figure 1 – Location of the Cerrado biome within South America (top left), location of the 18 traditional territories and areas where *Hancornia speciosa* populations were sampled under different prescribed burning seasons.

The PB carried out in the LRS and MDS coincide with objectives related to wildfire prevention (fuel reduction), while the PB carried out in the EDS coincides more with objectives related to fruitification. Some differences in the traditional fire regimes can

be observed between regions with well-drained soil, in the central and western parts of the biome, and regions subject to flooding or located in the northeast, as described below (Figure 2).

Season →	Rainy			Dry					Rainy			
Months of the year –	Jan.	Feb.	Mar.	Apr.	Mai	Jun.	Jul.	Aug.	Sep.	Oct	Nov.	Dec.
Ethnic groups ↓												
Timing and purpose of traditional burning in well-drained areas or located in the central and western regions of the biome ↓												
Bakairi/MT				Fructification								
Xerente/TO				Fructification	Prevention							
Krahô/TO				Fructification	Prevention							
Paresi/MT			Fructification		Prevention							
Kalunga/GO			Prevention			Prevention						
Fire Regime →	WF	Prescribed burnings-PB					Wildfires-WF					
Prescribed burning season →		Late Rainy Season-LRS		Early Dry Season-EDS		Mid Dry Season-MDS						
Ethnic groups ↓												
Timing and purpose of traditional burning in flooded areas or located in the northeast region of the biome ↓												
Gavião/MA				Fructification		Prevention						
Guajajara/MA				Fructification		Prevention						
Krikati/MA				Fructification								
Kanela/MA				Prevention								
Alto Xingu/MT			Prevention									
Araguaia/TO				Prevention								
Fire Regime →	WF	Prescribed burnings-PB					Wildfires-WF					
Prescribed burning season →		Late Rainy Season-LRS		Early Dry Season-EDS		Mid Dry Season-MDS						

Figure 2 – Ethnic groups, periods of the year (months and seasons) recommended by the communities for carrying out the fruiting and prevention fires, and the seasons of the prescribed burning treatments. Adapted from [37].

### Field sampling, evaluated parameters and statistical analysis

The season of the PB and time since last fire were identified through Prescribed Burn Plans, Wildfire Occurrence Records and satellite images. The areas were selected and monitored by previously trained fire brigade members, who filled out a spreadsheet with general information, defined a sampling point with greater abundance of the target species and performed the data collection in a standardized way for 20 minutes. During the sampling period (September to December), all *H. speciosa* adult trees were evaluated regarding phenological stage, fruit production and canopy damage (mortality, severity and losses of reproductive structures due to fire).

The loss of reproductive structures and the mortality rate were sampled only once, in the months following fire occurrence, while its impacts were still visible. The severity, the phenological stage and the fruit production per plant were sampled at intervals from 01 to 12, 13 to 24 and 25 to 36 months after PB, to assess whether the effects of the fire persisted over the years.

The mortality rate was calculated from the comparison between the number of registered dead trees and the total number of sampled trees. To assess the severity index, all surviving trees were classified according to the damage observed in their crowns (% of dead branches), through the presence of regrowth and dead branches, as shown in Figure 3.

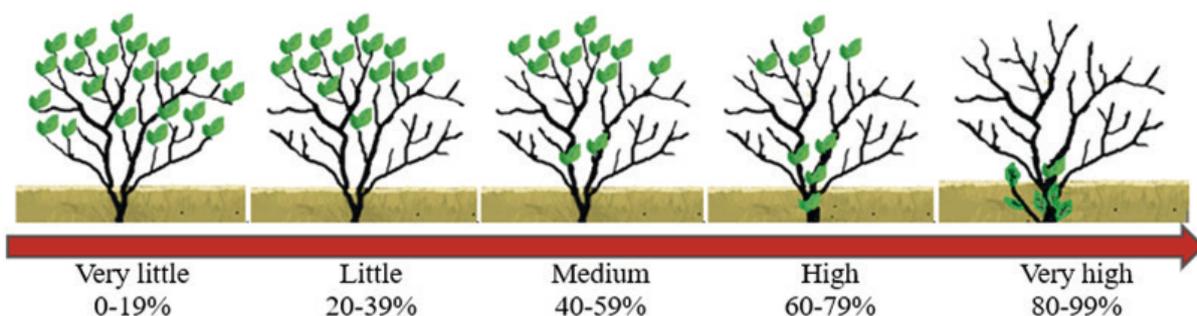


Figure 3 – Classes (indexes) of crown severity, according to the % of dead branches and regrowth [13][49][50].

To assess the loss of reproductive structures, all trees that lost flowers or fruits due to fire were accounted and compared with the total number of trees in the reproductive stage. To determine the proportion of plants in the reproductive stage, the number of trees that were in the reproductive phenophases (anthesis, flowering and fruiting) was compared with the total number of trees sampled. To evaluate the fruit production per plant, all the fruit trees were classified by the local fire brigade members as high or low production and compared with the total number of fruiting trees.

We evaluated 2,474 *H. speciosa* trees, distributed in the 18 protected areas (Figure 1). We used linear mixed effect models [51] to compare the effects of different seasons in each evaluated parameter. The seasons were considered as the fixed variable and the sampling locations as a random effect variable. The intervals since last fire were grouped with the respective burning season. From the results of the models, we performed the

Tukey test to verify whether the response variables showed significant differences between seasons. We considered p values <0.05 as significant differences and performed all statistical analyses in R software [52]. The mean values, standard error and n sample are shown from Tables A.1 to A.8 in the Appendices.

## Results and Discussion

### Mortality

The mortality rates ranged from 0.35 to 0.56% and showed no significant differences between PB seasons (Figure 4 and Table A.1 in the Appendices). In fact, a previous study already indicated that the mortality of adult *H. speciosa* individuals was low after prescribed burning, and mortality due to fire is a rare event for adult individuals of *H. speciosa*, generally associated with high intensity, severe wildfires or to very long periods without fire [13][15].

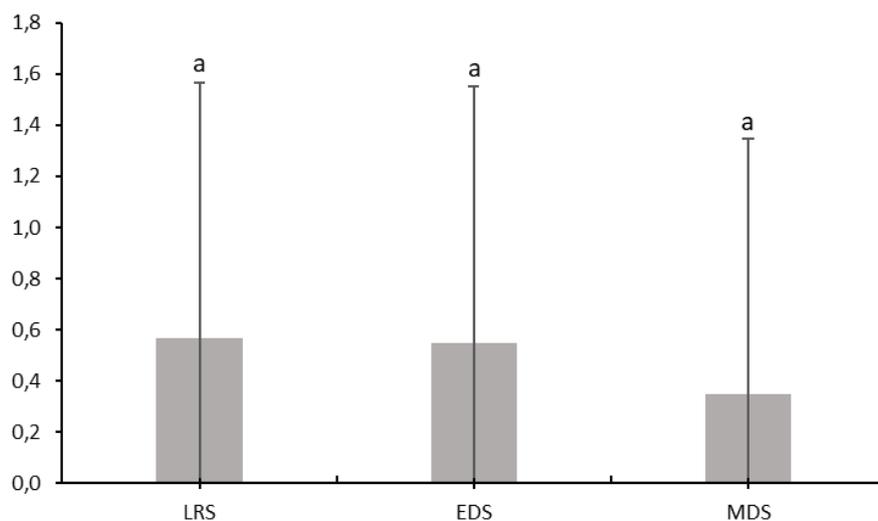


Figure 4 – Mortality rate of *Hancornia speciosa* trees subjected to different prescribed burning seasons (LRS = late rainy season; EDS = early dry season; and MDS = middle dry season). The bars represent the mean values (%) for each season and the lines that cross the bars show standard errors. Different letters indicate significant differences ( $p < 0.05$ ), according to linear mixed models followed by Tukey tests.

No specific studies were found on the effects of different PB seasons as applied here. The available studies, covering “precocious” burning in June, were carried out with the entire community of arboreal and herbaceous species. They found higher mortality rates than in the present study [53][54], but the

methodological differences require caution in the comparisons.

Higher mortality was expected, even in adult individuals, since *H. speciosa* does not present some of the morphological adaptations typical of other Cerrado species, such as that it does not reach great

heights, has an extensive canopy and relatively thin bark [14][17]. However, this did not occur. It seems that the species' adaptations to fire damage are more related to its capacity to regenerate and therefore it is important to analyze the severity and recovery of the canopy in the years following the PB.

## Severity

Different PB seasons showed significant difference in some of the severity index. *Hancornia*

*speciosa* populations managed in EDS had a higher proportion of trees classified as very little severity ( $81.41\% \pm 6.01$ ). In contrast, the populations managed in LRS had the lowest proportion of trees classified as very little severity ( $63.35\% \pm 6.01$ ) and the highest proportion classified as very high severity ( $4.26\% \pm 2.29$ ) in relation to trees managed in MDS ( $0.91\% \pm 0.41$ ) and in EDS ( $2.37\% \pm 2.29$ ) (Figure 5 and Table A.2). The differentiated responses of *H. speciosa* to PB seasons may be related to factors inherent to the species itself, such as the phenological stage during fire occurrence, or fire behavior.

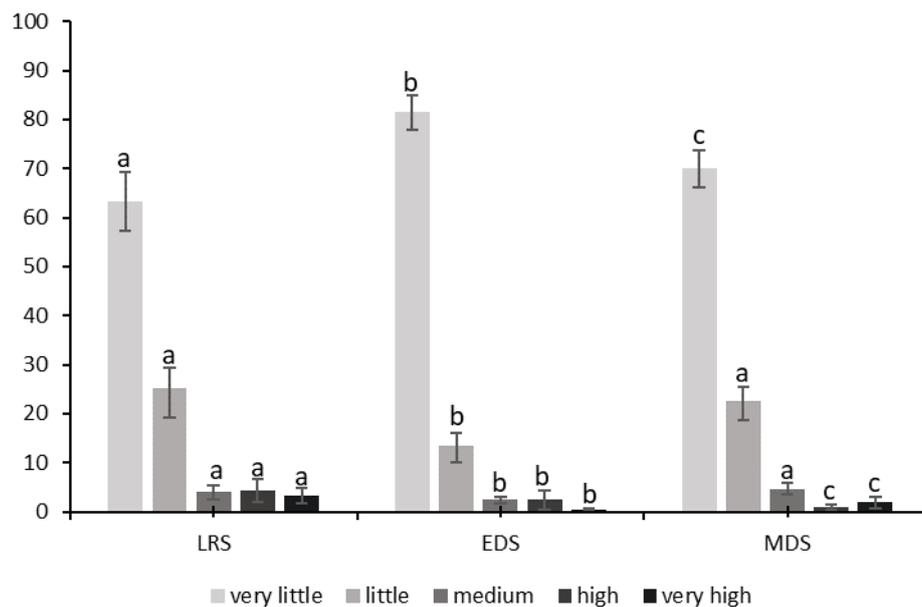


Figure 5 – Severity index for *Hancornia speciosa* trees subjected to different prescribed burning seasons (LRS = late rainy season; EDS = early dry season; MDS = and middle dry season). The bars represent the average values (%) of the number of trees in the three sampled years for each prescribed burning season, the lines that cross the bars show standard errors, and the gradual shades indicates the severity degree, with the lighter shade being very little severity and darkest being very high severity. Different letters indicate significant differences between prescribed burning seasons for each severity degree ( $p < 0.05$ ), according to linear mixed models followed by Tukey tests.

Fire behavior during PB is one of the factors that most influences tree damage. Although parameters such as fire intensity and flame height were not calculated, researches show that they tend to be more severe in the dry season than in the rainy season in tropical savannas [29][30][31][55]. However, in this case, the severity was greater after PB during the rainy season, indicating that other factors may have influenced plants' response to fire.

Regarding phenology, *H. speciosa* has deciduous characteristics, changing its leaves in the dry season [14][22][23]. Before this, leaves tend to reduce their physiological activities, transport nutrients and prepare for leaf fall. This moment coincides with the PB in the EDS and MDS, that burn leaves that are already in the process of senescence. On the other hand, it is likely that the PB in the LRS coincides with green foliage. This possibly explains

the greater severity when the trees are burned in the LRS, since branches and leaves with higher humidity and photosynthetic activity can be more affected by the flames, causing greater damage in the canopy.

Within relation to the severity rate, no specific studies were found investigating the effects of different seasons of PB on specific species. The studies available for the Cerrado biome covered the entire herbaceous and arboreal community, in biennial burning carried out in June [53][54]. They present basal and underground regrowth values corresponding to the ones we found for individuals accounted for high and very high severities, between 5.6 and 8.2%, more similar to the LRS treatment.

The analysis of the evolution of severity over the years shows that the *H. speciosa* trees recovered well, even in the treatments that presented the greatest damage. Areas managed with PB in LRS showed 48.73% of the trees in the very low severity indexes in the first year after the PB, 67.50% in the second year and reaching 81.38% in the third year (Figures A.1 to A.3 and Tables A.3 to A.5 in the Appendices).

## Phenological stage

The different PB seasons influenced the proportion of trees reproducing (Figure 6 and Table A.6 in the Appendices). In the first year after PB, LRS and MDS, the trees had the lowest reproduction rates. After that, *H. speciosa* trees showed some recovery and stability, except for the MDS treatment, which had the highest reproduction rate in the study in the third year after the PB. Considering the average of the three years, prescribed burning carried out in the EDS presented the highest values ( $41.20\% \pm 5.20$ ), significantly higher than MDS ( $35.73\% \pm 4.97$ ) and LRS ( $32.43\% \pm 7.45$ ).

*Hancornia speciosa* presents one of the lowest phenological synchronizations among the Cerrado species, with two well-differentiated reproduction peaks [17][22][23]. The PB carried out during early and mid-dry season coincided with the so-called “flower harvest” (April to June), which has low productivity and lower quality fruits, but produces flowers for the following harvest, called “button harvest”. This factor may have affected reproduction during the period in which the trees were evaluated (September to December), contributing to the low reproduction rates observed in trees managed with PB [13].

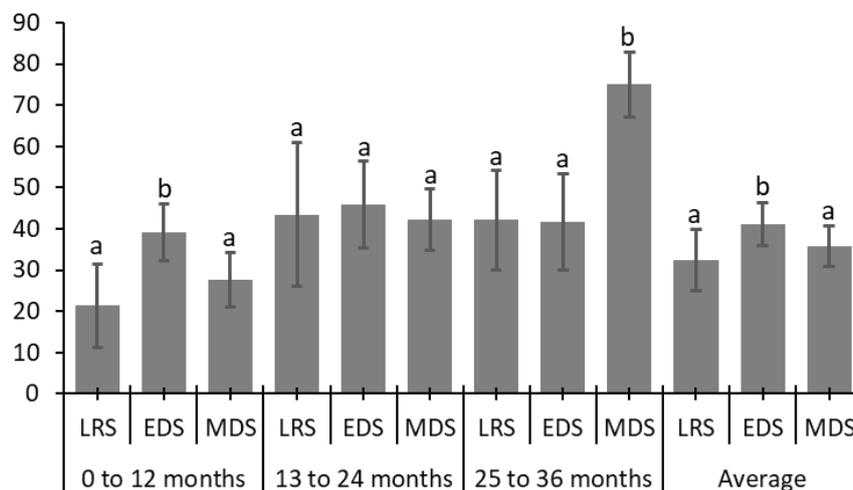


Figure 6 – Proportion of *H. speciosa* trees in reproductive stage under different prescribed burning seasons (LRS = late rainy season; EDS = early dry season; and MDS = mid dry season). The bars represent the mean values (%), separated into three periods after fire passage (0-12 months, 13-24 months and 25-36 months) and the average of all periods together. The lines across the bars show standard errors and different lower-case letters indicate significant differences between prescribed burning season ( $p < 0.05$ ).

### Loss of reproductive structures due to fire

*Hancornia speciosa* trees subjected to different PB seasons demonstrated significant differences in flowers and fruits losses (LRS  $3.05\% \pm 2.18$ , EDS  $0.00\% \pm 0.00$ , MDS  $7.67\% \pm 5.66$ ) (Figure 7 and Table A.7 in the Appendices). In all treatments, these losses in the reproductive structures were much lower

than those found in trees subjected to wildfires at the end of the dry season [13].

The EDS and MDS coincide with the “flower harvest” [17][22]. Although the PB carried out in MDS presented greater losses, they were not recorded in EDS. It is worth noting that the losses recorded refer mainly to unripe fruits, as it is difficult to record the losses of flowers, as they are very fragile.

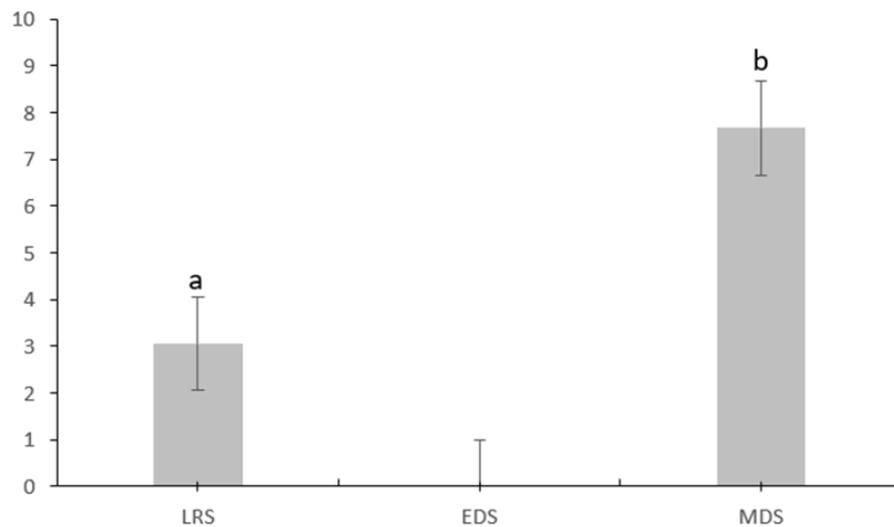


Figure 7 – Proportion (%) of *H. speciosa* trees that showed losses of reproductive structures subjected to different prescribed burning seasons (LRS = late rainy season; EDS = early dry season; and MDS = mid dry season). The bars represent the mean values (%) for each season and the lines that cross the bars show standard errors. Different letters indicate significant differences ( $p < 0.05$ ), according to linear mixed models followed by Tukey tests.

### Fruit production

As similarly to the values describing reproduction rates, trees subjected to the EDS fires showed the best results on the average fruit production over the three years ( $48.63\% \pm 5.83$ ), significantly higher than the MDS ( $39.23\% \pm 5.33$ ), and LRS. ( $36.94\% \pm 8.97$ ) (Figure 8 and Table A.8 in the Appendices). Increasing fruit production is one of the main objectives of fire management, as reported by indigenous

people [12]. However, there does not seem to have been a synchronized response to PB, as it has already been observed for other species [13][35] [38]. Previous studies with *H. speciosa* demonstrated that PB management has the same fruit production in areas under prolonged fire exclusion, but both treatments resulted in more fruit production than trees that were hit by wildfires in the end of the dry season [13].

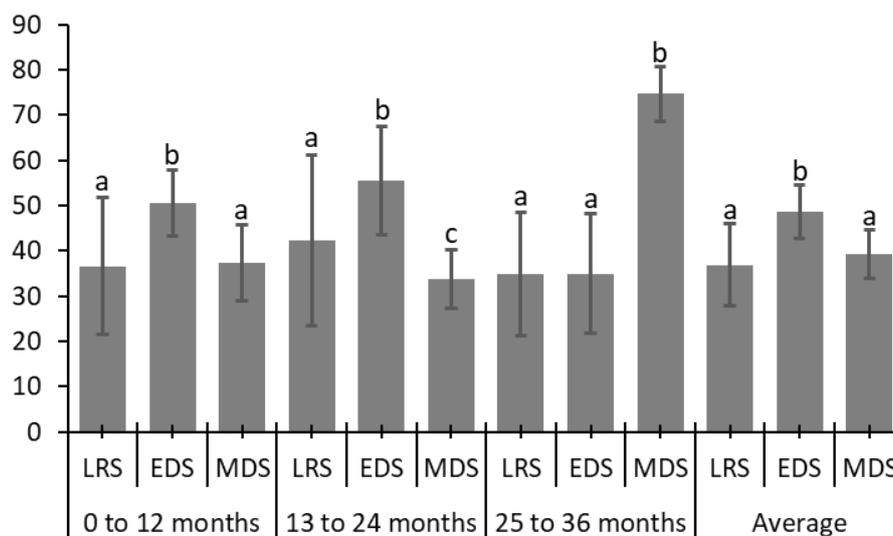


Figure 8 – Proportion of *H. speciosa* trees with high fruit production under different prescribed burning seasons (LRS = late rainy season; EDS = early dry season; and MDS = mid dry season). The bars represent the mean values (%), separated into three periods after fire passage (0-12 months, 13-24 months and 25-36 months) and the average of all periods together. The lines across the bars show standard errors and different lower-case letters indicate significant differences between prescribed burns season ( $p < 0.05$ ).

## Management considerations

There are still few studies, and a large knowledge gap related to the effects of fire on this important species, which makes our research even more relevant. This article complements the previous study that indicated prescribed burning as the best management alternative for *H. speciosa* [13]. However, the first study presented doubts regarding the best season for its execution.

This study indicates that the early dry season is the best season to carry out prescribed burning in areas where *H. speciosa* occurs. However, considering that the damage caused by wildfires is greater [13], prescribed burnings can be carried out in any of the seasons evaluated. This may help fire managers, who need larger burning windows to manage vast areas annually in Brazilian protected areas.

## Conclusions

Mortality rates of *H. speciosa* were low in all prescribed burning seasons evaluated, showing no significant differences between them.

The fire severity was greater in the trees managed with prescribed burning in the late rainy season, compared to those managed during mid dry season and especially early dry season.

The loss of reproductive structures was greater in the trees managed with prescribed burning in the middle of the dry season.

The trees managed in the early dry season showed lower damages, no loss of reproductive structures due to fire, higher reproduction rates and higher fruit production.

## Acknowledgements

We dedicate this work to the fire brigade Sidney de Oliveira Silva, a fundamental fire brigade for the implementation of integrated fire management and its evaluation. Unfortunately, he left us due to the violence that persists in the country.

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## Appendix

Table A.1 – Prescribed burning seasons, average, standard error and number of samples in Figure 4.

Prescribed Burning Season	Average (%)	Standard error	N Sample
Late Rainy Season-LRS	0.565	0.330	23
Early Dry Season-EDS	0.549	0.325	51
Late Dry Season-LDS	0.348	0.344	46

Table A.2 – Prescribed burning seasons, average (%), standard error and number of samples in Figure 5.

Severity class	Late Rainy Season-LRS			Early Dry Season-EDS			Mid Dry Season-MDS		
	Average	Error	n	Average	Error	n	Average	Error	n
Very little									
Little	63.348	6.011	23	81.412	6.011	51	70.022	3.775	46
Medium	25.130	4.239	23	13.451	4.239	51	22.478	2.963	46
High	3.957	1.422	23	2.392	1.422	51	4.717	1.151	46
Very high	4.261	2.293	23	2.373	2.293	51	0.913	0.417	46

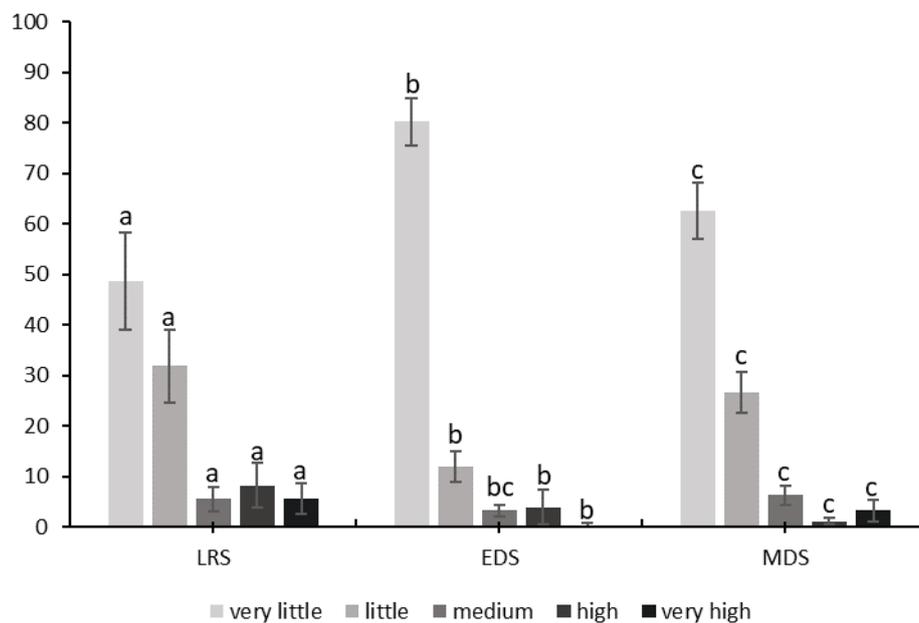


Figure A.1 – Fire severity indexes (mean %  $\pm$  standard error) in *H. speciosa* trees, between 1 and 12 months after the last fire. The letters indicate significant differences within the same index between prescribed burning seasons according to Tukey test. The data was collected in 18 study areas across the Brazilian savanna.

Table A.3 – Prescribed burning seasons, average, standard error and number of samples in Figure A.1.

Severity class	Late Rainy Season-LRS			Early Dry Season-EDS			Mid Dry Season-MDS		
	Average	Error	n	Average	Error	n	Average	Error	n
Very little									
Little	48.727	9.652	11	80.241	4.703	29	62.577	5.460	26
Medium	31.909	7.198	11	12.069	3.032	29	26.577	4.049	26
High	5.545	2.464	11	3.310	1.095	29	6.308	1.867	26
Very high	8.273	4.474	11	3.966	3.379	29	1.192	0.697	26

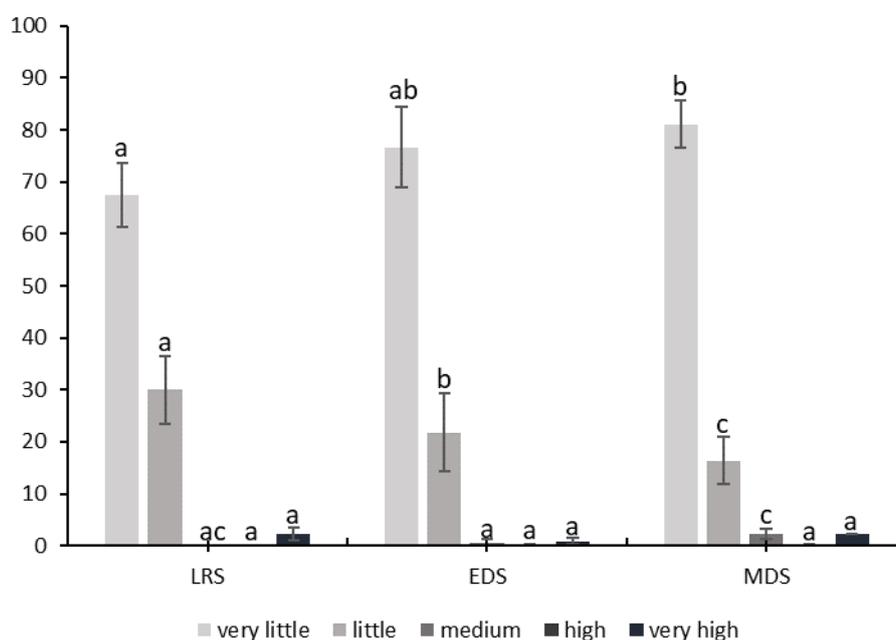
Figure A.3– Fire severity indexes (mean %  $\pm$  standard error) in *H. speciosa* trees, between 13 and 24 months after the last fire. The letters indicate significant differences within the same index between prescribed burning seasons according to Tukey test. The data was collected in 18 study areas across the Brazilian savanna.

Table A.4 – Prescribed burning seasons, average, standard error and number of samples in Figure A.2.

Severity class	Late Rainy Season-LRS			Early Dry Season-EDS			Mid Dry Season-MDS		
	Average	Error	n	Average	Error	n	Average	Error	n
Very little									
Little	67.500	6.139	4	76.692	7.833	13	81.118	4.529	17
Medium	30.000	6.510	4	21.769	7.531	13	16.412	4.470	17
High	0.000	0.000	4	0.615	0.591	13	2.353	0.988	17
Very high	0.000	0.000	4	0.308	0.296	13	0.176	0.171	17

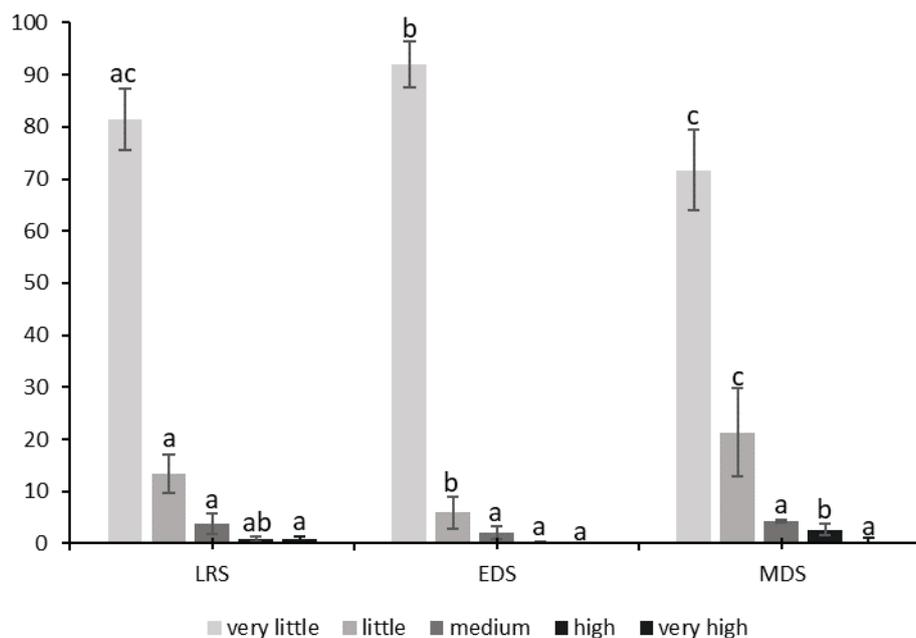


Figure A.4 – Fire severity indexes (mean %  $\pm$  standard error) in *H. speciosa* trees, between 25 and 36 months after the last fire. The letters indicate significant differences within the same index between prescribed burning seasons according to Tukey test. The data was collected in 18 study areas across the Brazilian savannah.

Table A.5 – Prescribed burning seasons, average, standard error and number of samples in Figure A.3.

Severity class	Late Rainy Season-LRS			Early Dry Season-EDS			Mid Dry Season-MDS		
	Average	Error	n	Average	Error	n	Average	Error	n
Very little	81.375	5.887	8	92.000	4.315	9	71.667	7.679	3
Little	13.375	3.653	8	5.889	3.020	9	21.333	8.555	3
Medium	3.750	1.951	8	2.000	1.247	9	4.333	0.272	3
High	0.875	0.543	8	0.222	0.210	9	2.667	1.089	3
Very high									

Table A.6 – Sampling intervals, prescribed burns season, average reproduction values, standard error and number of samples in Figure 6.

Sampling intervals	Prescribed burns seasons	Average (%)	Standard error	N Sample
0 to 12 months	Late Rainy Season-LRS	21.364	10.131	11
	Early Dry Season-EDS	39.103	6.909	29
	Mid Dry Season-MDS	27.571	6,530	28
13 to 24 months	Late Rainy Season-LRS	43.500	17.412	4
	Early Dry Season-EDS	45.833	10.614	12
	Mid Dry Season-MDS	42.235	7.369	17
25 to 36 months	Late Rainy Season-LRS	42.125	12.173	8
	Early Dry Season-EDS	41.778	11.634	9
	Mid Dry Season-MDS	75.000	7.930	3
Average	Late Rainy Season-LRS	32.435	7.448	23
	Early Dry Season-EDS	41.200	5.205	50
	Mid Dry Season-MDS	35.729	4.970	48

Table A.7 – Prescribed burns season, average of trees with losses, standard error and number of samples in Figure 7.

Prescribed burns season	Average (%)	Standard error	N Sample
Late Rainy Season-LRS	3.050	2.176	20
Early Dry Season-EDS	0.00	0.00	6
Mid Dry Season-MDS	7.667	5.661	18

Table A.8 – Sampling intervals, prescribed burns season, average, standard error and number of samples in Figure 8.

Sampling intervals	Prescribed burns seasons	Average (%)	Standard error	N Sample
0 to 12 months	Late Rainy Season-LRS	36.667	15.103	6
	Early Dry Season-EDS	50.650	7.343	20
	Mid Dry Season-MDS	37.412	8.328	17
13 to 24 months	Late Rainy Season-LRS	42.333	18.952	3
	Early Dry Season-EDS	55.500	11.937	10
	Mid Dry Season-MDS	33.857	6.474	14
25 to 36 months	Late Rainy Season-LRS	34.857	13.577	7
	Early Dry Season-EDS	35.000	13.203	8
	Mid Dry Season-MDS	74.667	5.988	3
Average	Late Rainy Season-LRS	36.938	8.969	16
	Early Dry Season-EDS	48.632	5.826	38
	Mid Dry Season-MDS	39.235	5.328	34

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