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Relationships between moisture content and flammability of campestral Cerrado species in Jalapão

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ABSTRACT: The objective of this study was to analyze the relationships between moisture content and the flammability of campestral Cerrado species in the Jalapão region. For that, six species were collected (*Trachypogon spicatus*, *Aristida* sp., *Davilla elliptica*, *Byrsonima verbascifolia*, *Hirtella ciliata* and *Dalbergia miscolobium*) and analyzed in four moisture levels (H1, H2, H3 and H4). The tests were performed in the epirradiator, with 50 replicates of 1 g sample for each species, to obtain the ignition frequency (IF), the mean time to ignition (MTI), the time of combustion (MTC) and flame height (MFH). Correlations between moisture and other variables were r = 0.94 (MTI), r = -0.43 (MTC), r = -0.87 (MFH) and r = -0.73 (IF). The linear regression equations had R^2aj values of 0.87 (MTI); 0.15 (MTC); 0.74 (MFH) and 0.50 (IF). There was influence of humidity in the change of flammability variables, however, there was little variation in the flammability values (FV), except for the species *Aristida* sp., and *Dalbergia miscolobium*, showing the high flammability of most species, even at the highest levels of moisture content.

Key words: epirradiator; forest fires; fuel availability; fuel moisture

Relação entre conteúdo de umidade e inflamabilidade de espécies do Cerrado campestre no Jalapão

RESUMO: O objetivo deste estudo foi analisar a relação entre o conteúdo de umidade e a inflamabilidade de espécies do Cerrado campestre na região do Jalapão. Para isso, foram coletadas seis espécies (*Trachypogon spicatus*, *Aristida* sp., *Davilla elliptica*, *Byrsonima verbascifolia*, *Hirtella ciliata* e *Dalbergia miscolobium*), que foram analisadas em quatro níveis de umidade (H1, H2, H3 e H4). Os testes foram realizados em epirradiador, com 50 repetições de amostra de 1 g para cada espécie, para obtenção da Frequência de ignição (IF), do Tempo médio para ignição (MTI), Duração da combustão (MTC) e Altura de chamas (MFH). As correlações entre a umidade e as outras variáveis foram de r = 0,94 (MTI), r = -0,43 (MTC), r = -0,87 (MFH) e r = -0,73 (IF). As Regression equations linear tiveram valores de R^2aj de 0,87 (MTI); 0,15 (MTC); 0,74 (MFH) e 0,50 (IF). Houve influência da umidade na mudança das variáveis de inflamabilidade, no entanto, pouca variação nos valores de inflamabilidade (FV), exceto para as espécies *Aristida* sp., e *Dalbergia miscolobium*, mostrando a alta inflamabilidade de grande parte das espécies, mesmo nos maiores níveis de umidade.

Palavras-chave: epirradiador; incêndios florestais; material combustível; umidade do combustível

Introduction

The knowledge of the fuel characteristics is extremely important for fire management, with the intention of reducing the negative impacts that can be caused by it, as well as determining the frequency and propagation of forest fires (Dimitrakopoulos & Papaioannou, 2001; Ganteaume et al., 2011; van Altena et al., 2012).

Hence, the intensity of a forest fire is related to factors such as type of vegetation and its structure; physiological state of the plant material; particle size (fine or coarse); moisture content of plant material; chemical composition and; space arrangement; in addition to factors such as terrain topography and climatic conditions (Hachmi et al., 2011; Xanthopoulos et al., 2012). According to Xanthopoulos et al. (2012), such fuel characteristics, mentioned above, define their flammability, which is directly related to the danger of forest fires.

As defined by Anderson (1970), flammability is considered as a result of ignition (time to ignition), sustainability (ability to sustain combustion from ignition) and combustibility (speed or intensity of combustion). In this way, flammability can be measured by determining the ignition frequency (IF), the time to ignition (TI), the time of combustion (TC) and the flame height (FH).

In spite of the importance of the knowledge of flammability of the fuel, studies involving the determination of flammability in herbaceous, shrub and tree species, occurring in the Cerrado biome, are extremely scarce and need to be carried out for the proper knowledge and correct handling of the fuel. In this sense, van Altena et al. (2012), emphasize the lack of knowledge about the properties of flammability, including herbaceous savanna species, as reported by Simpson et al. (2015).

There are several methods for measuring flammability variables (Ganteaume et al., 2011). However, the different forms of evaluation will depend on the scale considered (Etlinger & Beall, 2004; Madrigal et al., 2012; Ganteaume & Jappiot, 2014). Some studies are based on the evaluation of flammability through laboratory tests with small portions (1 g) of leaves and branches, using an electric epirradiator equipped with a pilot flame (eg. Valette, 1990; Petriccione, 2006; Curt et al., 2011; Ganteaume et al., 2013; Kovalsyki et al., 2016; Molina et al., 2017). Further studies are done using larger and non-destructive samples using calorimetric, thermogravimetric or oxygen index limitation analyzes (Hachmi et al., 2011; Ganteaume et al., 2011).

Regardless of the methodology, the moisture content of the fuel material acts as a major influence on the change in flammability (Dimitrakopoulos & Papaioannou, 2001; Curt et al., 2011; Madrigal et al., 2012; Simpson et al., 2015). For some authors (eg. Etlinger & Beall, 2004; van Altena et al., 2012), flammability is directly related to plant properties, such as structure, plant health and volatile organic compounds (VOCs) (Alessio et al., 2008; Ormeño et al., 2009). However, they are especially related to the moisture content present in the fuel (Santana & Marrs, 2014; Corona et al., 2014).

When considering the high influence of humidity on changing flammability variables (IF, TI, TC, and FH), regression relationships can be established for the estimation of such variables (eg. Dimitrakopoulos & Papaioannou, 2001; Hachmi et al., 2011), with the fuel moisture as an independent variable. However, studies addressing techniques for indirect estimation of flammability variables are poorly performed. Considering this context, the present study aims to analyze the relationships between moisture content and the flammability of campestral Cerrado species in the Jalapão region.

Material and Methods

Characterization of study area and selection of species

The species used in the flammability tests were collected at the Serra Geral do Tocantins Ecological Station (EESGT), which is a full protection conservation unit located in the Cerrado biome, in the Jalapão region. It covers the municipalities of Almas, Mateiros, Ponte Alta and Rio de Conceição, belonging to the state of Tocantins, and the municipality of Formosa do Rio Preto, which belongs to the state of Bahia.

According to the Köppen climate classification, the climate of the region is Aw, characterized by a tropical savanna climate with strong annual precipitation (rainy summer and dry winter), which is higher than annual potential evapotranspiration (ICMBio, 2014). The prevailing Cerrado vegetation (phytophysiognomy) is of the country type, covering the types of campo limpo, campo limpo úmido, campo sujo, campo sujo úmido and campo rupestre (Arruda & Behr, 2002).

In this study, there were two species of each vegetative stratum (herbaceous, shrub and arboreal) of the phytophysiognomy campo sujo: of the herbaceous stratum, the species *Trachypogon spicatus* (Capim agreste) and *Aristida sp.* (Capim vereda); of the shrub, *Davilla elliptica* (Sambaibinha) and *Byrsonima verbascifolia* (Murucí), and; of the arboreal, *Hirtella ciliata* (Pau pombo) and *Dalbergia miscolobium* (Pau ferro); totaling six species that were submitted to the flammability tests.

The plant material collected for the analysis consisted of leaves and branches with diameter less than 0.7 centimeters (cm) in diameter (Soares & Batista, 2007), at the end of the dry season (September).

Determination of moisture levels

Four moisture levels were used for each species studied: 1 (H1), 2 (H2), 3 (H3) and 4 (H4). Moisture levels H1 and H4 were represented by completely dried leaf material in muffle furnace and fresh leaf material, respectively. In order to determine the moisture content of the fresh material (H4), three subsamples of 200 g each were used and placed in a muffle furnace for 48 hours at 75 °C (Beutling et al., 2005), with humidity as a percentage (%) determined by dry base.

The H2 and H3 levels were obtained by dividing the moisture values of each species into three parts, in order words, it would be the level H4 divided by three. By knowing the total moisture of the plant material, for the determination of the levels H2 and H3, Eq. 1 was used to calculate the fresh weight of 200 g should have, knowing the content of Moisture (H%) to be reached, according to the definition of the levels previously exposed.

$$\mathrm{Fw} = \mathrm{Dw} \cdot (\mathrm{H}+1) \quad (1)$$

in which:

H - moisture;
Fw - fresh weight of plant material (g);
Dw - dry weight of the plant material (g).

By drying and weighting until the new wet weight established by Eq. 1, H2 and H3 levels of each species were established.

Flammability tests

The laboratory experiments and the analyzes of the study were carried out at the Environmental Monitoring Center and Fire Management (CeMAF), located at the Federal University of Tocantins (Gurupi Campus). The burnings were carried out by means of a 500 W electric epirradiator with a 10 cm diameter disc at a constant temperature of 600 °C. At the center of the disc, at a height of 4 cm, the pilot flame was located and at the level of the disc of the epirradiator, there was a scale graduated in centimeters for the taking of measures of the height of the flames. All tests were conducted under conditions free from the influence of air.

According to Valette's (1990) methodology, 50 repetitions weighing 1 ± 0.1 g each were performed for all treatments of the study (species vs. humidity levels), where each repetition was timed to know how long the fuel takes to enter ignition (TI) and Time of combustion (TC).

The measurements of Flame height (FH) were taken through the graduated scale. The Ignition frequency (IF) was calculated in percentage according to the number of repetitions that ignited in less than 60 seconds (positive burnings) - ignitions that exceeded 60 s were considered negative burnings. Therefore, each test with 50 repetitions was used to determine the means of time to ignition (MTI), time of combustion (MTC) and flame height (MFH).

The values of MTI and IF were used to determine the values of flammability (VI), according to the scale proposed by Valette (1990), with values ranging from 0 to 5 (0 = poorly flammable, 1 = little flammable, 2 = moderate flammable; 3 = flammable, 4 = highly flammable, 5 = extremely flammable). Furthermore, MFH values were used to determine the Combustion indices (CI): MFH < 1 cm indicates very low combustibility (CI = 1); MFH of 1 to 3 cm, low combustibility (CI = 2); MFH of 4 to 7 cm, medium combustibility (CI = 3); MFH of 8 to 12 cm, high combustibility (CI = 4) and; MFH > 12 cm, very high combustibility (CI = 5); according to Petriccione (2006).

Data analysis

Factorial variance analysis was performed, considering all six species and four moisture levels, in a completely randomized design. On the means comparison test, the Scott-Knott test (5% of significance) was used. In order to meet the normality and homoscedasticity assumptions, in the TI and TC variables, the square root transformation was used.

In the cluster analysis, based on the Euclidean distance, the nearest neighbor method was used, considering the flammability classes (six classes), and then the grouping results and the Flammability values (FV) were compared. In this analysis, the variables of flammability represented by the combination between species and moisture were considered.

A linear Pearson correlation analysis was performed at a significance level of 5 and 1% and, based on the best correlation obtained by the analyzes, a graph was plotted with the dispersions between MTI and MFH for visual analysis of the dispersions of each treatment.

For the linear regression analysis, the Stepwise method was used for the adjustment, having H% as an independent variable and the variables of flammability MTI, MTC, MFH, and IF as a dependent variable. The equations were analyzed according to their adjusted coefficient of determination (R^2aj), standard error of the absolute estimate and in percentage (Syx and Syx%) and graphical analysis of the residuals obtained for each adjusted equation. In the residue analysis, the standard residuals were used, with an average of zero and the variance approximately equal to 1, with values outside the range of 3 and -3 considered as outliers.

Results and Discussion

Moisture levels and ignition frequency

At level 4 (H4), the Moisture (H%) values ranged from 82% for the shrub species *Davilla elliptica* to 277% for the herbaceous species *Aristida sp*. (Table 1), showing the great difference of H% among the species when green. At level 3 (H3), H% values ranged from 72% for the species *Davilla elliptica* and *Hirtella ciliata* (arboreous) to 178% for *Aristida*

Table 1. Ignition frequency and humidity in percentage of each level for each species.

Espécie	H1		H2		H3		H4	
	IF	U	IF	U	IF	U	IF	U
T. spicatus	100	0	100	65	100	95	100	121
Aristida sp.	100	0	94	99	80	178	54	277
D. elliptica	100	0	100	27	100	72	100	82
B. verbascifolia	100	0	100	43	100	78	100	116
H. ciliata	100	0	100	24	100	72	100	103
D. miscolobium	100	0	98	66	66	137	18	199

H1, H2, H3 and H4 - humidity levels; IF - ignition frequency in percentage (%); U - humidity in percentage (%) of each level.

sp.; for level 2 (H2), the variation was 24 to 99% of the species *Hirtella ciliata* and *Aristida sp*., and; at level 1 (H1), in all species, the entire H% was extinguished (0%).

Studying species in southern Spain, Molina et al. (2017), obtained values of H% of fresh biomass ranging from 73 to 297%. Kovalsyki et al. (2016), in southern Brazil, reached values of H% of fresh biomass ranging from 128 to 210%. Ganteaume et al. (2013), working with species from the southeast of France, obtained contents of H% of fresh biomass varying from 92 to 203%. Determining H% of fresh biomass of species from the Mediterranean region, Petriccione (2006), reached values of 76% up to approximately 200%. These results demonstrate similar variations to those found in the present study among different species with fresh biomass (level H4 of the study).

As for the Ignition frequency (IF), the species *Trachypogon spicatus spicatus*, *Davilla elliptica*, *Byrsonima verbascifolia* and *Hirtella ciliata* had 100% IF regardless their humidity level. The species *Aristida sp*. and *Dalbergia miscolobium*, at levels H2, H3 and H4 did not present 100% IF, varying from 18 to 98%.

Working with leaf litter flammability in three different types of shrub vegetation and two types of forest in southeastern France, Curt et al. (2011), obtained results of 90% ignition dry litter IF, regardless of the type of vegetation studied. In the same region, with shrub and tree species, Ganteaume et al. (2013), obtained IF values ranging from 46 to 100%. Ormeño et al. (2009), evaluating the possibility of the use of terpene content of leaf litter to estimate flammability changes in southern France, obtained IF of 100% for all combinations of leaf litter.

Statistical analysis of averages

When analyzing Table 2, it can be observed that all flammability variables evaluated had significant differences at the 5% probability level, in the moisture analysis within each species (comparison in the lines). In the analysis of species within each level of humidity (comparison in the columns), it was observed that only for the MTC and MFH variables at H1 level (0% humidity) there were no significant differences ($p < 0.05$).

Furthermore, in the formation of statistical groups of averages in the moisture condition of fresh material (H4), it was possible to observe that species of the same stratum presented significant differences. For example, in the MTI variable, the species of the herbaceous stratum (Her), *T. spicatus* (11.2 s) and *Aristida sp*. (30.3 s) presented statistically different values.

The results above may indicate that differences in the values of flammability variables between species may be more related to the chemical composition of each species (Batista et al., 2012; Ormeño et al., 2009), since factors such as stratum, of H% or even leaf morphology, did not explain the differences between species. In addition to that, Molina et al. (2017), point out that besides the H%, factors such as the flammability measurement method, differences

Table 2. Values of MTI, MTC and MFH flammability variables for each species at each moisture level.

Vr	St	Espécie	H1	H2	H3	H4
MTI	Her	*T. spicatus*	3.0 Ac	9.7 Ab	10.3 Cb	11.2 Ca
	Her	*Aristida sp.*	2.1 Bd	10.2 Ac	21.8 Ab	30.3 Aa
	Shr	*D. elliptica*	2.9 Ac	5.0 Bb	10.8 Ca	12.4 Ca
	Shr	*B. verbascifolia*	3.5 Ad	5.8 Bc	10.2 Cb	16.2 Ba
	Arb	*H. ciliata*	2.5 Ac	3.3 Cc	6.2 Db	9.1 Da
	Arb	*D. miscolobium*	1.6 Bd	4.0 Cc	14.8 Bb	33.6 Aa
		CV (%)	24.65			
		F (interação)	31.72 (p < 0.01)			
MTC	Her	*T. spicatus*	13.7 Ac	20.7 Ab	24.4 Aa	19.0 Bb
	Her	*Aristida sp.*	12.3 Aa	8.5 Cb	5.0 Dc	3.4 Ed
	Shr	*D. elliptica*	14.0 Ab	16.8 Ba	13.9 Bb	15.0 Cb
	Shr	*B. verbascifolia*	15.4 Ac	20.0 Ab	24.8 Aa	19.4 Bb
	Arb	*H. ciliata*	13.8 Ac	18.4 Ab	23.8 Aa	23.6 Aa
	Arb	*D. miscolobium*	14.1 Aa	16.4 Ba	7.0 Cb	5.8 Db
		CV (%)	15.8			
		F (interação)	39.86 (p < 0.01)			
MFH	Her	*T. spicatus*	20.0 Aa	18.2 Bb	17.2 Bb	17.9 Ab
	Her	*Aristida sp.*	20.0 Aa	13.3 Cb	7.1 Dd	8.6 Bc
	Shr	*D. elliptica*	20.0 Aa	20.0 Aa	19.3 Ab	18.8 Ab
	Shr	*B. verbascifolia*	20.0 Aa	19.9 Aa	19.6 Aa	18.2 Ab
	Arb	*H. ciliata*	20.0 Aa	20.0 Aa	19.4 Aa	18.5 Ab
	Arb	*D. miscolobium*	20.0 Aa	19.1 Ba	12.6 Cb	9.6 Bc
		CV (%)	13.19			
		F (interação)	51.27 (p < 0.01)			

MTI - mean time to ignition (s); MTC - mean time of combustion (s); MFH – mean flame height (cm); Vr - Flammability variable; St - stratum belonging to the vegetable; Her - herbaceous stratum; Shr - shrub stratum; Arb - arboreal stratum; H1 - at level one of humidity (dry material); H2 - level two of humidity; H3 - level three of humidity; H4 - level four of humidity. Averages followed by upper and lower case letters do not differ from each other within the columns and lower case letters do not differ from each other within the lines, by the Scott-Knott test, both at the 5% probability level.

in height of material collection, density and maturity of selected individuals can serve as explanations for variations in flammability of the plant.

The MTI values ranged from 1.6 to 3.5 seconds (s) at the H1 level; from 3.3 to 10.2 s at the H2 level; from 6.2 to 21.8 s at the H3 level; and from 9.1 to 33.6 s at the H4 level. For MTC, values ranged from 12.3 to 15.4 s; from 8.5 to 20.7 s; from 5.0 to 24.8 s; and from 3.4 to 23.6 s respectively at levels H1, H2, H3, and H4. MFH values at H1 level were equal or greater than 20 centimeters (cm) in all species; at H2 level values ranged from 13.3 to 20 cm; at H3 level ranged from 7.1 to 19.6 cm, and at H4 level ranged from 8.6 to 18.8 cm.

The herbaceous species *Aristida sp*. and the arboreal species *D. miscolobium* presented the highest MTI values at the H4 level (30.3 and 33.6 seconds respectively) and had the lowest MTI’s at the H1 level (2.1 and 1.6 seconds respectively), and with non-significant values. Such behavior, when free of moisture, can be explained by the fact that the species possess a higher surface-volume relation of the leaves, which facilitates the rapid absorption of heat (Ganteaume et al., 2013).

Based on the mean values of each species at the different moisture levels (Table 2), a direct relation between the MTI variable and H% can be noticed, that is, as the humidity increases, the time spent for the material to enter ignition also increases. This fact can be explained by the amount of water that the material must lose until it burns (Simpson et al., 2015), which is higher in the higher levels of humidity.

When analyzing the behavior of MTC values, at different moisture levels, species *T. spicatus*, *B. verbascifolia,* and *H. ciliata* presented a directly correlated behavior, thus, as moisture increased, the longer the duration of the combustion took. However, the species *Aristida sp*., and *D. miscolobium*, presented MTC behavior inversely correlated to moisture and that in some way agrees with the report of Simpson et al. (2015), that highlight the possibility of such reverse behavior of MTC. The species *D. elliptica* presented atypical behavior from the others in relation to MTC, which can be explained by the fact that the species does not have a pattern of change in the time of combustion as the humidity increases or decreases.

In all cases, the behavior between MFH and moisture was inversely correlated, that is, the higher the moisture of the plant material, the lower the flame height. In this way, it is possible to verify the influence of the humidity in the change of the values of the flammability variables for the studied species.

Flammability values and combustibility indexes

Figure 1 graphically shows the behavior of the Flammability values (FV) and Combustibility indexes (CI), where the most distant points of zero (considering the "y" axis) present higher flammability, on a scale from zero to five according to Valette's (1990) methodology; and Petriccione (2006). The species *T. spicatus* (herbaceous), *D. elliptica* (shrubby) and *H. ciliata* (arboreal), at all moisture levels, presented very high CI values (CI = 5) (Figure 1B) and high FV rates (FV = 5) (Figure 1A), being considered extremely flammable in any level of humidity.

In all cases, at H1 level, the species had the highest values for both CI and FV. At H2 level, only the herbaceous specie *Aristida sp*. presented lower value of FV (FV = 4) than the other species. Likewise, it was observed in species *B. verbascifolia* (H4 level with FV = 4), *D. miscolobium* (H3 and H4 levels with FV = 1 and 0 respectively), and *Aristida sp*. (H2 levels, H3 and H4 with FV = 4; 2 and 0 respectively). The CI values only changed at H3 levels with the species *Aristida sp*., (CI = 3) and H4 with the species *Aristida sp*., and *D. miscolobium* (CI = 4 for both species).

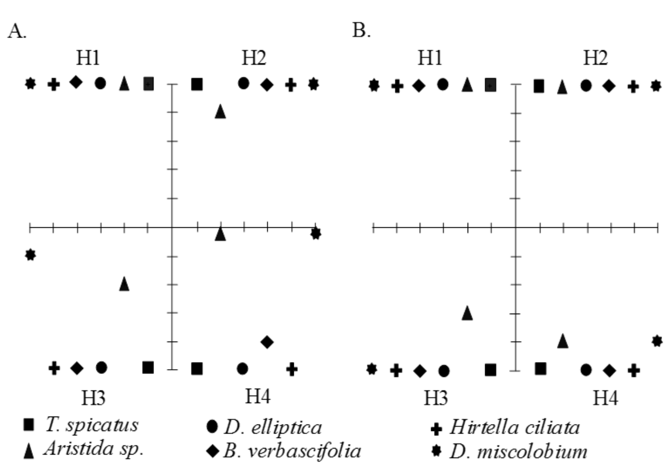

Figure 1. Flammability values - FV (A.) and combustion indexes - CI of the species (B.) in each moisture level (H1, H2, H3, and H4).

Therefore, only the species *Aristida sp*., and *D. miscolobium* showed large variations in levels H3 and H4. Humidity was a factor of high influence in this case since the species with humidity levels were much higher than the others (277 and 199% respectively), and at levels, H1 and H2 were extremely and highly flammable with lower contents of moisture. Therefore, in the present study, species with very high humidity were evaluated with lower FV's and CI's. However, other factors may be explanatory and may also influence, such as the content of chemical compounds of the species when wet (Ormeño et al., 2009; Alessio et al., 2008), as well as the influence of leaf area-volume surface of the species, which are larger than the others (Etlinger & Beall, 2004).

To determine flammability of leaf litter and plant biomass (leaves) of different species in the Mediterranean region, with different characteristics (hardwoods, conifers, and shrubs), Petriccione (2006), obtained results in which hardwood species were considered extremely flammable (except one species), the conifers presented low to moderate flammability and shrubs had low flammability, according to Valette's (1990) methodology. Kovalsyki et al. (2016), who carried out experiments using an epirradiator with the objective of identifying potential species for safety curtain in southern Brazil with five species, found results ranging from poorly flammable (four species) to flammable for a species of Pinus.

With the objective of identifying ignition index based on flammability potential in southern Spain (Mediterranean region), Molina et al. (2017), obtained flammability results ranging from moderately flammable to extremely flammable. The same results were obtained by Rodríguez et al. (2016), in his monthly distributed study of flammability with species of pine ecosystems and, Batista et al. (2012), with arboreal and shrub species in southern Brazil. Biondi et al. (2014), studying the flammability of three herbaceous ornamental species, native to the southern region of Brazil, which had potential to prevent forest fires around highways, had results varying between low and moderate flammability. Ganteaume et al. (2013), studying six ornamental species of arbustive and arboreal species (only one species) in the southeast region of France, obtained values varying from poorly to extremely flammable.

The explanations for the extremely flammable behavior of most species of this study may be varied, such as the high flammability of Cerrado species, with adaptability mechanisms because they are species of a phytophysiognomy fire-dependent biome (Soares & Batista, 2007). The results obtained by the authors mentioned above, with species from the Mediterranean region and Pinus forests, corroborate to the fact that they are dependent and adapted to the fire, presenting frequent fires and as a result they have highly flammable species, whereas species less flammable habitually belong to fire-sensitive plant formations and exhibit high mortality rates when subjected to fires (Mutch, 1970; Valette, 1990; Dimitrakopoulos & Papaioannou, 2001; Soares & Batista, 2007).

Cluster analysis

The results of the analysis of Cluster groups (Figure 2) indicate which treatments were similar, based on the averages of the variables that were cut to form six groups, similar to Valette's classification. Thus, through the analysis they can be classified as weak flammability, the treatments As-H4 and Dm-H4; low-flammability, As-H3 treatments; moderate flammability, Dm-H3; flammable, As-H2; high flammability, Bv-H4 and; extremely flammable, Ts-H1, De-H1, Hc-H1, Dm-H1, As-H1, Bv-H1, Dm-H2, De-H2, Hc-H2, Bv-H2, Ts-H3, Hc-H4, Bv-H3, Ts-H2, Ts-H4, Hc-H3, De-H3, and De-H4.

It is worth pointing out that the division of the groupings by cluster analysis demonstrates some divergences with the results obtained by the method of Valette (1990). For example, in the As-H3, Dm-H3 and As-H2 treatments, classified as moderately, poorly and highly flammable, respectively, the clustering analysis classified them as slightly, moderately and flammable, respectively. These differences are due to the fact that the method proposed by Valette (1990), considers only the MTI and IF, once the analysis done in the present study takes into account MTI, MTC, MFH, and IF.

The dispersion of the MTI and MFH values (Figure 3) demonstrates the most flammable treatments (high and

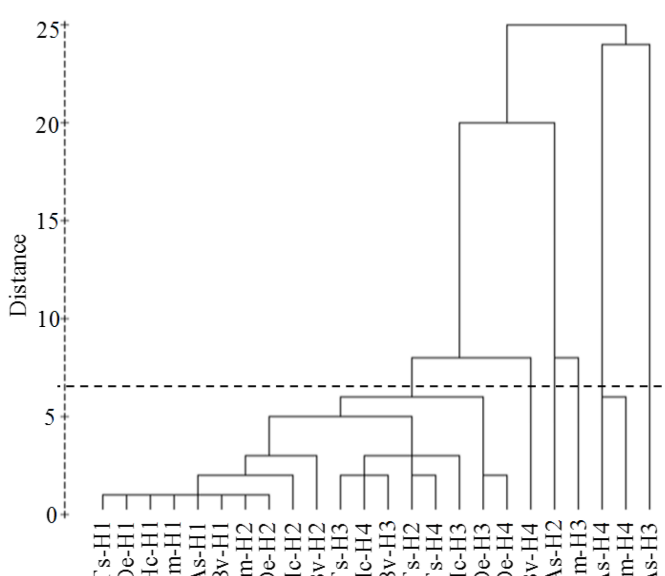

Figure 2. Dendrogram resulting from cluster analysis of the species at their respective moisture levels (As - *Aristida sp.*, Bv - *Byrsonima verbascifolia*, Dm - *Dalbergia miscolobium*, De - *Davilla elliptica*, Hc - *Hirtella ciliata*, Ts - *Trachypogon spicatus*).

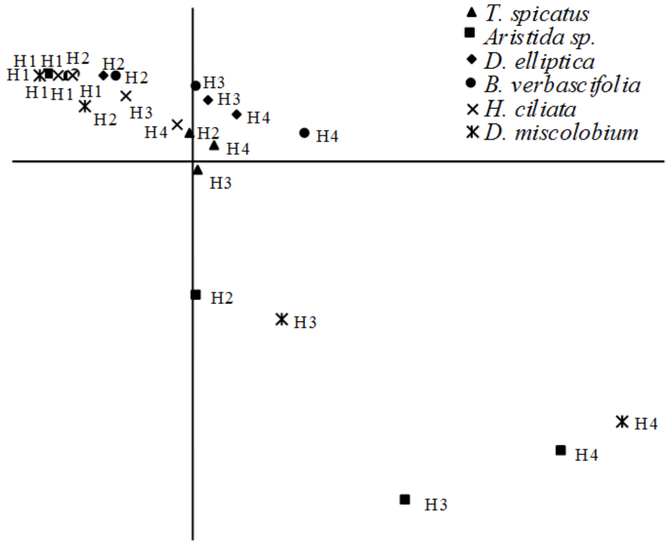

Figure 3. Dispersion around the TI averages (X axis) and FH (Y axis).

extreme flammability), close to the crossing of the averages. The species *D. miscolobium* and *Aristida sp.*, at H3 level of humidity, considered as low flammability (according to Cluster grouping analysis) are isolated in the graph, far from the points of the most flammable species.

The treatment of the species *Aristida sp.*, at level H2 of humidity (low flammability), and also the treatments of species *D. miscolobium* at level H2, (moderate flammability), *Aristida sp.* at level H1 (flammable) are separated from the grouping of the treatments considered as highly flammable.

Correlations and linear regressions

All the variables of flammability presented significant correlations ($p < 0.05$) with H% of plant material, among which the correlations between H% and MTI ($r = 0.94$) and between H% and MFH ($r = -0.87$) (Table 3). Despite the significant correlation ($p < 0.05$), the MTC variable was the only one without a significant correlation at 1%, since, as previously explained, some species showed a directly correlated behavior, while others were inversely correlated (*Aristida sp.*, and *D. miscolobium*).

Kovalsyki et al. (2016), who performed experiments in an epirradiator, found correlations with H% and MTI ($r = 0.70$), MTC ($r = -0.70$), and MFH ($r = -0.60$). Hachmi et al. (2011), observed significant linear correlations between H% and MTI ($r = 0.85$), with MTC ($r = -0.34$), MFH ($r = -0.81$), and IF (r

Table 3. Linear correlation between Humidity (H%) and flammability parameters (MTI, MTC, MFH and IF).

	H (%)	MTI (s)	MTC (s)	MFH (cm)	IF (%)
H (%)	1				
MTI (s)	0.94**	1			
MTC (s)	-0.43*	-0.52**	1		
MFH (cm)	-0.87**	-0.87**	0.72**	1	
IF (%)	-0.73**	-0.85**	0.67**	0.80**	1

* p < 0.05; ** p < 0.01.

= -0.61). However, as in the present study, the correlation of H% with MTC, although significant ($p < 0.05$), was not considered high ($p < 0.01$). Rodríguez et al. (2016), found correlations between H% and MTI (r = 0.37) and between H% and MTC (r = 0.28).

Unlike this study, Petriccione (2006), did not obtain correlations between H% and MTI (r = 0.0054), MTC (r = 0.0596) and with flammability value (r = 0.0385). However, Batista et al. (2012), found correlations between H% and MTC (r = 0.58) and between H% and MFH (r = 0.85). According to these authors, the moisture content of vegetation is one of the most important flammability properties of living and dead vegetation, but they emphasize the need for more detailed studies on other aspects of vegetation, such as volatile organic compounds.

In the study conducted by Molina et al. (2017), H% was not the main determinant of flammability, but for Pinus species located in southern Spain, H% was the explanatory factor for flammability differences, ranging from flammable to extremely flammable.

As for the correlation between H% and FV, a high correlation coefficient (r = -0.82, $p < 0.01$) was observed, unlike studies by Petriccione (2006), and Batista et al. (2012). This fact was also observed in the correlation between H% and CI, which presented r = -0.67 ($p < 0.01$).

Based on the significant correlations between H% and the average values of the flammability variables (Table 3), linear regression equations were adjusted for indirect estimation of the averages of the flammability variables (Table 4). The adjusted equations had satisfactory results for the adjusted coefficient of determination (R^2aj) and for the standard error of the absolute estimate (Syx) and in percentage (Syx%), except for MTC.

The equation for estimation of the MTI variable ($p < 0.001$) obtained the highest R^2aj value (0.87) and Syx% value (30.07). For MFH ($p < 0.001$), the R^2aj value was 0.74 with a Syx% value of 11.56 and for IF ($p < 0.001$), the adjusted equations had values of R^2aj equal to 0.50 and Syx% equal to 15.08.

The adjusted equation for estimation of MTC (p = 0.034) reached the lowest value of R^2aj and higher value of Syx% (0.15 and 37.07 respectively) when compared to the other variables (MTI, MFH and IF). The variable MTC was the only one that presented alteration of the values in the different levels of humidity among the species, as discussed previously.

Table 4. Adjusted regression equations for the estimation of flammability variables (MTI, MTC, MFH and IF).

Dv	Regression equations	R^2_{aj}	Syx	Syx%
MTI (s)	1.3909 + H% * (0.1118) + ε	0.87	3.01	30.07
MTC (s)	18.3036 + H% * (-0.0378) + ε	0.15	5.70	37.07
MFH (cm)	21.1402 + H% * (-0.0487) + ε	0.74	2.01	11.56
IF (%)	107.6170 + H% * (-0.2011) + ε	0.50	13.89	15.08

Dv - dependent variable; R^2aj - adjusted determination coeficient; Syx - standard error of estimate; Syx (%) - standard error of the estimate in percentage and ε - error of the model.

Dimitrakopoulos & Papaioannou (2001), developed regression equations to establish the relation between H% and time for ignition, finding values of R^2aj varying from 0.73 to 0.94 for species in the Mediterranean region.

Figure 4 graphically shows the dispersion of the standardized residuals of the adjusted equations for MTI (Figure 4A), MTC (Figure 4B), MFH (Figure 4C) and IF (Figure 4D). The more values near the midline (zero value), the better the estimation of the parameters by the equation, that is, the closer the estimated values will be to the actual values.

Although influencing all the statistical treatments and the FV's and IC's of the study, the humidity content of the fuel material obtained different behaviors at each stage of the study. In the analysis of the averages of MTI, MTC, MFH and in the IF values, humidity performed a high influence in the alterations of its values, once the linear correlations proved this fact and allowed the adjustment of regression equations that can be used to estimate variables of flammability. On the other hand, the influence of moisture in the FV's and CI's was verified only in the species *Aristida sp*., and *D. miscolobium*, and the other species had higher flammability in all moisture levels, as explained previously.

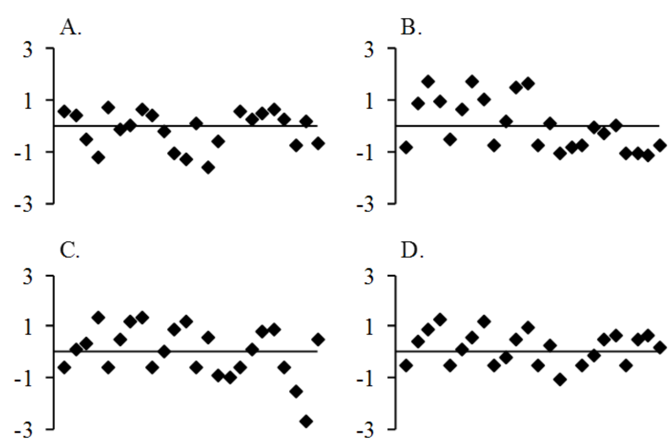

Figure 4. Distribution of the standardized residuals of the adjusted equations to estimate the flammability parameters: (A) MTI; (B) MTC; (C) MFH and (D) IF.

Conclusions

The behavior of the MTI, MTC, MFH and IF flammability variables were dependent of the humidity content of the plant material. Therefore, humidity can be used as an independent variable for the adjustment of regression equations to estimate the flammability variables, presenting satisfactory results.

The flammability difference between each species was not explained by difference in stratum (herbaceous, shrub and arboreus) being better related to the content of volatile organic compounds.

The values of flammability and combustion indexes varied little among the species, possibly due to the characteristic behavior of the Cerrado species.

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Literature Cited

Alessio, G.; Peñuelas, J.; Lusia, J.; Ogaya, R.; Estiarte, M.; De Lillis, M. Influence of water and terpenes on flammability in some dominant Mediterranean species. International Journal of Wildland Fire, v.17, n. 2, p.274–286, 2008. https://doi.org/10.1071/WF07038.

Anderson, H.E. Forest fuel ignitability. Fire Technology, v.6, n.4, p.312–319, 1970. https://doi.org/10.1007/BF02588932.

Arruda, M.B.; von Behr, M. Jalapão: Expedição científica e conservacionista. Brasília: Ibama, 2002. 93p.

Batista, A.C. Biondi, D.; Tetto, A.F.; Assunção, R. de; Tres, A.; Travenisk, R.C.C.; Kovalsyki, B. Evaluación de la inflamabilidad de árboles y arbustos utilizados en la implementación de barreras verdes en el sur del Brasil. In: González-Cabán, A. (Coord.). Proceedings of the Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfres. Albany: U.S. Department of Agriculture; Forest Service; Pacifc Southwest Research Station, 2012. p.278-286. https://www.fs.fed.us/psw/publications/documents/psw_gtr245/es/psw_gtr245_278.pdf. 20 Dez. 2017.

Beutling, A.; Batista, A.C.; Soares, R.V.; Vitorino, M.D. Quantificação de material combustível superficial em reflorestamentos de *Araucaria angustifolia* (Bert.) O. Ktze. Revista Floresta, v.35, n.3, p.465-472, 2005. https://doi.org/10.5380/rf.v35i3.5187.

Biondi, D.; Batista, A.C.; Martini, A. The flammability of ornamental species with potential for use in highways and wildland urban interface (WUI) in southern Brazil. In: Viegas, D.X. (Ed.). Advances in forest fire research. Coimbra: University of Coimbra, 2014. p.992-997. https://doi.org/10.14195/978-989-26-0884-6_108.

Corona, P.; Ferrari, B.; Cartisano, R.; Barbati, A. Calibration assessment of forest flammability potential in Italy. IForest, v.7, p.300-305, 2014. https://doi.org/10.3832/ifor1123-007.

Curt, T.; Schaffhauser, A.; Borgniet, L.; Dumas, C.; Estève, R.; Ganteaume, A.; Jappiot, M.; Martin, W.; N'Diaye, A.; Poilvet, B. Litter flammability in oak woodlands and shrublands of southeastern France. Forest Ecology and Management, v.261, n. 12, p.2214–2222, 2011. https://doi.org/10.1016/j.foreco.2010.12.002.

Dimitrakopoulos, A.P.; Papaioannou, K.K. Flammability assessment of mediterranean forest fuels. Fire Technology, v.37, n. 2, p.143–152, 2001. https://doi.org/10.1023/A:1011641601076.

Etlinger, M.G.; Beall, F.C. Development of a laboratory protocol for fire performance of landscape plants. International Journal of Wildland Fire, v.13, n. 4, p.479–488, 2004. https://doi.org/10.1071/WF04039.

Ganteaume, A.; Jappiot, M. Assessing the fire risk in the wildland-urban interfaces of SE France: Focus on the environment of the housing. In: Viegas, D. X. (Ed.). Advances in Forest Fire Research. Coimbra: University of Coimbra, 2014. p. 648–656. https://doi.org/10.14195/978-989-26-0884-6_73.

Ganteaume, A.; Jappiot, M.; Lampin, C.; Guijarro, M.; Hernando, C. Flammability of Some Ornamental Species in Wildland–Urban Interfaces in Southeastern France: Laboratory Assessment at Particle Level. Environmental Management, v.52, n. 2, p.467–480, 2013. https://doi.org/10.1007/s00267-013-0067-z.

Ganteaume, A.; Jappiot, M.; Lampin-Maillet, C.; Curt, T.; Borgniet, L. Effects of vegetation type and fire regime on flammability of undisturbed litter in Southeastern France. Forest Ecology and Management, v.261, n. 12, p.2223–2231, 2011. https://doi.org/10.1016/j.foreco.2010.09.046.

Hachmi, M.; Sesbou, A.; Benjelloun, H.; Handouz, N.E.; Bouanane, F. A simple technique to estimate the flammability index of moroccan forest fuels. Journal of Combustion, v.2011, Article ID 263531, 2011. https://doi.org/10.1155/2011/263531.

Icmbio, 2014

Instituto Chico Mendes de Conservação da Biodiversidade - ICMBio. Plano de manejo para Estação Ecológica Serra Geral do Tocantins (EESGT). Brasília: ICMBio, 2014. 575p. http://www.icmbio.gov.br/portal/images/stories/docs-planos-de-manejo/esec_serra_geral_do_tocantins.pdf. 25 Dez. 2017.

Kovalsyki, B.; Takashina, I.K.; Tres, A.; Tetto, A.F.; Batista, A.C. Inflamabilidade de espécies arbóreas para uso em cortinas de segurança na prevenção de incêndios florestais. Pesquisa Florestal Brasileira, v.36, n.88, p.387-391, 2016. https://doi.org/10.4336/2016.pfb.36.88.991.

Madrigal, J.; Marino, E.; Guijarro, M.; Hernando, C.; Díez, C. Evaluation of the flammability of gorse (Ulex europaeus L.) managed by prescribed burning. Annals of Forest Science, v.69, n.3, p.387–397, 2012. https://doi.org/10.1007/s13595-011-0165-0.

Molina, J.R.; Martín, T.; Silva, F.R.Y.; Herrera, M.A. The ignition index based on flammability of vegetation improves planning in the wildland-urban interface: A case study in southern Spain. Landscape and Urban Planning, v.158, p.129–138, 2017. https://doi.org/10.1016/j.landurbplan.2016.11.003.

Mutch, R.V. Wildland fires and ecossistems: a hypothesis. Ecology, v.51, n.6, p.1046-1051, 1970. https://doi.org/10.2307/1933631.

Ormeño, E.; Céspedes, B.; Sánchez, I.A.; Velasco-García, A.; Moreno, J.M.; Fernandez, C.; Baldy, V. The relationship between terpenes and flammability of leaf litter. Forest Ecology and Management, v.257, n. 2, p.471–482, 2009. https://doi.org/10.1016/j.foreco.2008.09.019.

Petriccione, M. Infiammabilità della lettiera di diverse specie vegetali di ambiente Mediterraneo. Napoli: Università Degli Studi Di Napoli Federico II; Dipartimento di Biologia Strutturale e Funzionale, 2006. 48p. Doctoral Thesis. http://www.fedoa.unina.it/1355/. 29 Nov. 2017.

Rodríguez, Y.C.; Rodríguez, M.P.R.; Mesa, F.J.; Hernández, Y.C.; Becerra, L.W.M. Inflamabilidad de especies vegetales del ecosistema de pinares. Revista Cubana de Ciencias Forestales, v.4, n.1, p.36-47, 2016. http://cfores.upr.edu.cu/index.php/cfores/article/view/134. 19 Dez. 2017.

Santana, V.M.; Marrs, R.H. Flammability properties of British heathland and moorland vegetation: models for predicting fire ignition. Journal of Environmental Management, v.139, p.88-96, 2014. https://doi.org/10.1016/j.jenvman.2014.02.027.

Simpson, K.J.; Ripley, B.S.; Christin, P.; Belcher, C.M.; Lehmann, C.E.R.; Thomas, G.H.; Osborne, C.P. Determinants of flammability in savanna grass species. Journal of Ecology, v.104, n.1, p.138-148, 2015. https://doi.org/10.1111/1365-2745.12503.

Soares, R.V.; Batista, A.C. Incêndios Florestais: controle, efeitos e uso do fogo. Curitiba: Ronaldo Viana Soares e Antonio Carlos Batista, 2007. 264 p.

Valette, J.C. Inflammabilités des espèces forestières méditerranéennes. Conséquences sur la combustibilité des formations forestières. Revue Forestière Française, v.42, n. sp., p.76–92, 1990. https://doi.org/10.4267/2042/26171.

van Altena, C.; van Logtestijn, R.S.P.; Cornwell, W.K.; Cornelissen, J.H.C. Species composition and fire; non-additive mixture effects on ground fuel flammability. Frontiers in Plant Science, v.3, p.1-10, 2012. https://doi.org/10.3389/fpls.2012.00063.

Xanthopoulos G.; Calfapietra C.; Fernandes P. Fire hazard and flammability of European forest types. In: Moreira F.; Arianoutsou M.; Corona P.; De las Heras J. (Eds.) Post-fire management and restoration of Southern European Forests. Dordrecht: Springer, 2012. p.79-92. (Managing Forest Ecosystems, 24). https://doi.org/10.1007/978-94-007-2208-8_4.