RELATIONSHIP BETWEEN MOISTURE CONTENT AND FLAMMABILITY OF CERRADO SPECIES IN SOUTHERN TOCANTINS

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Resumo

Análise entre teor de umidade e inflamabilidade de espécies do cerrado no sul do Tocantins. A finalidade desse trabalho foi analisar a relação entre teor de umidade e inflamabilidade de 9 espécies do Cerrado no Sul do Tocantins. As espécies estudadas foram: *Machaerium brasiliense*, *Qualea grandiflora*, *Luehea grandiflora*, *Campomanesia guaviroba*, *Astronium fraxinifolium*, *Curatella americana*, *Bauhinia forficata*, *Vatairea macrocarpa* e *Anacardium Occidentale*. Estas foram analisadas em quatro níveis de umidade (H1, H2, H3 e H4). Para cada nível, foram coletadas 50 amostras de 1g (± 0,1 g) de cada espécie e realizadas 50 repetições de queima, obtendo em cada tratamento as variáveis de Tempo para Ignição (TI), Frequência de ignição (FI), Duração de Combustão (DC), Índice de Combustão (IC) e Valor de Inflamabilidade (VI). Os resultados mostraram que o teor de umidade exerce influência na inflamabilidade das espécies do Cerrado. As correlações entre umidade e variáveis de inflamabilidade foram de r = 0,951 (Tempo médio de ignição), r = -0,962 (Tempo médio de duração de combustão), r = -0,977 (Altura média das chamas) e r = -0,988 (Frequência de ignição).
Palavras-chave: Inflamabilidade; Material combustível; Incêndios florestais; Umidade do combustível.

Abstract

This study aimed to analyze the relationship between moisture content and flammability of nine plant species from the Cerrado in southern Tocantins. The species studied were: *Machaerium brasiliense*, *Qualea grandiflora*, *Luehea grandiflora*, *Campomanesia guaviroba*, *Astronium fraxinifolium*, *Curatella americana*, *Bauhinia forficata*, *Vatairea macrocarpa*, and *Anacardium Occidentale*. The plants were analyzed at four moisture contents (M1, M2, M3, and M4). For each level, 50 samples (1 g ± 0.1 g) of each species were collected, and 50 repetitions of burning were performed. The parameters analyzed were: time to ignition (TI), frequency of ignition (FI), duration of combustion (DC), combustion index (CI), flammability value (FV), and height of flames (HF). Our results showed that moisture contents influence flammability in Cerrado plant species. The correlation coefficients between moisture and flammability parameters were r = 0.951 (TI), r = -0.962 (DC), r = -0.977 (HF), and r = -0.988 (FI).
Keywords: Flammability, Combustible material, Forest fires, Fuel moisture.

INTRODUCTION

Cerrado biome is an ecosystem associated with wildfires as responsible for its formation and shaping for thousands of years. However, due to climate change and urban sprawling, anthropic action has become the main causes of forest fires.

Forest fires are of a complex nature and often turn into boundless environmental and socioeconomic damages (CASAVECCHIA *et al.*, 2019). Associated with the interrelationship known as 'the fire triangle,' forest fires involve three main combustion elements: fuel, oxygen, and heat (SOARES; BATISTA; TETTO, 2017).

Fire action in the Cerrado biome has been widely studied and has aroused the interest of researchers to understand fire behavior, serving as strategies for its prevention and management (SOARES; BATISTA; TETTO, 2017).

Forest fire intensity vary with combustible material aspects, such as: vegetation typology, physiology, moisture content, and chemical composition (HACHMI *et al.*, 2011). These aspects can be expressed as flammability of forest fuels, which is associated with ignition time, combustion duration, combustibility and consumability, and can be measured by frequency of ignition (FI), time to ignition (TI), duration of combustion (DC), and height of flame (HF) (ANDERSON, 1970; MARTIN *et al.*, 1994).

Among the factors that influence the flammability of forest species, combustible material moisture plays a fundamental role (NOLAN *et al.*, 2018).

Besides moisture, plant structural properties, health status, and volatile organic compounds content influence its flammability. In this sense, Biondi and Batista (2010) classified forest species according to dendrological criteria for efficiency in protecting forest fires. Thus, the greater the dendrological positive factors in response to fire, the more suitable the plant will be to compose fire protection walls.

Despite the intrinsic knowledge of combustible material, studies on forest species flammability in the Cerrado biome are scarce, but essential for forest fire prevention (DA SILVA *et al.*, 2019; SANTOS *et al.*, 2018 e RAMOS *et al.*, 2019).

Most studies of forest species flammability have focused on calorimetry of chemical compounds, by thermogravimetry or laboratory tests, using branch and leaf samples incinerated in an electric epiradiator with a pilot flame (CURT *et al.*, 2011; VALETTE, 1992; GANTEAUME *et al.*, 2013; MOLINA *et al.*, 2017; SANTOS *et al.*, 2018; RAMOS *et al.*, 2019 e DA SILVA *et al.*, 2019).

The hypothesis of this study is composed by the following topics:

- Moisture content of combustible material is the factor that most influences flammability of Cerrado forest species;
- Cluster analysis based on Euclidean distance by nearest neighbor method can be used to classify flammability considering the six classes of Valette (1992).

Thus, the present study aimed to analyze the relationship between moisture content and flammability of Cerrado forest species and, more specifically: (1) to evaluate the relationship between moisture content in combustible material and flammability values of forest species from Cerrado sensu stricto from a forest at the Experimental Station of Environmental Monitoring and Fire Management Center (CeMAF) and; (2) to compare Cluster Analysis based on Euclidean distance by nearest neighbor method with the classification proposed by Valette (1992).

MATERIAL E METHODS

Study Area

The study was carried out at Biondi, the Environmental Monitoring and Fire Management Center (CeMAF), which is in the Federal University of Tocantins (UFT), Campus of Gurupi - TO (11º 44' south latitude and 49º 03' west longitude, and 286-m altitude). Nine species were evaluated, namely: *Machaerium brasiliense* Vogel, *Qualea grandiflora* Mart, *Luehea grandiflora* Mart. & Zucc., *Campomanesia guaviroba*, *Astronium fraxinifolium*, *Curatella americana*, *Bauhinia forficata*, *Vatairea macrocarpa* (Benth.) Ducke, and *Anacardium Occidentale.*

The forest has a Cerrado sensu stricto phytophysiognomy with a typical Cerrado subtype (Ribeiro and Walter, 1998), with predominantly arboreal-shrubby vegetation with an average height of three to six meters.

Sampling

Samples were collected from October 22 to 26, 2019 when there was no rainfall, preventing leaves from being moisture saturated. All species were sampled for leaves and branches (about 600 g each), with samples being classified as fine combustible material with diameters below 0.7 cm (SOARES; BATISTA; TETTO, 2017).

Fine combustible material was collected and handled using latex gloves and tweezers. The material was subjected to a flammability test within a maximum of 2 hours after field collection. That was to maintain samples the closest to their natural conditions (KOVALSYKI *et al.*, 2017).

Moisture content and moisture levels

Four moisture levels[1] were used for each species: M1 (0%), M2 (33%), M3 (66%), and M4 (100%), of which M1 and M4 consisted of fully kiln-dried and fresh leaves, respectively. The other two (M2 and M3) corresponded to total moisture content divided into three parts, i.e., M4 divided by three (SANTOS *et al.*, 2018). Once the total moisture content of plant material was known, M2 and M3 could be determined by equation 1.

$$WW = DW'(M' + 1) \tag{1}$$

Where:
WW: wet weight
DW': dry weight
M': material moisture content

By weighing and drying each new wet weight (WW) established using equation 1, M2 and M3 of each species were then established.

Flammability test

Combustible material was tested for flammability in the laboratory of the CeMAF. The burnings were carried out in a 500-W electric epiradiator with a 10 cm diameter disk, at a constant temperature of 600 °C. The epiradiator was equipped with a pilot flame 4 cm above the center of the disc. At the level of the epiradiator disc, a graduated scale in centimeters was installed to measure flame heights (HF).

The experiment was conducted in a controlled environment and free from air currents. A total of 50 replicates (1 ± 0.1 g each) were burned (VALETTE, 1992) for all treatments (species *versus* moisture level).

For each repetition, time for the fuel material to ignite (TI) and duration of combustion (DC) were recorded. Height of flames (HF) was measured by the graduated scale. Frequency of ignition (FI) was given as a percentage as a function of the number of repetitions igniting within less than 60 seconds, longer ignitions were considered negative.

Thus, each 50-repetition test at different moisture contents was used to determine the averages for time to ignition (ATI), duration of combustion (ADC), height of flames (AHF), and frequency of ignition (FI). Thereafter, ATI and FI were used to determine flammability values (IV) according to the scale proposed by Valette (1992).

Statistical analysis

A factorial analysis of variance was performed considering species (9) and moisture content (4) as factors. Then, the Scott-Knott test (at 5% significance) was used for average comparisons.

Cluster analysis was performed based on Euclidean distance, using the nearest neighbor method, comparing the clusters to the six flammability classes proposed by Valette (1992).

Pearson's linear correlation analysis was performed at 5 and 1% significance levels. Based on the best correlations, a graph was plotted with dispersions between ATI, ADC, and AHF for visual effects and dispersion analysis of each treatment.

Regression Analysis

A stepwise method was used for linear regression analysis, with moisture content as independent variable, and ATI, ADC, AHF, and FI flammability as dependent variables. Equations were analyzed statistically according to an adjusted coefficient of determination (R^2adj) and absolute standard error of estimation in percentage (Syx%). For residual analysis, standardized residuals with an average of zero and variation of about 1 were used, and values outside the range between 3 and -3 were considered outliers.

RESULTADOS

A frequência de ignição e umidade em porcentagem de cada nível e para cada espécie estão descritas na Tabela 1. O teor de umidade das espécies ao nível H4 variou entre 95% (*Anacardium occidentale*) e 223% (*Qualea grandiflora)*, ao nível H3 a variação foi de 63% a 148% e ao nível H2 houve variação de 31% a 74%.

Tabela 1. Frequência de ignição e umidade em cada espécie
Table 1. Ignition frequency and humidity in each species

Species	Popular name	M1		M2		M3		M4	
		FI	**U**	**FI**	**U**	**FI**	**U**	**FI**	**U**
Machaerium brasiliense	Jacarandá	100	0	100	54	94	108	88	162
Qualea grandiflora	Pau-terra-grande	100	0	96	74	86	148	68	223
Luehea grandiflora	Açoita-cavalo	100	0	98	43	100	87	88	131
Campomanesia guaviroba	Gabiroba	100	0	98	62	98	125	92	188
Astronium fraxinifolium	Gonçalo-Alves	100	0	90	37	70	74	60	112
Curatella americana	Lixeira	100	0	92	56	64	113	40	170
Bauhinia forficata	Pata-de-vaca	100	0	98	40	94	81	78	122
Vatairea macrocarpa	Amargoso	100	0	82	60	68	120	54	180
Anacardium occidentale	Caju	100	0	86	31	56	63	50	95

Note: M1- moisture level of 0% (dry material), M2 - moisture level of 33%, M3 – moisture level of 66%, M4 – moisture level of 100% (fresh material); FI – frequency of ignition in %; M - moisture content in %

Regarding frequency of ignition (FI), the species ranged from 50 to 92% in fresh material. Among the analyzed species, *A. occidentale* had the lowest moisture content and FI value. The species *M. brasiliense*, *L. grandiflora*, and *C. guaviroba* had a minimum of 88% FI, regardless of the moisture level. At M3, FI ranged from 56 to 100%, whereas at M2 it was from 82 to 100%. Finally, at M1, FI did not vary, with all species showing 100% FI.

Table 2 presents the average values of time to ignition (ATI), duration of combustion (ADC), and height of flames (AHF). All these variables showed a significant difference at 5% probability by the Scott-Knott test, except for ATI at M1, which was significant at 5% probability.

At M4, AHF ranged from 5.64 cm (*Curatella americana*) to 20.36 cm (*Campomanesia guaviroba*), therefore HF varied a lot among species while fresh. Also, at M4, ATI did not vary significantly among the species *Q. grandiflora*, *A. fraxinifolium*, *V. macrocarpa*, and *A. occidentale*, but these differed significantly from the other species. Among all species, *A. occidentale* had the lowest ATI (9.3s) at M4 and the highest (4.13s) at M1; however, this variable did not differ significantly among species at M1.

In terms of duration of combustion (DC), *V. macrocarpa* had the shortest time (7.31s) at M1, and the second-shortest time (2.2s) at M4. By comparing M1 and M4, all species had higher DC at M1. Moreover, only *A. fraxinifolium*, *C. americana*, *B. forficata*, *V. macrocarpa*, and *A. occidentale* showed a linear trend for ADC when comparing all moisture levels.

Regarding average height of flames (AHF), *M. brasiliense* had the highest values at M1 and M2 (51.10 cm and 35.90 cm, respectively). Yet, the smallest values were observed for *A. occidentale* (32.62 cm) at M1, and for *C. americana* (5.64 cm) at M4.

Tabela 2. Valores das variáveis de inflamabilidade ATI, ADC e AHF
Table 2. Values of the flammability variables ATI, ADC and AHF

Variável	Species	M1	M2	M3	M4
ATI	*Machaerium brasiliense*	1.87 Aa	4.26 Aa	9.91 Bb	12.08 Bb
	Qualea grandiflora	2.01 Aa	8.46 Bb	7.67 Ab	10.96 Ab
	Luehea grandiflora	2.08 Aa	6.15 Ab	8.85 Bb	15.19 Bc
	Campomanesia guaviroba	2.30 Aa	8.19 Bb	9.98 Bb	14.05 Bc
	Astronium fraxinifolium	2.42 Aa	9.63 Bb	10.91 Bb	10.27 Ab
	Curatella americana	2.51 Aa	10.35 Bb	10.45 Bb	15.19 Bb
	Bauhinia forficata	2.81 Aa	9.62 Bb	14.81 Cc	13.11 Bc
	Vatairea macrocarpa	3.06 Aa	8.31 Bb	9.66 Bb	9.59 Ab
	Anacardium occidentale	4.13 Aa	7.72 Bb	6.11 Aa	9.30 Ab
	CV%	**93%**			
	F (Interaction)	**2.63 (p <0.001)**			
ADC	*Machaerium brasiliense*	9.01 Ab	11.65 Cc	10.88 Cc	6.72 Ba
	Qualea grandiflora	12.36 Cc	10.33 Cc	6.71 Bb	3.18 Aa
	Luehea grandiflora	11.96 Cb	15.48 Dc	11.13 Cb	7.85 Ba
	Campomanesia guaviroba	10.15 Bb	10.69 Cb	12.16 Cb	8.09 Ba
	Astronium fraxinifolium	10.22 Bc	6.19 Ab	3.28 Aa	2.88 Aa
	Curatella americana	10.63 Bc	9.17 Bc	5.30 Ab	2.06 Aa
	Bauhinia forficata	11.27 Cc	10.14 Cc	6.84 Bb	3.85 Aa
	Vatairea macrocarpa	7.31 Ab	6.44 Ab	4.22 Aa	2.20 Aa
	Anacardium occidentale	8.30 Ab	7.55 Ab	4.53 Aa	2.54 Aa
	CV%	**56%**			
	F (Interaction)	**2.63 (p <0.001)**			
AHF	*Machaerium brasiliense*	51.1 Dc	35.9 Cb	22.04 Ba	19.92 Ca
	Qualea grandiflora	38.74 Bc	20.78 Ab	10.7 Aa	8.58 Aa
	Luehea grandiflora	38.44 Bc	27.82 Bb	30.72 Cb	11.22 Aa
	Campomanesia guaviroba	43.82 Cb	26.44 Ba	24.28 Ba	20.36 Ca
	Astronium fraxinifolium	40.18 Bc	24.08 Ab	15.46 Aa	13.64 Ba
	Curatella americana	38.1 Bc	23.78 Ab	10.2 Aa	5.64 Aa
	Bauhinia forficata	40.24 Bc	26.6 Bb	22.28 Bb	14.90 Ba

	Vatairea macrocarpa	44.9 Cc	23.76 Ab	22.56 Bb	8.98 Aa
	Anacardium occidentale	32.62 Ac	21.76 Ab	12.90 Aa	8.16 Aa
	CV%	**44%**			
	F (Interaction)	**2.6 (p <0.001)**			

Note: ATI - average time to ignition (s), ADC - average duration of combustion (s), AHF - average height of flames (cm); M1- moisture at 0% (dry material), M2 - moisture at 33%, M3 – moisture at 66%, M4 – moisture at 100% (fresh material). Means followed by the same uppercase letters within columns and lowercase letters within rows do not differ from each other by the Scott-Knott test, both at 5% probability.

Table 3 shows that all species had flammability value equal to 5 at M1 (0% moisture level). However, at M2 (33% moisture), flammability values ranged from 2 (*Curatella americana* and *Bauhinia forficata*) to 5 (*Machaerium brasiliense*).

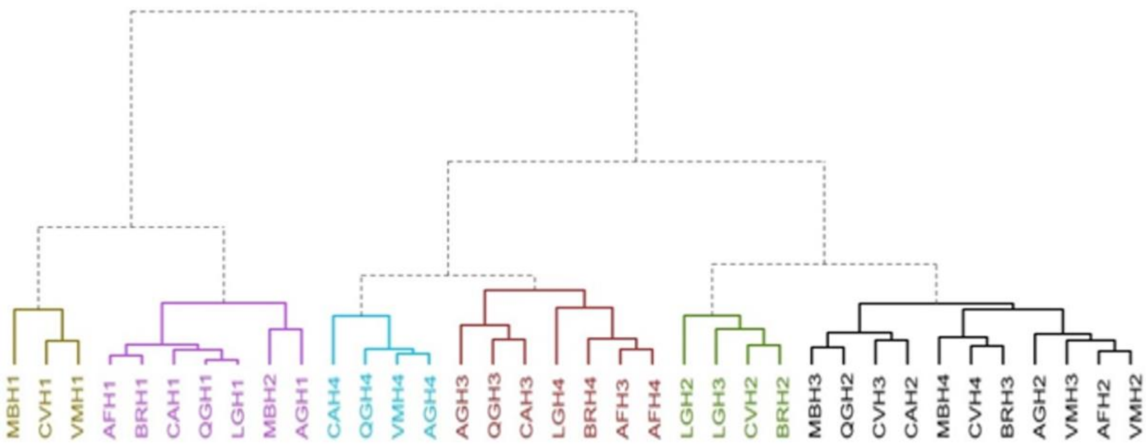
Tabela 3. Valor de inflamabilidade - Método de Valette (1992)
Table 3. Flammability value - Method of Valette (1992)

Species	Popular name	M1	M2	M3	M4
Machaerium brasiliense	Jacarandá	5	5	2	1
Qualea grandiflora	Pau-terra-grande	5	3	3	2
Luehea grandiflora	Açoita-cavalo	5	3	4	1
Campomanesia guaviroba	Gabiroba	5	4	3	1
Astronium fraxinifolium	Gonçalo-Alves	5	4	2	2
Curatella americana	Lixeira	5	2	2	1
Bauhinia forficata	Pata-de-vaca	5	2	1	1
Vatairea macrocarpa	Amargoso	5	3	2	1
Anacardium occidentale	Caju	5	3	3	2

Note: M1- moisture level of 0% (dry material), M2 - moisture level of 33%, M3 – moisture level of 66%, M4 – moisture level of 100% (fresh material); Flammability value (FV) was classified according to the corresponding number, wherein: FV = 0 (poorly flammable); FV = 1 (poorly flammable); FV = 2 (moderately flammable); FV = 3 (flammable); FV = 4 (highly flammable) or FV = 5 (extremely flammable). Source: Valette (1992).

At M3 (66% moisture), *L. grandiflora* showed the highest FV (4). At M4 (100% moisture), *Q. grandiflora*, *A . fraxinifolium*, and *A. occidentale* had FV equal to 2, while the other species had FV equal to 1.

Cluster analysis (Figure 1) indicated which treatments were similar based on the means of variables grouped into six groups, just as in the classification by Valette (1992). Therefore, MBH1, CVH1, and VMH1 were clusters indicating extreme flammability; AF11, BRH1, CAH1, QGH1, LGH1, MBH2, and AGH1 high flammability, decreasing flammability as clusters approach the right side.



Note: The abbreviations (letters) correspond to the initials of the scientific names of each species. M refers to the treatment to which the species were subjected, namely 1 at 0%, 2 at 33%, 3 at 66%, and 4 at 100% moisture content level.

Figura 1. Dendrograma Ligação completa; Distância Euclideana
Figure 1. Dendrogram Complete connection; Euclidean Distance

Table 4 shows the Pearson correlation analysis among the variables M%, ATI, ADC, AHF, and FV. Based on these results, we could note that moisture content showed a significant correlation at 5% with all flammability parameters.

Tabela 4. Correlação de Pearson
Table 4. Pearson's correlation

	M%	**ATI**	**ADC**	**AHF**	**FI**
M%	1				
ATI	0.951*	1			
ADC	-0.962*	-0.830	1		
AHF	-0.977*	-0.995**	0.881	1	
FI	-0.988*	-0.921	-0.964*	-0.954*	1

Note: Disregarding the sign, Pearson's coefficients approaching 0 pointed to a weak correlation, while those approaching 1 meant a strong correlation. Wherein: M%= moisture content, ATI = Average time to ignition (s), ADC = Average duration of combustion (s), AHF = Average height of flames (cm), FI = Frequency of ignition. * Significant at 5%, ** significant at 1%.

Based on significant correlations with moisture level (Table 4), four linear equations were fitted to predict the dependent variables (Table 5). The adjusted equations had satisfactory results for the adjusted coefficient of determination (R^2adj) and standard error of the estimate, which was described as a percentage (Syx%), except for ADC, thus corroborating the findings of Santos *et al.* (2018).

The highest R^2adj was obtained in the equation for estimating AHF (0.75), which had Syx% of 24.08. For ATI, R^2adj was 0.72, with a Syx% of 26.36, while for FI the adjusted equations had the lowest R^2adj (0.38) and a Syx% of 14.05. When compared to the other variables, ADC had the highest Syx% (33.81).

Tabela 5. Ajuste de equações de regressão
Table 5. Regression Equation Adjustments

Variable	**Equation**	**R^2**	**R^2aj**	**Syx%**
ATI	$3.60 + M\% * (0.09) + \varepsilon$	0.80	0.72	26.36
ADC	$10.82 + M\% * (-0.05) + \varepsilon$	0.45	0.40	33.81
AHF	$38.41 + M\% * (-0.27) + \varepsilon$	0.79	0.75	24.08
FI	$100.73 + M\% * (-0.29) + \varepsilon$	0.39	0.38	14.05

Note: ATI = Average time to ignition (s), ADC = Average duration of combustion (s), AHF = Average height of flames (cm), FI = Frequency of ignition; and ε= model error.

Figure 2 shows the standardized residual scatter plot for equations fitted to ATI, ADC, AHF, and FI, which were numbered 2.1, 2.2, 2.3, and 2.4, respectively. The closer to the midline (zero value), the better the parameter estimation by the equation, that is, the closer the estimates to the real values.

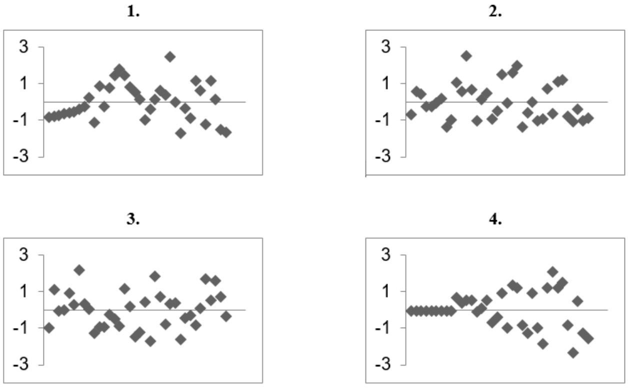


Figura 2. Distribuição dos resíduos padronizados das equações ajustadas para estimar os parâmetros de inflamabilidade: 1 (Média do Tempo de Ignição - ATI), 2 (Média de Duração de Combustão - ADC), 3 (Média de Altura de Chamas - AHC) e 4 (Frequência de Ignição - FI)

Figure 2. Distribution of standardized waste from the adjusted equations to estimate flammability parameters: 1 (Time to ignition - ATI), 2 (Duration of combustion - ADC), 3 (Height of flames - AHF) e 4 (Frequency of ignition - FI)

DISCUSSION

The lowest moisture content was observed for A. occidentale and the highest for Q. grandiflora at all moisture levels studied. Santos *et al.* (2018) also evaluated flammability of Brazilian Cerrado species and found moisture contents for species in a fresh state from 82 to 277% and 72 to 178% at M3 level, and from 24 to 99% at M2 level.

Regarding frequency of ignition (FI), as moisture contents decreased, FI increased for all species. Batista *et al.* (2012) stated that the moisture content of living vegetation varies with phenological stage with branch and leaf characteristics. Molina *et al.* (2019) evaluated the flammability of species on a roadside in Spain and found that altitude and slope variations influence moisture content of species, and hence their fuel availability. These authors also explained that moisture contents usually decrease because of exposure to the sun, especially in flat terrain, as it contributes to incidence of solar radiation. Likewise, Krix and Murray (2018) also found that leaf flammability varies throughout landscapes, as this is strongly related to the response of leaf characteristics to environmental factors.

When analyzing AHF (Table 2), all species, except *L. grandiflora*, showed a decreasing linear behavior, i.e., HF decreased as leaf moisture content increases. Essaghi *et al.* (2016) observed similar results and reported that moisture content significantly affected HF. Similarly, Hachmi *et al.* (2011) stated that HF influences species flammability since it can be an indicator of the presence of volatile organic compounds (VOC) in leaves. A within-species analysis revealed that ATI was always lower at 0% than at M4 moisture level. However, only *M. brasiliense*, *L. grandiflora*, *C. guaviroba*, and *C. americana* showed an increase in ATI as moisture contents increased in the four moisture levels tested.

Figure 1 shows some divergences of our results with those obtained by the method of Valette (1992). For instance, treatments VMH4, LGH4, and QGH2 were classified respectively as flammable, moderately flammable, and weakly flammable in our cluster analysis, but respectively as low flammable, low flammable, and flammable by the method of Valette (1992). Santos *et al.* (2018) also obtained similar findings and explained that such differences are because, in the method of Valette (1992), only ATI and FI are considered, whereas in our analysis ATI, ADC, AHF, and FI were considered.

Batista *et al.* (2012) found a correlation between M% with ATI (r = 0.58) and with AHF (r = 0.85), but none with FV (r = 0.043). Furthermore, these authors found that species with the smallest FV also had the smallest ADC and AHF values. In this context, Kovalsyki *et al.* (2017) performed a flammability analysis of tree species for use as firebreak and observed a correlation between M% and ATI (r = 0.7), and between ADC (r = -0.7) and AHF (r = -0 .6). To develop a flammability index formula for forest fuel of Moroccan species, Hachmi *et al.* (2011) obtained a high correlation between M% and the flammability parameters ATI (r = 0.85), AHF (r = 0.81), and FI (r = -0.61), except ADC (r = - 0.34). The latter, despite having a significant correlation ($p<0.05$), it was not considered high ($p<0.01$). A similar situation was observed by Santos *et al.* (2018), who found high correlations between M% and ATI (r = 0.94), AHF (r = -0.87), and FI (r = -0.73), and despite significant ($p<0.05$), the correlation between M% and ADC (r = -0.43) was not high ($p<0.01$).

In studying the moisture content effect on eucalyptus leaf combustion, Possell and Bell (2013) found that CO2 emissions are reduced as moisture content in eucalyptus leaves increases. According to Ward and Hardy (1991), increases in fuel moisture contents are expected to decrease combustion efficiency. Finally, Lobert and Warnatz (1993) also stated that increases in moisture contents raise emissions of volatile organic compounds.

CONCLUSÕES

- The flammability variables average time to ignition (ATI), average duration of combustion (ADC), average height of flames (AHF), and flammability value (FV) vary with moisture content (M%) in plant materials. As M% is closely related to the flammability of a plant species, its moisture percentage can be used as an independent variable to adjust regression equations for estimation of flammability variables. For most of the species studied, FV linearly increases as their moisture contents decrease. For the species *A. fraxinifolium* and *B. forficata*, FV remains unchanged at the beginning of drying, but once their moisture contents fall below a certain threshold, it linearly increases.
- There are divergences between cluster analysis results and Valette's classification (Valette, 1992). In the cluster analysis, *V. macrocarpa* and *L. grandiflora* are considered flammable and moderately flammable, respectively, at the highest moisture level (M4). On the other hand, the same species were considered as low flammable in the classification by Valette (1992). At the moisture level M2, *Q. grandiflora* was considered as weakly flammable by cluster analysis, but flammable by the method of Valette (1992). Therefore, cluster analysis by the nearest neighbor method cannot be used as a classification criterion when the six flammability classes of Valette (1992) are considered.

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