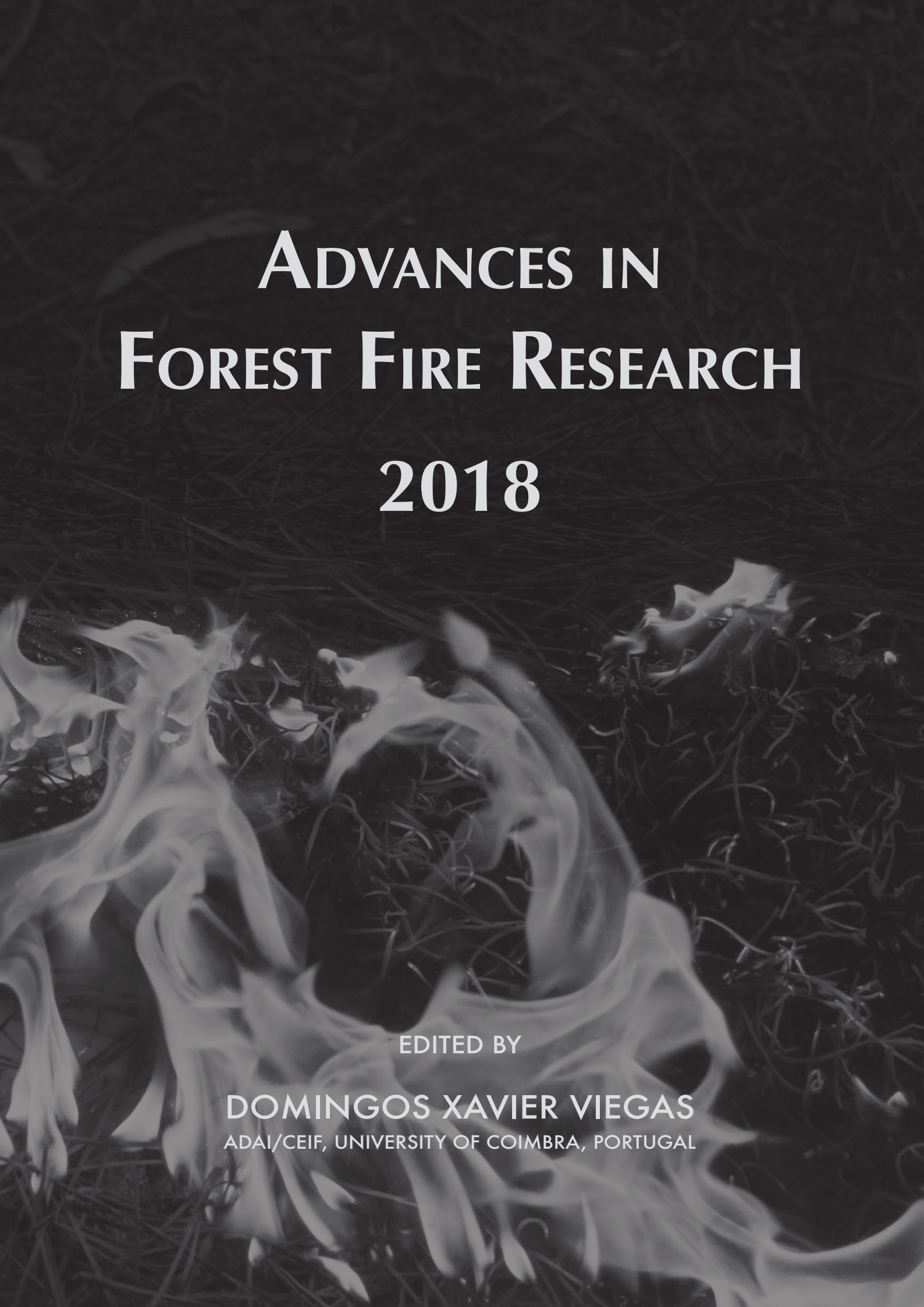
Advances in Forest Fire Research 2018



EDITED BY

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https://doi.org/10.14195/978-989-26-16-506_23

Flammability of native species of two Brazilian ecosystems

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Abstract

The Cerrado (Brazilian savanna) presents species with adaptations to fire and, therefore, is considered a fire dependent ecosystem. On the other hand, the Mixed Ombrophilous Forest (FOM), characterized by the presence of higher levels of moisture, is considered a fire sensitive ecosystem. Flammability is defined as the ability of the fuel to ignite after being subjected to an increase of caloric energy, until the material reaches the ignition stage, after the reduction in the moisture content. The objective of this research was to test and classify species from the Cerrado and the Araucaria Forest (FOM) according to their flammability. The following species from the Cerrado were tested: *Vatairea macrocarpa*, *Myrcia splendens*, *Davilla elliptica*, *Ouratea hexasperma*, *Copaifera langsdorffi*, *Diospyros hispida*. The tested species from the FOM were: *Ocotea puberula*, *Araucaria angustifolia*, *Allophylus edulis*, *Cupania vernalis* and *Luehea divaricata*. Using an epirradiator, 50 replications of burning for each species were carried out. Each tested sample consisted of 1.0 ± 0.1 g of green fuel material less than 0.7 cm of diameter, containing leaves and branches. The measures parameters were: Time of ignition (Ti), combustion duration (Dc), ignition frequency (Fi) and flame height (Hc). The species were classified according to their flammability rating value (Vi). To validate the classification and determine which parameters were the main flammability inductors, a Principal Component Analysis (PCA) was carried out. Araucaria angustifolia presented poor flammability, due to the higher ignition time. Allophylus edulis presented the higher flammability among the FOM species, and the ignition frequency was the decisive parameter to this classification. The species from the Cerrado showed similar values of combustion duration, except *Davilla elliptica* and *Myrcia splendens*, which presented intermediate values of ignition time. *Vatairea macrocarpa and Copaifera langsdorffi*, were highly and extremely flammable, respectively. The flammability values validated the hypothesis that the Cerrado species present higher flammability when compared to the FOM species. The Principal Components Analysis was effective in the results validation and allowed to explain what parameters determined the flammability.

Keywords: Principal component analysis; ignition, Cerrado, Araucaria forest.

1. Introduction

The Cerrado (Brazilian savanna) presents species with adaptations to fire and, therefore, is considered a fire dependent ecosystem. On the other hand, the Mixed Ombrophilous Forest (FOM), characterized by the presence of higher levels of moisture, is considered a fire sensitive ecosystem (Myers, 2006). The forest fuel is essential to the occurrence of fire, along with the moisture condition which controls the level of flammability (Soares *et al*., 2017).

Mutch (1970) affirms that plant communities dependent on the fire burn more easily than non-dependent communities of fire, because natural selection has favored the development of characteristics that make it more flammable. Pausas *et al*. (2017), adds that there are several strategies of flammability selected in different evolutionary contexts and confer benefits of suitability to plants that live under the regime of recurrent fires, in addition to being able to act as a means by which the plants can modify fire regimes to create favorable conditions for development (Schwick, 2003).

According to Vallete (1990), the flammability is defined as the ability of the fuel to ignite after being subjected to an increase of caloric energy, until the material reaches the ignition stage, after the

reduction in the moisture content. However, this characteristic does not necessarily represents how well a plant burning under field conditions, and to a lesser extent, the flammability depends on the size, thickness and shape of the plant, which can be evaluated directly by laboratory tests. (Pausas *et al.*, 2016).

Considering the characteristics of each ecosystem and the lack of research related to the flammability of native species in Brazil, the hypothesis that the species from the Cerrado are more flammable than those from the Araucaria Forest (FOM) was tested. The objective of this research was to test and classify species from the Cerrado and Mixed Ombrophilous Forest and determine which parameters present higher influence in the species flammability.

2. Methodology

The tests were developed at the "Centro de Monitoramento Ambiental e Manejo do Fogo - CeMAF, Universidade Federal do Tocantins" and the "Laboratório de Incêndios Florestais do Departamento de Ciências Florestais da Universidade Federal do Paraná", in accordance with the methodology presented by Valette (1990) and Petriccione (2006). Eleven species, five from the FOM (*Ocotea puberula, Araucaria angustifolia, Allophylus edulis, Cupania vernalis e Luehea divaricata*) and six from the Cerrado (*Vatairea macrocarpa, Myrcia splendens, Davilla elliptica, Ouratea hexasperma, Copaifera langsdorffi, Diospyros hispida*) were tested.

For each evaluated species, 50 replications of burning were carried out. Each sample consisted of 1.0 ± 0.1g of green combustible material less than 0.7cmdiameter, containing leaves and branches. The tests were conducted up to two hours after the material collection to prevent loss of moisture. The experimental burnings were performed in an epirradiator, with controlled temperature range of 250°C to 350°C, to prevent highly flammable fuels from being classified as poorly flammable (Kauf *et al*. 2014), and with the aid of a pilot flame 4 cm above the center of the disc in a place free of air currents (Figure 1).

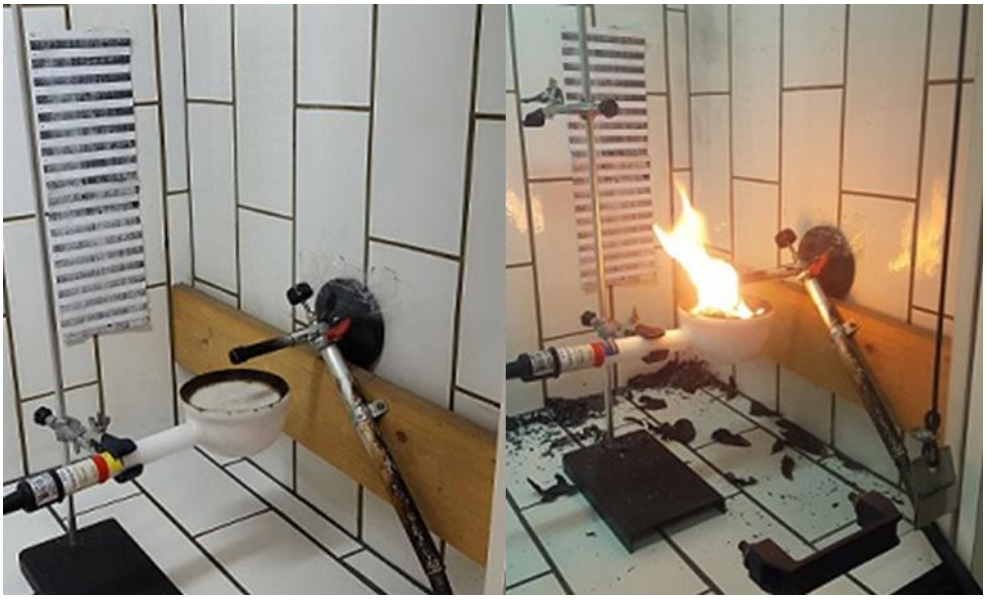

Figure 1 - Epirradiador in the test chamber and in operation.gure

The samples collected were dried in an oven for a period of 48 hours at 75 ºC and the moisture content was determined by the gravimetric method by the following equation:

$$MC = (WM - DM)/DM * 100$$

Where MC is the moisture content of combustible material in percentage, WM is the mass (wet) of combustible material at the time of collection and the DM mass (dry) of combustible material after drying in the oven.

The measured variables were time of ignition (Ti) and combustion duration (Dc), in seconds; flame height (Hc), in centimeters; and ignition frequency (Fi). The data obtained were submitted to the flammability rating value (Vi) and Principal Components Analysis (PCA), with the objective of validate the classification and identify the variables that present higher influence in the species flammability.

3. Results and discussion

The flammability rating values are presented in Table 1.

Table 1 - Values of the flammability variables of the tested species and the final classification.

Espécies	Ti (s)	Dc (s)	Hc (cm)	Fi	Vi
Ocotea puberula	35,14	11,65	24,03	37	I
Araucaria angustifolia	47,25	15,25	13,50	4	I
Cupania vernalis	31,03	16,48	18,31	29	I
Luehea divaricata	23,21	14,50	13,50	14	I
Myrcia splendens	25,30	7,60	11,16	32	I
Allophylus edulis	28,10	14,51	19,44	41	II
Davilla elliptica	21,63	7,86	12,19	22	II
Ouratea hexasperma	19,00	8,00	15,20	38	II
Diospyros hispida	20,35	11,45	15,21	32	II
Vatairea macrocarpa	12,71	13,42	19,88	50	V
Copaifera langsdorffi	9,45	11,45	19,20	50	VI

Vi: Flammability rating value of Valette (1990); I: Low flammability; II: Slightly flammable; III: Moderately flammable; IV: flammable; V: highly flammable; VI: Extremely flammable.

Figure 1 shows the results of the Principal Component Analysis, in which the species with similar parameters are forthcoming in the plan, while those with very different parameters are distant (Petriccione, 2006).

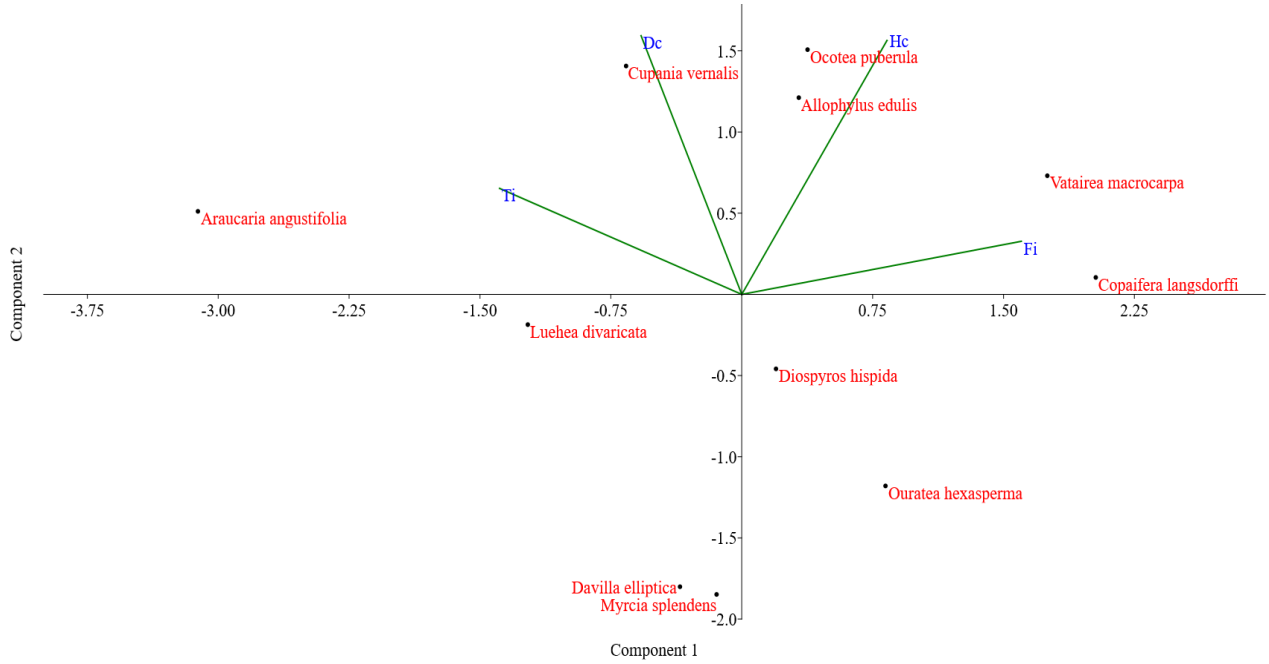

Figure 1 - Principal Components Analysis based on the flammability variables of the tested species.

Analyzing the PCA, along with the table 1 it can be observed that ignition time and frequency are opposites in the plan, corroborating, therefore, with the Vi classification (Vallete, 1990), while the variables Dc and Hc, when plotted on biplot, explain the behavior of the species regarding to fire (Petriccione, 2006; Vélez, 2009).

White and Zipperer (2010) emphasize that the moisture content is a preponderant factor for flammability by increasing the thermal capacity of the material and hamper the start of combustion. According to Hernando (2009), the variables related to the fire are directly related to the moisture content of fuels, especially the time of ignition and the height of the flame. Therefore, among the species examined for the cerrado, *V. macrocarpa* and *C. langsdorffi* were those that showed a lower content of moisture, 89.23% and 76.38%, respectively, and consequent higher flammability, getting next to the right side of the plan, with higher Fi and lower Ti. It is important to remember that, in addition to the moisture, characteristics such as lignin content, mineral salts and compounds also affect the flammability of forest fuels (Batista and Biondi, 2009).

It was found that the *A. edulis* was the most flammable of species of FOM, although classified as poorly flammable, with the frequency of ignition being the determining parameter for this classification, even with moisture content of 253.73%, a result similar to that found by Molina *et al*. (2017) for the specie *Ailanthus altissima*, with moisture content of 297.5%, in a study conducted in Spain. The specie *L. divaricata* presented 80.76% of moisture content, being that has lower moisture content among the species of FOM but was classified as poorly flammable due to low frequency of ignition.

Araucaria angustifolia showed a moisture content of 123.45% and proved to be poorly flammable, due to the high ignition time, positioning itself in the left quadrant of the graph. The *Ocotea puberula* showed a similar behavior, with 110.12% moisture content, even with the greatest value of flame height, being classified as poorly flammable, due to the fact it has a relatively high, although with higher values of Dc and Hc. These results corroborate those found by Weise *et al*. (2005), evaluating ornamental plants of low flammability, found moisture contents of 180 to 304%. Hachimi *et al*. (2011) in a study of the flammability of forest fuels, found a high correlation between moisture content and the parameters related to the flammability of fire. Petriccione (2006), in evaluation of species of the Mediterranean, stated that it had found a correlation between moisture and time of ignition or duration of combustion.

Generally, in areas with forest formations in advanced stage, for example, the fire has difficulties to enter due to the high humidity, however, Nepstad *et al*. (1999) clarify that the higher the frequency of fires, the greater becomes the flammability of the forest, because there is a substitution of species by an increase in the density of grasses, under the risk of the forest becoming a savanna.

Only fires of medium to high intensity may consume the plants that usually have moisture from 75 to 150% of its dry weight (Rodriguez, 2011). The meteorological variables, such as relative humidity and air temperature, wind and solar radiation are factors that directly affect the moisture content of a plant tissue, and, therefore, the living material is more stable in relation to the moisture that the dead material, because this does not require great energy to ignite (Fernandes and Cruz. 2012). Therefore, much of the initial heat of the combustion, before starting the combustion itself, is spent primarily to vaporize the water present in the fuel and water vapor resulting will reduce the oxygen near reducing the combustion of flammable gases (Soares *et al*. 2017).

All species showed similar values of Dc, with the exception of *Davilla elliptica* and *Myrcia splendens*, with intermediate values of Thee, positioning itself more to the center, in the lower left quadrant of the PCA.

4. Conclusions

The hypothesis that the Cerrado species present higher flammability was confirmed through the flammability rating values. The Principal Components Analysis was effective in the results validation and allowed to explain what variables determined the species flammability.

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