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Flammability characteristics of typical garden species

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Wildland urban interface; WUI; fuel characteristics; plants, trees, fire behavior, fire modelling

Abstract

The large fires in recent years have caused tragic episodes that have led to the death of many hundreds of people and the loss of buildings of great social and economic value. Several of these impacts could have been avoided if the fuel management around buildings had been appropriate. Many studies on flammability are dedicated to wild fuels present in the forests, shrublands or grasslands. However, the existing data on the vegetation typical of the surroundings closest to the constructions (e.g., gardens) is scarce. Besides being the fuels closest to the buildings, these are fuels that normally can be effectively managed by the building owners, i.e., their management is within the reach of the common citizens.

This work aimed to characterize the flammability parameters for several typical garden species in the Mediterranean Basin. An extensive experimental program was carried out to characterize individual plants of the following species: holly (Ilex aquifolium), linden (Tilia nobilis), anacardia (Rhus typhina), laurel (Laurus nobilis), olive tree (Olea europaea), pacific madrone (Arbutus menziesii), apple tree (Malus sylvestris), cherry tree (Prunus avium), sloe (Prunus Spinosa), fig tree (Ficus carica), loquat (Eriobotrya japonica), kiwi plant (Actinidia deliciosa), grapevine (Vitis vinifera), hydrangea (Hydrangea macrophylla), oleander (Nerium oleander), ivy (Hedera helix). In this work, the results for only three of those plants will be presented, namely: oleander, fig tree and laurel. The following parameters will be presented: mass-loss rate, vertical profile of temperature, heat flux and flame dimensions.

This study has two main objectives: 1) to provide data that allows fire behavior modelling in the proximity of dwelling houses; and 2) the determination of the acceptable safety distance that species must be from buildings to prevent their ignition. Some of the tests performed showed that the presence of some species in the proximity of buildings (not attached) can be beneficial due to their low inflammability and because they can constitute an obstacle to the passage of firebrands, which can ignite the construction.

1. **Introduction**

The greatest impacts that have been registered in the last decade as a result of wildfires highlighted the relevance of the wildland-urban interface (WUI), with a special focus on the potential loss of people and animals' lives, as well as the destruction of buildings. The various studies concerning large wildfires (Viegas et al., 2017; Viegas et al., 2019) concluded that improper fuels management in the vicinity of constructions is among the main causes of its destruction. In addition, the lower confidence of citizens regarding the fire resistance of buildings leads to people often feeling impelled to leave their homes putting their lives at risk due to untimely evacuation processes.The fuel management in the WUI scenario requires knowledge of the flammability characteristics of the fuels. For example, it is important to know the minimum distance at which a certain tree shall be planted from a construction, to avoid ignitions by direct heat transfer from vegetation to houses. Moreover, this knowledge is important for selecting the species that should be placed closer to buildings or those that should not exist in their immediate vicinity. Naturally, the probability of ignition of a structure depends not only on the characteristics of the surroundings, but also on the construction characteristics and the self-protection capacity (e.g., sprinkler systems) that may exist.

The fuels around buildings can be divided into natural fuels (e.g., trees, ornamental plants) and man-made fuels (e.g., vehicles, plastic covertures, GPL tanks). The present work is exclusively dedicated to natural fuels, namely typical garden plants. Thus, any mention of fuels in this text shall be understood in that context.

In the analysis of fire behavior modelling in WUI, the knowledge of the flammability characteristics of the species that feed the combustion processes is essential. Although there is some information on the flammability of wild species (e.g., forests, shrublands or grasslands), the characterization of the typical species of the areas in the immediate surroundings of the buildings is poorly developed – Weise et al. (2005), Ganteaume et al. (2013) and Zhang et al. (2011) are examples of exceptions. Thus, the accuracy of the fire behavior simulators applied to the WUI is compromised. Physical properties of the fuel, e.g., fuel moisture content (FMC), bulk density, porosity, thermochemical characteristics such as the equivalent hydrocarbon (CHON) content for gas-phase reactions, and applying realistic boundary conditions are major factors to be considered in the fire dynamics simulations (FDS) (Weise et al., 2005). The boundary conditions entail several parameters, e.g., domain characteristics, heat release rate per unit area (HRRPUA) of the burner, environmental conditions with a trade-off between the grid size, and the computational capacity of the solver.

A laboratory work program was carried out to determine the flammability characteristics of typical garden plants, specifically: holly (*Ilex aquifolium*), linden (*Tilia nobilis*), anacardia (*Rhus typhina*), laurel (*Laurus nobilis*), olive tree (*Olea europaea*), pacific madrone (*Arbutus menziesii*), apple tree (*Malus sylvestris*), cherry tree (*Prunus avium*), sloe (*Prunus Spinosa*), fig tree (*Ficus carica*), loquat (*Eriobotrya japonica*), kiwi plant (*Actinidia deliciosa*), grapevine (*Vitis vinifera*), hydrangea (*Hydrangea macrophylla*), oleander (*Nerium oleander*), ivy (*Hedera helix*). The results of this study apply to other scenarios where these species are present – for example, the road sides, the surroundings of industrial facilities or the periphery of settlements. The main objective of this work is to provide relevant data for modelling fire behavior in the WUI and to increase the knowledge that allows defining with scientific support the best practices of fuel management in the immediate surroundings of buildings. In this manuscript, as an example, the results for one shrub – oleander – and for two trees – laurel and fig tree – will be presented (Figure 1). Besides the flammability data a valuation of the acceptable safety distance between those plants and a building will be provided.

(a) (b) (c)

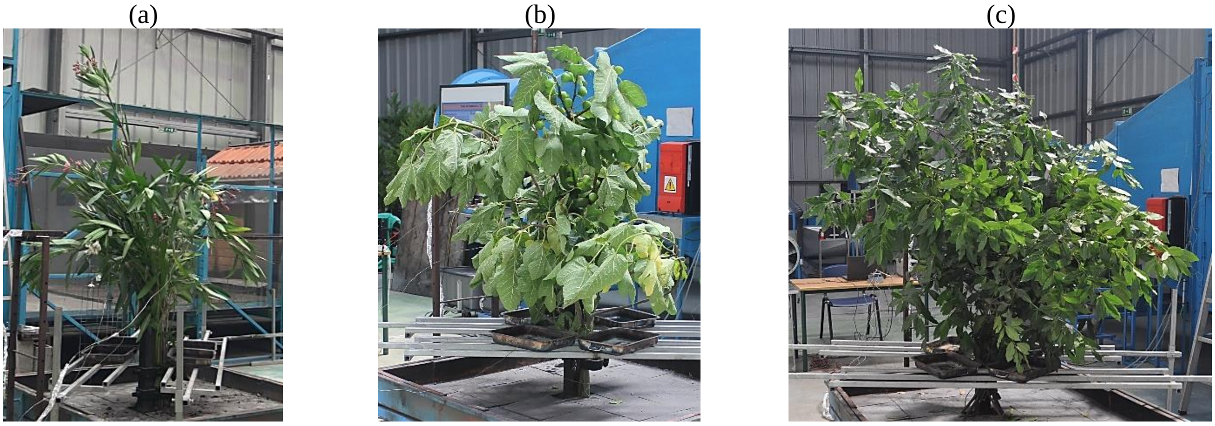

Figure 1: Image of the species used in the tests that will be described: a) oleander; b) fig tree; c) laurel.

2. Methodology

The laboratory tests were performed at the ADAI's Laboratory for Forest Fire Studies, in Lousã - Coimbra (Portugal). All tests were performed between July and August 2021.

2.1. Experiments description

Fuel sampling

Each plant to be tested was collected from its natural environment no more than 24 hours before being burnt. After their transport to the laboratory, the plants were kept in a shady environment, with indoor conditions never exceeding 25ºC.

Experimental setup

The plants were burnt in the "Tree Burning Platform" (Ganteaume et al., 2013) that has attached a weighing system allowing the determination of the mass decay throughout the burning. A *Pitot* tube and a thermocouple were placed above the plant at a fixed height of 3.5m to determine the convective flow velocity. Besides the thermocouple at a height of 3.5m, in the same vertical axis connecting the center of the plant to the *Pitot* tube, two thermocouples were also placed in the middle and at the top of the plant's crown. A radiative heat flux meter was installed at 1.0m height and 50cm from the edge of the plant canopy. Furthermore, the tests were recorded with a pair of IR cameras and another pair of RGB cameras, settled parallel and transversally to the flame front. The analysis of the images captured by these cameras allowed the determination of the flame dimensions - height, length and depth - along with the test. Figure 2 presents the experimental setup described.

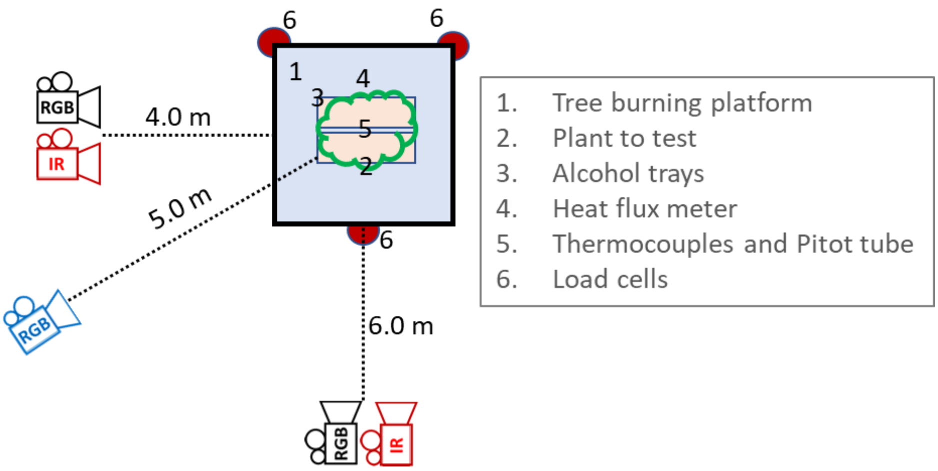

Figure 2 – Experimental setup.

Experimental procedure

Ignition: Since the plants tested alone could not sustain the fire, it was necessary to add a heat source. Thus, 20cm below the base of the plant crowns, trays were placed with denatured alcohol (96% v/v) allowing the ignition and sustaining the fire, just like what happens with the understory in real fire events. The trays were used to distribute the heat evenly to the entire base of the canopy. It was used an area of trays per horizontal projected area of the crown of 0.75 m^2/m^2, which corresponds to 1.6 L of alcohol per cm^2 of the horizontal projected area of the plant.

To facilitate data synchronization, the measuring equipment was started simultaneously with the ignition that occurred at the same time in all trays.

The trays were installed on a shelf that did not interfere with the mass acquisition system so it was not necessary to make the correction of this parameter. A reference burning test was performed only with alcohol in order to understand the influence of this fuel on the heat flux acquisition values during the regular tests. The methodology used throughout these experiments was the same as described in Almeida et al. (2021). Five repetitions per plant were carried out.

2.2. Calculations

Mass loss coefficient

The mass loss was analyzed based on the mass loss coefficient k of Equation 1 for determining the absolute value of mass m and for Equation 2 which allows the determination of the relative mass m_r. In these equations m_0 corresponds to the initial mass and t is the time elapsed since ignition.

$$m = m_0 \times e^{-k \times t} \quad \text{[Equation 1]}$$

$$m_r = \frac{m}{m_0} = e^{-k \times t} \quad \text{[Equation 2]}$$

Figure 3 shows an example of mass loss determination with the respective curve for each test carried out for the same species. The final k value for each species is determined based on of the mean value of the k values obtained in the five test repetitions.

(a) (b)

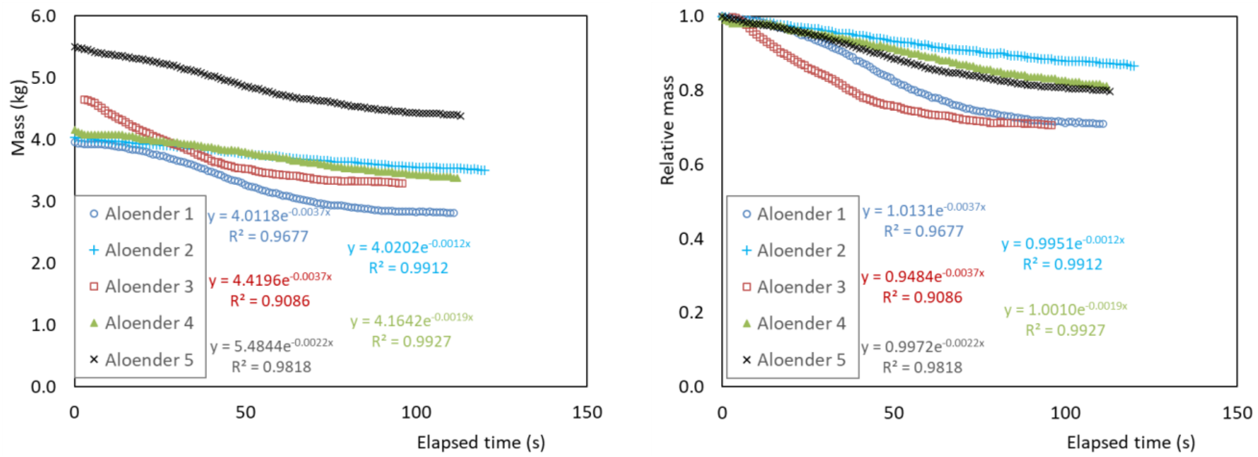

Figure 3: Example of the mass loss curves for the five tests performed with oleander: a) absolute mass values (Equation 1); b) relative mass values (Equation 2).

Heat flux reference tests

Reference tests were performed with the same configuration and quantity of trays containing the same amount of denatured alcohol used during the experiments with plants. It was found that the heat flux recorded is higher than in some tests with plants (Figure 4). This is because the plants are themselves a barrier to heat flux from the alcohol. Thus, the error associated with the burning of alcohol is assumed not to be very high and so is not considered.

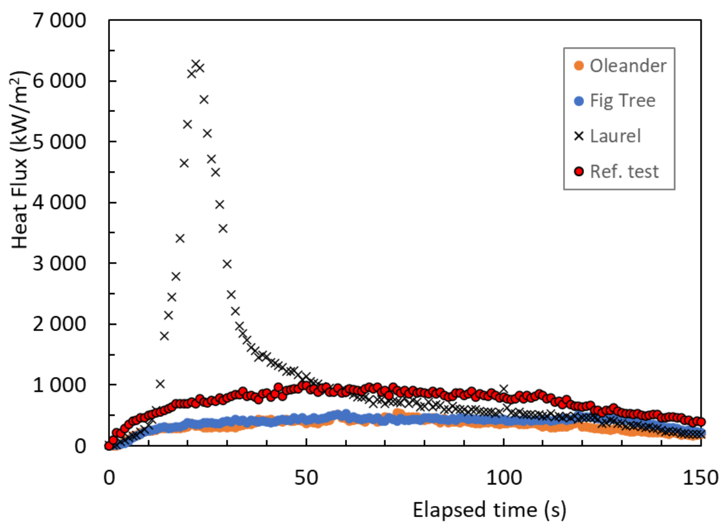

Figure 4: Heat flux values emitted by denatured alcohol and plants.

Acceptable safety distance

The acceptable safety distance *ASD* was determined using the model developed by Rossi et al. (2011), presented by Equation 3. Table 1 expresses the details of the Rossi's *ASD* definition.

$$ASD = \left[\frac{L_f \cos(\gamma)\sqrt{-4\Phi^2+\left(BT_f^4\varepsilon\tau\right)^2}}{2\Phi_{thres}} + L_F \sin(\gamma)\right] \times \left[1 - exp\left(-\frac{2L}{L_f}k\right)\right] \quad \textit{[Equation 3]}$$

Table 1: Description of the variables in Equation 3 and presentation of the values used in the simulations.

Symbol	Parameter	Values used
ASD	Acceptable safety distance	Variable
L_F	Flame length (m)	Variable

Φ	Heat flux limit (W.m-2)	Variable
h	Height difference between the base of the flame and the target (m)	1.7
k	Empirical parameter	1
L	Half of the length of the flame front (m)	20
γ	Angle of inclination of the flame (°)	0
B	Stephan-Boltzmann constant ($W.m^{-2}.K^{-4}$)	5.670374419×10^{-8}
Tf	Average flame temperature (K)	1350
τ	Atmospheric transmittivity	0.9
ε	Equivalent flame emissivity	0.8

2.3. Resume

Table 2 – Summary of the experiments: m_0- initial mass; m_f- final mass; FMC- fuel moisture content; CH- crown height; CD- average crown diameter; CBH- crown base height.

Species type	*Case*	m_0 (kg)	m_f (kg)	FMC%	CH (m)	CD (m)	CBH (cm)
Oleander	1	3.98	2.89	50.4	0.90	0.90	15
	2	3.97	3.10	36.2	1.75	1.15	15
	3	4.57	3.63	36.2	1.80	1.05	30
	4	4.00	3.28	36.9	1.85	1.55	17
	5	5.50	4.30	37	1.70	1.00	15
Fig tree	1	5.25	4.82	43.6	1.5	1.15	25
	2	5.94	5.49	58.8	1.4	1.30	25
	3	5.41	4.85	59.2	1.3	1.15	25
	4	6.10	4.88	58.8	1.4	1.25	25
	5	5.46	4.58	58.9	1.35	1.15	25
Laurel	1	3.89	2.24	53.7	1.50	1.30	15
	2	4.44	3.12	53.7	2.00	1.35	15
	3	3.45	2.12	53.7	1.30	1.10	20
	4	3.17	2.04	57.7	1.85	1.00	15
	5	3.97	2.89	63.4	2.00	1.05	10

3. Results and discussion

Mass loss

As previously mentioned, the mass loss is presented through the average value of the mass loss coefficient *k* for each species, as presented below. Fig tree is clearly the species that presents the lowest value of *k*, i.e., a slower mass decay. On the other side, the laurel presents a very high value of *k*, which is a reflection of its great inflammability, which was verified in the tests.

Table 3: Average mass loss coefficient determined for each species. In parentheses the standard deviation values are shown.

Parameter	Oleander	Fig tree	Laurel
Mass loss coefficient *k* (s^{-1})	0.00254 (0.0012)	0.00106 (0.00058)	0.00776 (0.00425)

Temperature

The temperature values were measured in the central longitudinal axis of the plant at various heights, as previously mentioned. Figure 5 (a, b, c) presents the temperature variation along the tests, for several heights. Figure 5d presents the temperature variation measured in several tests in the thermocouple located at half the height of the plant. The values obtained for the oleander and fig are very close, while the temperature values for the laurel are much higher. In the first two species, the thermocouple located at 20 cm is the one that reaches higher temperatures because it is close to the trays with alcohol. However, in the tests with the laurel, due to the higher intensity of the flame, the highest temperature value was obtained for the thermocouple located at mid-height of the plant.

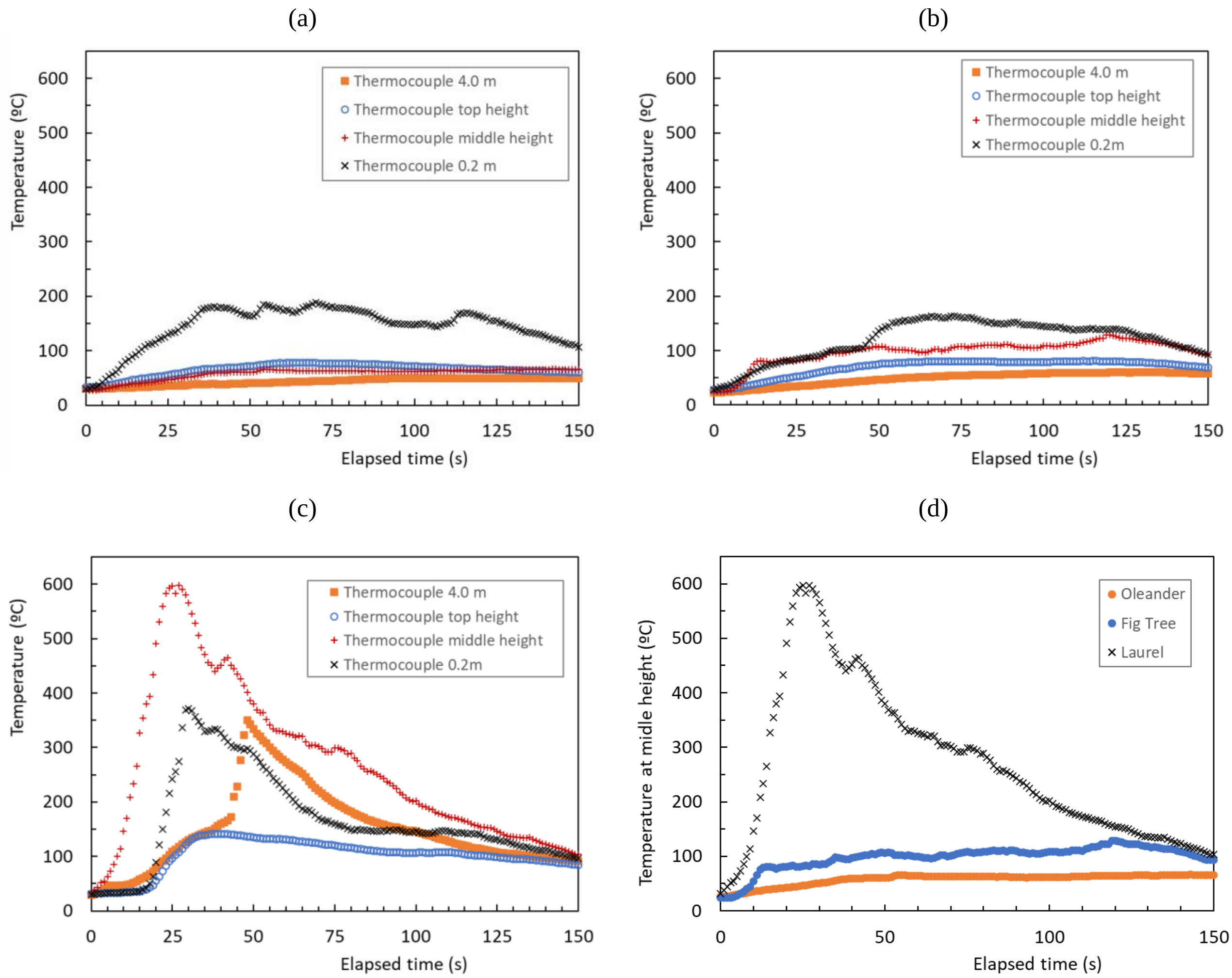

Figure 5- Temperature variation along the tests since ignition (t=0s). a), b) and c) refer to the measurements obtained at the different thermocouples for the oleander, fig tree and laurel, respectively; d) comparison between the temperature variation recorded at the thermocouple located at mid-height of the plant.

Heat flux and flame dimensions

Figure 6a presents the heat flux variation values for the three species. Once again, the heat flux measured in the tests with oleander and fig tree are merely residual, while the values reached for laurel present a maximum of 6281 kW/m^2.

(a)

(b)

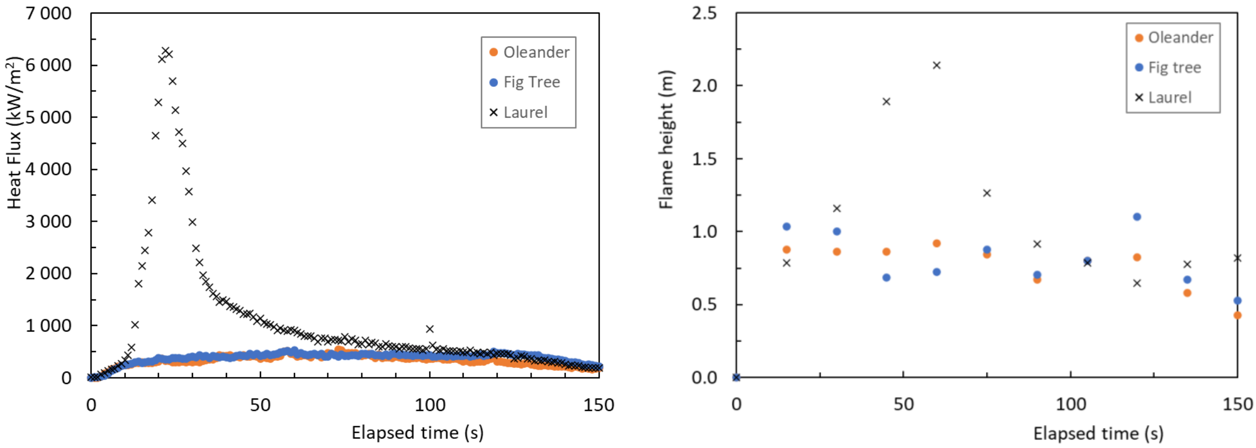

Figure 6 – Variation of heat flux (a) and flame height (b) during the tests performed for each species

Figure 6b presents the values of the flame height for the various species. Once again, the flame size of the laurel burning stands out from the other species due to its high burning intensity.

Acceptable safety distance

The table below presents the ASD values determined for the three species. In the sequence of the results presented above, it is easy to understand that laurel is the species that should be more distant from a building.

Table 4: Resume of the Acceptable safety distance determined for each species.

Species	Oleander	Fig tree	Laurel
Acceptable safety distance (m)	1.4	1.4	12.8

4. Conclusions

Values of flammability parameters for three species typically used in gardens, namely oleander, fig and laurel, were presented. These results may be of great interest for simulations of fire behavior in areas where these species exist. The laurel was the species that exhibited the highest flammability.

In addition, these test results allow the determination of what should be the acceptable safety distance that these species should be from a building. Normally, the regulations and standards in the scope of these matters do not distinguish between the species of shrubs and trees. However, as could be seen, trees such as laurel should be much more distant from buildings than, for example, fig trees. Given its low flammability, the existence of trees such as fig tree in the WUI can be beneficial to reduce the wildfires risk since they hardly spread fire to buildings, constituting a barrier to the projection of firebrands and reducing the turbulence in these areas.

5. Acknowledgements

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6. References

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

Viegas, D. X., Almeida, M. A., Ribeiro, L. M., Raposo, J., Viegas, M. T., Oliveira, R., Alves, D., Pinto, C., Rodrigues, A., Ribeiro, C., Lopes, S., Jorge, H., & Viegas, C. X. (2019). Análise dos Incêndios Florestais Ocorridos a 15 de outubro de 2017. Centro de Estudos sobre Incêndios Florestais (CEIF/ADAI/LAETA).

Coimbra, Portugal. https://www.portugal.gov.pt/pt/gc21/comunicacao/documento?i=analise-dos-incendios-florestais-ocorridos-a-15-de-outubro-de-2017

Viegas, D. X., Almeida, M. F., Ribeiro, L. M., Raposo, J., Viegas, M. T., Oliveira, R., Alves, D., Pinto, C., Jorge, H., Rodrigues, A., Lucas, D., Lopes, S., & Silva, L. F. (2017). O complexo de incêndios de Pedrógão Grande e concelhos limítrofes, iniciado a 17 de junho de 2017. Centro de Estudos sobre Incêndios Florestais (CEIF/ADAI/LAETA). Coimbra, Portugal. https://www.portugal.gov.pt/pt/gc21/comunicacao/documento?i=o-complexo-de-incendios-de-pedrogao-grande-e-concelhos-limitrofes-iniciado-a-17-de-junho-de-2017

Weise, D. R., White, R. H., Beall, F. C., & Etlinger, M. (2005). Use of the cone calorimeter to detect seasonal differences in selected combustion characteristics of ornamental vegetation. International Journal of Wildland Fire, 14(3), 321–338. https://doi.org/10.1071/WF04035

Zhang, Z., Zhang, H., & Zhou, D. (2011). Flammability characterisation of grassland species of Songhua Jiang-Nen Jiang Plain (China) using thermal analysis. Fire Safety Journal, 46(5), 283–288. https://doi.org/10.1016/j.firesaf.2011.03.004