Toy-Opazo *et al. Fire Ecology* (2024) 20:21
https://doi.org/10.1186/s42408-024-00250-6

Fire Ecology

Association for Fire Ecology

REVIEW **Open Access**

Flammability features of native and non-native woody species from the southernmost ecosystems: a review

Octavio Toy-Opazo[1,2,3], Andrés Fuentes-Ramirez[1,3*], Valeria Palma-Soto[1,3], Rafael A. Garcia[4,5], Kirk A. Moloney[6], Rodrigo Demarco[7] and Andrés Fuentes-Castillo[7]

Abstract

Background Vegetation plays a crucial role in the ignition, propagation, and severity of fire, and understanding the relationship between plants and fire through flammability attributes has become a useful tool that is increasingly used in studies on fire dynamics worldwide. However, in the southern cone of South America, rather few studies have systematically and specifically addressed the flammability of vegetation, and yet fewer have compared native and non-native species. Given the increasing interest in knowing the flammability characteristics of vegetation, this review aims to assess the potential differences in flammability between native and non-native plant species that inhabit the southern cone and to identify the main methodologies and experiments used to analyze vegetation flammability.

Results Twenty-eight species were identified, 18 native to the region and 10 non-native. Additionally, 64 experimental tests were revised to evaluate plant flammability. It was found that *Cryptocarya alba*, *Acacia dealbata*, *Eucalyptus globulus*, and *Pinus ponderosa* are the species with a high flammability index. By contrast, the species *Araucaria araucana*, *Austrocedrus chilensis*, *Embothrium coccineum*, and *Persea lingue* showed low flammability. The methodologies used to evaluate vegetation flammability were highly variable, with the use of epiradiators being the most frequent.

Conclusions Our review indicates that the geographic origin of vegetation (native vs. non-native in South America) is not a decisive factor in determining species-level differences in flammability. Other relevant factors that contribute with the degree of plant flammability include fuel moisture, the morphology of the species, and its internal chemical compounds. We highlight the necessity of continuing the study of plant flammability and advance in the standardization of protocols and measurements, using uniform criteria and increasing comparative studies between species, particularly in the southern cone of South America where catastrophic wildfires are increasing.

Keywords Forest fires, Geographic origin, Plant species, Flammability, Southern cone of South America, Burn experiments, Wildfires

*Correspondence:
Andrés Fuentes-Ramirez
andres.fuentes@ufrontera.cl
Full list of author information is available at the end of the article

Resumen

Antecedentes La vegetación juega un rol crucial en la ignición, propagación, y severidad de los incendios forestales, y conocer las relaciones entre las plantas y el fuego a través de los atributos de inflamabilidad, se ha transformado en una herramienta valiosa que ha sido cada vez más usada en estudios sobre la dinámica del fuego a nivel mundial. Sin embargo, en el cono sur de Sudamérica, muy pocos estudios se han enfocado sistemática- y específicamente, en la inflamabilidad de la vegetación, y aún muchos menos la han comparado entre especies nativas y no nativas. Dado el creciente interés en conocer las características de inflamabilidad de la vegetación, esta revisión se enfoca en determinar las diferencias potenciales en inflamabilidad entre especies de plantas nativas y no nativas que habitan el cono sur de Sudamérica, e identificar las principales metodologías y experimentos usados para analizar la inflamabilidad de la vegetación.

Resultados Veintiocho especies fueron identificadas, 18 nativas de la región y 10 no nativas. Adicionalmente, 64 pruebas experimentales fueron revisadas para evaluar la inflamabilidad de las plantas estudiadas. Se encontró que *Cryptocarya alba*, *Acacia dealbata*, *Eucalyptus globulus*, y *Pinus ponderosa* son especies con un alto índice de inflamabilidad. En contraste, las especies *Araucaria araucana*, *Austrocedrus chilensis*, *Embothrium coccineum*, y *Persea lingue* mostraron una baja inflamabilidad. Las metodologías usadas para evaluar la inflamabilidad fueron altamente variables, siendo el uso de epirradiadores una de las más frecuentes.

Conclusiones Nuestra revisión indica que el origen geográfico de la vegetación (nativas o no nativas de Sudamérica) no es un factor decisivo en la determinación de las diferencias en la inflamabilidad a nivel de especies. Otros factores relevantes que contribuyen con el grado de inflamabilidad de las plantas incluyen la humedad del combustible vegetal, la morfología de las especies, y sus componentes químicos internos. Destacamos la necesidad de continuar realizando estudios sobre la inflamabilidad de plantas y avanzar en la estandarización de protocolos y mediciones, usando criterios uniformes e incrementando los estudios comparativos entre especies, particularmente en el cono sur de Sudamérica, donde los incendios catastróficos se están incrementando.

Introduction

Wildland fires have existed long before the first records of human beings appearing on the earth and have co-existed concomitantly with the evolution of terrestrial plants (Ubeda and Sarricolea 2016). In addition, they have played an important role in the development and evolution of plant species, since fire is a critical element in the evolutionary history of terrestrial flora, and many species have developed specific features that allow them to survive and even prosper in environments affected by fire (Pausas and Keeley 2009; North et al. 2015; Pausas et al. 2017; Arroyo-Vargas et al. 2022). An example of this occurs in places where fire removes non-resistant plants and woody debris, increasing the availability of nutrients and other resources and reducing competition (Bowman et al. 2009, 2011). Resistant species also take advantage of fire, quickly using the released nutrients to increase their growth rates (Goodwin and Sheley 2001). Although forest fires occur naturally in various regions throughout the world, they are not always caused by meteorological phenomena but are often caused by human activity (Bowman et al. 2019). In fact, in the USA, one of the countries with the highest number of natural fires in the world, 84% are directly caused by humans (Balch et al. 2017).

In recent decades, wildland fires have become one of the most concerning environmental issues with the greatest global impact (Reszka and Fuentes 2015). Furthermore, they are cataloged as one of the most frequent disturbances worldwide and one of the most recognizable due to their enormous ecological (Rasilla et al. 2010; Stetler et al. 2010; Moreira et al. 2020) and economic impacts (Syphard et al. 2009; Bowman et al. 2019), especially in Mediterranean areas (Pausas 2015; Fares et al. 2017; Moreira et al. 2020). Approximately 200 to 500 million hectares of forest are burned worldwide annually, affecting a wide diversity of natural ecosystems, including tropical and temperate forests, savannas, and shrublands (Lavorel et al. 2007; Syphard et al. 2009; Stetler et al. 2010). In addition, based on the predictions and the current global change scenario, the scientific community is concerned about the significant increase in forest fires across the globe (Moriondo et al. 2006; Liu et al. 2010; Jolly et al. 2015). An increase in the occurrence and severity of fire will potentially affect biodiversity, the functioning of ecosystems, and the goods and services; these will provide to society nowadays and in the future (Brennan et al. 2009; Murray et al. 2013; Riis et al. 2020).

Most plant species are highly susceptible to being burned under suitable climatic conditions (Krawchuk and Moritz 2011; Pausas et al. 2017). This fact has been confirmed by various scientific studies that indicate that year after year, hundreds of thousands of hectares in different ecosystems are consumed by increasingly frequent and severe fires (Nepstad et al. 1999; Brando et al. 2012; Fuentes-Ramirez et al. 2016). The occurrence and spread of fire require the combination of an ignition source, a suitable climate (i.e., dry and hot), and the accumulation of plant biomass that serves as fuel (Archibald et al. 2013; Alam et al. 2020). Thus, the flammability features of plants play a crucial role in the ignition, propagation, and severity of forest fires (Beckage et al. 2009; Curt et al. 2011; Pausas et al. 2017; Alam et al. 2020). Each plant species might have specific flammability and combustibility traits and therefore potentially behave differently upon a forest fire (Dimitrakopoulos and Papaioannou 2001; Fernandes 2009; Fuentes-Ramirez et al. 2016; Pausas et al. 2017). Understanding more about the characteristics of plant flammability is quite useful as it provides a comprehensive and essential perspective for better forest and fire management, mainly in terms of fire prevention and planning more resilient forest landscapes.

Plant flammability is defined as the capacity or facility of plant biomass to ignite and maintain combustion over time when exposed to fire (Anderson 1970; Pausas et al. 2017; Alam et al. 2020). Flammability is composed of the following variables: (1) ignitability, which is the time it takes for the biomass to generate a flame when in contact with a heat source; (2) sustainability, referring to the time the flame remains visible in the combustion of the vegetation; (3) combustibility, which is the speed at which the fire burns and burns the plant material; and (4) consumability, which refers to the proportion of mass or volume consumed by the fire (Anderson 1970; Martin et al. 1993). It must be noted that vegetation passes through several stages in its burning process, since before reaching ignition, different processes occur, such as dehydration of plant tissues, pyrolysis, evaporation of volatile organic compounds, and flameless combustion (Liodakis et al. 2002; Alzate-Guarín et al. 2022). It is relevant to bear all these variables in mind when studying the flammability of plant species. More recently, researchers have also used heat release (calorimetry) and thermal analyses to measure flammability and combustion of the vegetation (White and Zipperer 2010).

Human actions have greatly influenced fire regimes in a number of ways, most notably by changing the type, structure, and continuity of fuel primarily through land use change (Bowman et al. 2011, 2019). Nowadays, the global landscape has undergone significant changes in the composition of vegetation (Simberloff et al. 2010; Ammerman 2022). It is increasingly common to find non-native species introduced by humans in territories where they were not previously established, which has significantly impacted biodiversity and the propensity of wildfires to occur (Defosse 2015). In fact, several studies have reported that on surfaces where there is mainly a presence of non-native species, there is a greater severity of fire than in areas dominated by native species (Brooks et al. 2004; Taylor et al. 2017; Nuñez et al. 2021). Therefore, non-native species are commonly cataloged as more flammable species, i.e., they are more prone to ignite and stay ignited for longer, which significantly increases the risk of forest fires in areas invaded by non-native species (Bowman et al. 2011, 2019; Carmona et al. 2012; Murray et al. 2013; Bianchi et al. 2019). However, these claims are often related to fuel property modification at landscape scale rather than specific studies of the non-native species flammability.

Most of the studies on plant flammability of non-native and native plant species have focused on the Northern Hemisphere (Behm et al. 2004; Dibble et al. 2007; Curt et al. 2011; Murray et al. 2013; Grootemaat et al. 2015; Mason et al. 2016; Livingston and Varner 2016; Fuentes-Ramirez et al. 2016; Cubino et al. 2018; Curran et al. 2018; Hernández et al. 2018; Ganteaume 2018; Dewhirst et al. 2020; Popović et al. 2021; Kinoshita et al. 2022; Barnes et al. 2022). In the southern cone of South America (comprising Chile, Argentina, and Uruguay), there are rather few systematic studies on the flammability of the vegetation specifically occurring in this region (Blackhall et al. 2012; Bianchi and Defosse 2014; Bianchi et al. 2019), and even fewer that compare native and non-native species (Bianchi and Defosse 2015; Blackhall and Raffaele 2019; Bianchi et al. 2019; Franzese et al. 2020, 2022). Furthermore, the fundamental assumption underpinning the discussion of flammability of native vs. non-native plant species is that a given species will be more flammable because of its positive history related to fire. It remains to be determined whether non-native species are significantly more flammable than native species in most regions. To date, many studies have asserted this (Brooks et al. 2004; Murray et al. 2013; Moreira et al. 2020), but few have examined this assumption empirically (Bianchi and Defosse 2014; Fuentes-Ramirez et al. 2016). It is important to highlight that, although wildland fires occurred in the southern cone of South America before European colonization, most of them were not of natural origin but were caused by the native inhabitants of the territory at that time. Later on, wildland fires became more frequent as a result of the European colonization of the southern countries in South America (Lara et al. 1999). Thus, native species in the area did not have an evolutionary history closely tied to fire as the species that were introduced in these territories (Holz and Veblen 2011; Ubeda and Sarricolea 2016). These non-native species have historically been associated with natural forest fires, even before human settlements (Pausas and Keeley 2009; Pausas et al. 2017).

The following review evaluates the potential difference between the flammability metrics of non-native vs. native plant species in the southern cone region. Specifically, we aimed at (i) reviewing the available literature and identifying which variables are commonly used to determine the flammability of plant species and (ii) identifying and describing the different experimental methods used to determine the flammability of a species. For this, the following questions are considered:

1. Is the geographic origin of a plant species a relevant factor in determining whether a non-native plant species is more flammable than a native species within a given range (i.e., southern cone of South America)?
2. Is there any methodological standardization in the different experiments carried out to construct flammability indexes or classifications that are comparable for different species (i.e., native vs. non-native) and regions around the world? Which of the existing ones is the most complete?
3. What are the main variables employed to evaluate the flammability of different plant species, and what is the frequency of these variables used in flammability tests?

Systematizing this information (today dispersed in scattered studies, regions, and for several different species) will substantially contribute to gain better understanding of the potential synergy between vegetation (and its origin) in relation to fire and the flammability features associated to different plant species. Moreover, our results will provide useful insights into generating relevant information on ecological restoration and sustainable forest management in a scenario of recurring forest fires. This is a useful element for urban-rural planning and the use of appropriate plant species in the wildland-urban interface to minimize the risk of major wildfires affecting natural forests, infrastructure, and human populations.

Methods

The bibliographical review was carried out by adapting the PRISMA methodology (Page et al. 2021). The choice of this methodology is based on the fact that the PRISMA 2020 method is intended to be used in systematic reviews that include synthesis (meta-analysis of pairwise comparisons). This statement is based on 7 sections with a total of 27 items to verify the structure of the review, which allows for better organizing the search and synthesis of results, accompanied by a flow chart which exposes all the steps followed for the choice of articles to be reviewed (Page et al. 2021). The bibliographical reference manager Zotero 6.0.26 was used to manage the scientific articles consulted. In addition, it is worth mentioning that all the analyses developed in this review follow a qualitative approach, which is based on the complexity of making inferential analyses and statistical comparisons using data obtained from different studies with significant variations in terms of methods, variables, and measurements involved.

Literature search

The methodology consisted of a systematic bibliographical review between 1 and 21 April 2023. The Web of Science (WOS) and Scopus databases were used as the primary tools to search indexed articles. The search included general words and concepts linked to the flammability of woody plant species and then filtered by native and non-native species. The final syntax search for each database was TITLE-ABS-KEY= ((“*flammability*”) OR (“*flammable*”) OR (“*ignition*”)) AND ((“*vegetation*”) OR (“*species*”)) AND ((“*native*”) OR (“*non-native*”)). The search was carried out by document type, where only empirical scientific articles and reviews published between 1990 and 2023 were reviewed. The languages of the selected articles included English and Spanish. For the article selection, the title and abstracts were reviewed to assess whether they fulfilled the eligibility criteria of the review. The article was read in full for those in line with the research topic. The article selection criterion discarded opinions, books, or any non-peer-reviewed document. The selection criteria for each of the selected items are detailed below.

The search strategies continued with the exclusion of (1) duplicate documents, (2) articles that did not compare or analyze the flammability of plant species based on experimental studies, (3) articles not focused on the comparison of non-native and native species, and (4) studies that were not conducted around species found in the southern cone—i.e., Chile, Argentina, and Uruguay (Fig. 1a). This last point was exclusive to respond to the first research question.

After applying all the search criteria (i.e., inclusion and exclusion), the articles were selected for review. Then, a general bibliographical analysis of all the selected articles was done using the R Core Team v. 4.3.1 (R Core Team 2023) software, specifically the libraries *ggplot2* and *agricolae*. In addition, the articles were cataloged according to (1) database of origin (i.e., WOS or SCOPUS), (2) title, (3) year of publication, (4) authors, (5) journal, (6)

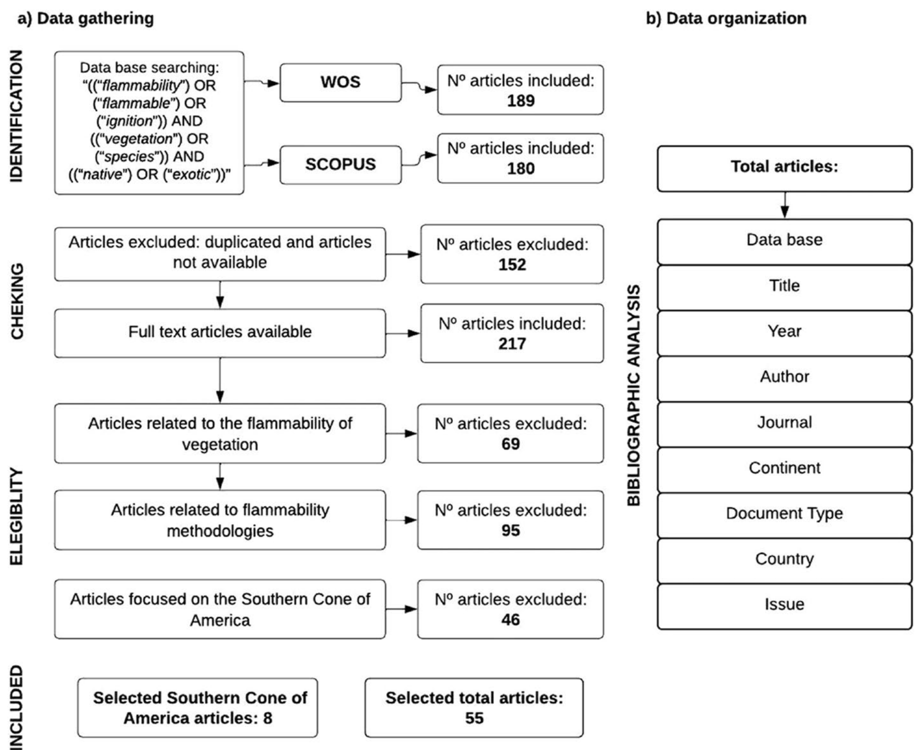

Fig. 1 **a** Flow diagram of the stages of the methodological procedure for the search for information and selection of articles for the review. **b** Organization of the articles included for the review

continent, (7) document type (i.e., empirical articles, scientific review), (8) country of origin of the study, and (9) specific subject the publication addresses (i.e., comparison of flammability of species, forest fires, relevant flammability variables) (Fig. 1b).

Data analysis

A specific bibliographical analysis was performed for describing the plant species evaluated in the southern cone, where each species that was tested was classified according to (1) origin (native or non-native), (2) growth form (tree or shrub), (3) type of foliage (conifer or broadleaved), (4) botanical family, (5) species, (6) author, (7) country, and (8) category of flammability. This latter was established to classify plants as low flammability (LF), slightly flammable (SF), moderately flammable (MF), flammable (FL), high flammability (HF), and extremely flammable (EF). This classification was adapted from Valette (1990).

Upon bibliographic data compilation, three different procedures were carried out. First, we compared the different methods used to determine plant flammability, including which part of the plant is more often subjected to burn trials. Secondly, a qualitative analysis of the flammability of vegetation found in the southern cone of South America was carried out, using the categories mentioned above. We are aware that by using different methodologies to obtain the data, they are hardly comparable in a statistical fashion. Therefore, the main objective of this review is to identify which species have been measured and which flammability categories would better represent those species. This will contribute to advancing the research by discussing and testing whether or not there is a great difference in the flammability of native and non-native species in our region, as it has been postulated (Taylor et al. 2017; Nuñez et al. 2021). Finally, we identified and described the methods that are commonly employed to determine plant flammability. We further expanded the discussion of the results relating plant flammability with other relevant variables such as moisture, plant chemistry, plant morphology, and calorimetry.

Results and discussion

Search results

In the first search of the database, and using the keywords "(("*flammability*") OR ("*flammable*") OR ("*ignition**")) AND (("*vegetation*") OR ("*species*")) AND (("*native**") OR ("*non-native**"))", a total of 189 scientific articles were found in WOS and 180 in SCOPUS, totaling

369 scientific articles. From this total, 152 articles were excluded as duplicates, leaving 217 to analyze (Fig. 1).

After reviewing the title, abstract, and, in many cases, the full text, (1) 69 articles were excluded for not focusing on the flammability of plant species and (2) 96 articles for not being related to direct methodologies to define the flammability of the species. Finally, 53 articles were included for the analysis in this review. It is relevant to highlight that only 8 empirical articles were identified and selected, addressing the comparison of flammability between native and non-native species in the southern cone region of America (Fig. 1a). Additionally, other articles were included for the respective discussions that may be generated around the results.

For the publication frequency at different periods (from 1990 to 2023), a considerable growth is noted in the number of publications today over previous decades (Fig. 2). Specifically, from 2015 on, the increase in publications related to the flammability of species is remarkable. The data indicate that the first four periods analyzed (from 1995 to 2014) concentrate 19% of publications, whereas the last two (from 2015 to 2022) represent 81% of the analyzed articles. This can be explained by (1) the increase in forest fires in recent decades (Rasilla et al. 2010; Stetler et al. 2010; Jolly et al. 2015), (2) the development of advanced technology to conduct specific experiments (Hernández et al. 2018; Reszka et al. 2020), and (3) the growing interest of the scientific community in investigating the role of vegetation in forest fires (Pausas et al. 2017).

Experimental flammability measurements

The experimental methods used to measure vegetation flammability vary widely among the articles reviewed (Table 1). For this review, a comparison was made according to the type or methodology of flammability and samples used. Eight different methodologies were found for the assessment of the flammability of vegetation (Table 2). The use of intense heat by radiation stands out with the greatest frequency. In addition, it has been observed that approximately 13% of the analyses are based on the pyric properties of the plant species. These properties refer to variables not determined by flammability tests, meaning the absence of burn trials, like those described by Anderson (1970), but are inherent qualities of the species related to their flammability potential. These qualities include moisture, morphology, chemical composition, calorific value, and others. The results obtained through these analyses are sufficiently similar to those obtained by conventional burning methods, as some articles have demonstrated (Dimitrakopoulos 2001; Dibble et al. 2007; Ntoufas et al. 2016; Blackhall and Raffaele 2019; Dewhirst et al. 2020; Guerrero et al. 2020; Murray et al. 2020).

The two most commonly used methods to evaluate flammability were the epiradiator device and the Jaureguiberry method (Fig. 3). The epiradiator consists of an electrical heating resistor that reaches a standard surface temperature of 500 °C. The samples are placed on a 10-cm diameter silica disk once the electrical radiator is heated. In addition, a thermocouple (type K, range 50–1000 °C) connected to a data logger is placed 8 cm above the epiradiator disk to record flame and heat temperature during complete combustion (Blackhall and Raffaele 2019). This type of method was used in 16 tests, where on 13 occasions, small leaves and branches were used (Núñez-Regueira et al. 1996; Bianchi and Defosse 2015; Della Rocca et al. 2015; Fenesi et al. 2016; Gibson et al. 2016; Essaghi et al. 2017; Ganteaume 2018; Bianchi et al. 2019; Blackhall and Raffaele 2019; Guerrero et al. 2021, 2022; Batista et al. 2021; Rosavec et al. 2022). The three remaining

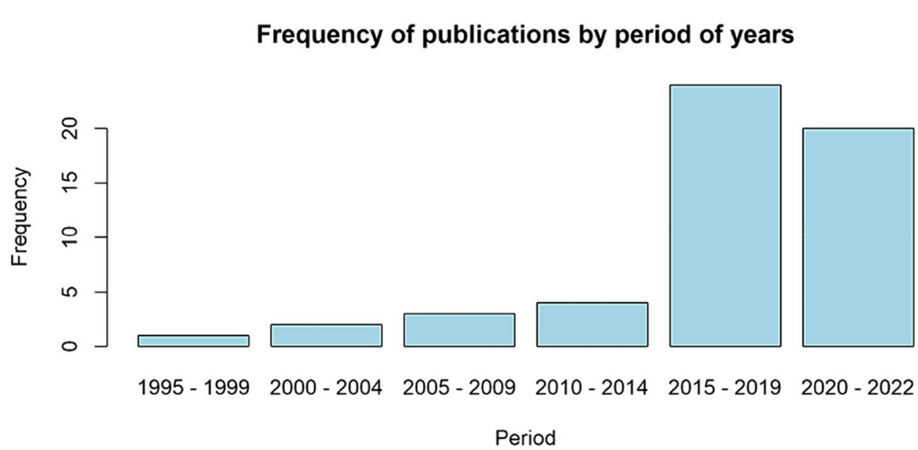

Fig. 2 Frequencies of publications related to comparative flammability of different species in different periods, from 1995 to 2022

Table 1 Description of the different flammability methods used in lab-based trials, accompanied by the authors who used these methods and whether it is employed in studies conducted in South America

Flammability test	Description	Authors	Present in South America
Flat flame burner	Method in which the flat burner is located at the base and the sample is suspended between 20 and 30 cm from the burner. In addition, everything is enclosed by high temperature resistant glass and a hood at the top. The temperature recorded ranges from 80 to 871 °C.	(Fletcher et al. 2007; Safdari et al. 2018)	No
Analysis of pyric property	The samples are analyzed for their chemical properties, such as calorific value, volatile organic compounds, humidity, and morphology.	(Dimitrakopoulos 2001; Dibble et al. 2007; Shan et al. 2008; Cobar-Carranza et al. 2014; García et al. 2015; Ntoufas et al. 2016; Dewhirst et al. 2020; Guerrero et al. 2020; Murray et al. 2020; Radhaboy et al. 2019)	Yes
Direct ignition lighter	It consists of leaving the samples in a stainless steel tray and applying direct fire with a burner until the sample ignites.	(Fuentes-Ramirez et al. 2016; Rasooli et al. 2021)	Yes
Epiradiator 500 W	The epiradiator consists of an electrical heating resistor that reaches a standard surface temperature of 500 °C. The samples are placed on a 10-cm diameter silica disk once the electrical radiator is heated. In addition, a thermocouple (type K, range 50–1000 °C) connected to a data logger is placed 8 cm above the epiradiator disk to record flame and heat temperature during complete combustion.	(Núñez-Regueira et al. 1996; Curt et al. 2011; Bianchi and Defosse 2015; Della Rocca et al. 2015; Kauf et al. 2015; Fenesi et al. 2016; Simpson et al. 2016; Essaghi et al. 2017; Ganteaume 2018; Bianchi et al. 2019; Blackhall and Raffaele 2019; Franzese et al. 2020; Batista et al. 2021; Guerrero et al. 2021; 2022; Rosavec et al. 2022)	Yes
Fonda method	This method involves placing the sample on a stainless steel platform and placing cotton threads soaked in xylene on it, which are ignited in different parts until ignition is initiated.	(Kane et al. 2019, 2022; Barnes et al. 2022)	No
Idealized Firebrand Ignition Test (I-FIT method)	This heater consists of a 5-cm-long cylindrical radiator with an operating range of up to 260 V. It is lowered and inserted in the central part of a cylindrical stainless steel sample holder.	(Hernández et al. 2018; Reszka et al. 2020; Rivera et al. 2021)	Yes
Jaureguiberry method	The apparatus consists of a metal barrel that is oriented horizontally with a removable top half. The metal barrel is connected to a grill thermometer, a removable gas cylinder and a blowtorch. It has an initial temperature of about 150 °C and a maximum temperature of 800 °C.	(Jaureguiberry et al. 2011; Burger and Bond 2015; Calitz et al. 2015; Wyse et al. 2016; Cubino et al. 2018; Santacruz-García et al. 2019; Alam et al. 2020; Cui et al. 2020; Msweli et al. 2020; Kraaij et al. 2022; Potts et al. 2022)	Yes
Muffle furnace	The muffle furnace method consists of placing the samples in the furnace at an estimated temperature ranging from 300 to 600 °C and waiting until the samples ignite.	(Liodakis et al. 2002; Murray et al. 2013; Grootemaat et al. 2015; Mason et al. 2016; Massuque et al. 2021; Krix et al. 2022)	No

Table 2 Frequency of different part of the vegetation used for the flammability trials in the studies considered in the review and the proportion representation as percentage

Samples	Count	% of total
Leaves and branches	32	62.7%
Leaves and wood	1	2.0%
Shoots	12	21.6%
Trash	6	11.8%
Wood	1	2.0%
	52	100.0%

tests used leaf litter as plant material combustion (Curt et al. 2011; Kauf et al. 2015; Franzese et al. 2020). The Jaureguiberry method (Jaureguiberry et al. 2011) consists of an 85 × 60 cm metal barrel cut in half, placed horizontally, with part of the remaining half used as a removable windbreak. Inside the barrel are three parallel burners (80 cm long and 2.5 cm in diameter) located 7 cm above the bottom of the barrel and 8 cm apart. The grill is preheated to 150 °C then increases in temperature until the plant material is ignited, approximately between 500 and 800 °C. This method was used in 11 case studies where plant shoots under 70 cm high were used (Jaureguiberry et al. 2011; Burger and Bond 2015; Calitz et al. 2015; Wyse et al. 2016; Cubino et al. 2018; Bianchi et al. 2019; Alam et al. 2020; Cui et al. 2020; Msweli et al. 2020; Kraaij et al. 2022; Potts et al. 2022).

In addition to the methods described above, it is pertinent to mention two additional methods that have been used in the assessment of the flammability of plant material. However, by virtue of their relevance in the ecological context, these methods were not found in the search carried out in this review nor discussed further on. These approaches, known as flash point analysis (FPA) and calorimetric cone, reveal a more pronounced connection to the assessment of homogeneous combustible substrates, particularly hydrocarbon derivatives (i.e., fuels). These two methods are geared toward identifying the critical temperature at which homogeneous fuels release flammable vapors in sufficient quantity to sustain self-sustaining combustion upon contact with an external ignition source (Brohez et al. 2006; Quan et al. 2022; Park and Yoon 2013).

With respect to the plant material used for the flammability tests, it was found that whole leaves and small branches (rachis) are the most frequently used in flammability experiments, counting 31 studies where they use this sampling method (Table 3). Additionally, many studies (12) also used plant shoots under 70 cm, including the roots, stems, leaves, small branches, fruits, and flowers. Finally, it is worth noting that the least used method and plant material are the burning of wood/bark, as these were reported in only 2 case studies (Massuque et al. 2021; Rasooli et al. 2021).

Another relevant aspect to discuss in the review is the variability in drying time and temperature of the species prior to the burning test. This ranges from species not

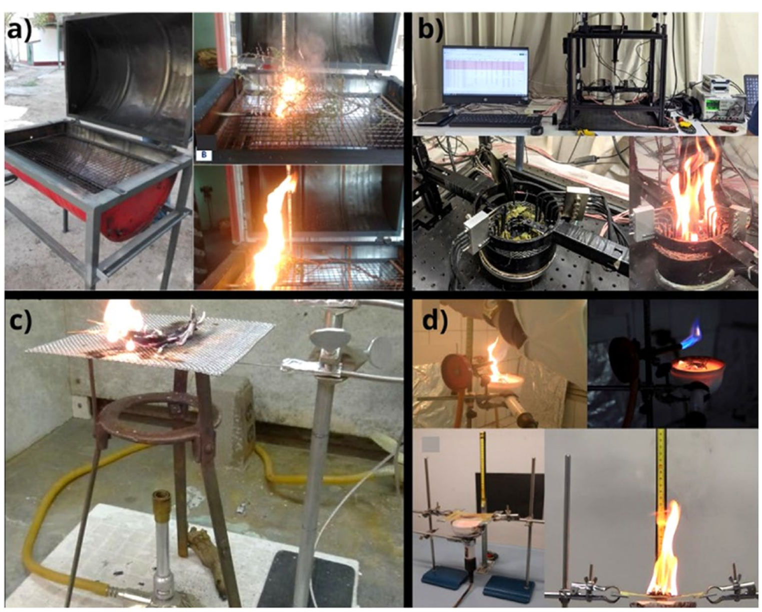

Fig. 3 Examples of some commonly used ignition methodologies. **a** Jaureguiberry method (Jaureguiberry et al. 2011). **b** Idealized Firebrand Ignition Test (Hernández et al. 2018). **c** Direct ignition lighter (Fuentes-Ramirez et al. 2016). **d** Epiradiator method (Della Rocca et al. 2015)

Table 3 Flammability classification of families studied in the southern cone of South America. *LF* low flammability, *SF* significantly flammable, *MF m*oderately flammable, *FL* flammable, *HF* high flammability, *EF* extremely flammable, *fr* absolute frequency

Family	Flammability categories						fr
	LF	SF	MF	FL	HF	EF	
Anacardiaceae	1	1	2	0	0	0	4
Apiaceae	0	1	0	0	0	1	2
Araucariaceae	2	0	0	0	0	0	2
Berberidaceae	0	0	0	1	1	0	2
Celastraceae	0	1	0	1	0	0	2
Cupressaceae	0	2	2	0	0	0	4
Elaeocarpaceae	1	1	0	0	0	0	2
Fabaceae	0	1	0	2	0	1	4
Lauraceae	0	1	0	0	0	1	2
Myrtaceae	0	0	0	0	0	2	2
Nothofagaceae	1	1	0	5	2	0	9
Pinaceae	1	2	1	0	7	1	12
Poaceae	0	0	0	0	2	2	4
Proteaceae	1	1	1	2	0	0	5
Quillajaceae	0	0	1	0	0	0	1
Rosaceae	0	0	1	0	0	0	1
Salicaceae	2	0	0	0	0	0	2
Saxifragaceae	2	0	0	0	0	0	2
Solanaceae	0	1	0	0	1	0	2

subjected to any prior drying process to those dried at 120 °C. In terms of drying time, it is observed that this varies from 0 h (no drying) to a maximum of 72 h. This difference in the manipulation of the samples prior to the flammability tests can cause a great difference in the results because variables such as the moisture and terpene content in the vegetation samples vary according to the time and temperature to which they are exposed, and both variables are highly correlated with the flammability of the species (Bianchi and Defosse 2015; Guerrero et al. 2021, 2022; Popović et al. 2021).

It is also important to understand the limitations of evaluating flammability in laboratory tests, which are related to several factors that affect the accuracy of the results. One of the main challenges lies in the difficulty of faithfully replicating an evaluated sample, which may be composed of various elements such as leaves, branches, shoots, and other plant components. The complexity of the structure and composition of an area covered by vegetation, whether it consists of trees, shrubs, or herbaceous species, makes it difficult to accurately reproduce the sample under laboratory conditions (Fernandes and Cruz 2012). Natural ecosystems present a great diversity in terms of the configuration of their vegetation, with variations in the size, shape, density, and distribution of the combustible elements (Pausas et al. 2017; Moreira et al. 2020; Arroyo-Vargas et al. 2022). These factors directly influence the propagation and maintenance of the fire, being directly related to the flammability conditions of the vegetation (Pausas and Keeley 2009; Pausas 2015; Pausas et al. 2017). As a result of these limitations, any attempt to extrapolate the results obtained in the laboratory to fires occurring in natural ecosystems is difficult (Fernandes and Cruz 2012).

It is important to recognize the need to address this issue and to seek realistic and replicable approaches to evaluate vegetation flammability. This means considering not only the properties intrinsic to the combustible materials, but also their population size and structure, interaction with the environment, and specific environmental conditions (Reszka and Fuentes 2015; Fuentes-Ramirez et al. 2016; Pausas et al. 2017). Furthermore, it is fundamental to promote integrated research that combines laboratory studies with field observations to obtain a more advanced understanding of the factors that affect the propagation of fire in natural ecosystems.

Differences in flammability between native and non-native species in the southern cone

For the southern cone region, 8 scientific articles were found that related directly to the potential difference in flammability between native and non-native plant species (Cobar-Carranza et al. 2014; Bianchi and Defosse 2015; Blackhall and Raffaele 2019; Bianchi et al. 2019; Guerrero et al. 2020, 2021, 2022; Franzese et al. 2020). These studies mostly correspond to tests conducted in Argentina, where many species have also been measured (24), for which flammability methodologies employing epiradiators and Jaureguiberry's method (Jaureguiberry et al. 2011) were used. In Chile, there are also studies related to the comparison of native and non-native species but fewer, where only 10 species have been measured, of which 5 are native and 5 are non-native.

Our results identified 20 tree species and 8 shrub species, giving a total of 28 woody plants, of which 18 are native to the southern cone (Chile and Argentina), whereas the 10 remaining are non-native species, which in their majority are highly invasive and abundant in the region (Fuentes et al. 2020; Fuentes-Ramírez et al. 2010). For these 28 plant species, a total of 64 flammability tests were analyzed, since in several cases, more than 1 experiment per species was found (Table 4). In terms of the testing frequency, the non-native species *Pinus radiata* stands out (5 articles), and the most frequent natives species are *Chusquea culeou* (4), *Nothofagus antartica* (4), and *Lomatia hirsuta* (4).

Of all the experiments reported, 67% used native species and 33% non-natives species of southern cone. This unbalanced data, with different approaches makes establishing a comparison between the different groups complex and, even more so, knowing the different methodologies employed to determine flammability. Thus, showing the different results and identifying which species have been studied in our study region is the first step to develop further research and comparisons across species. From tests conducted on native vegetation and based on Valette (1990), 19% classify them as species of low flammability; 23% slight flammability; 14% moderate

Table 4 Classification of flammability of the 28 species studied in the southern cone of South America, which included a total of 64 flammability tests performed. *LF* low flammability, *SF* significantly flammabl, *MF* moderately flammable, *FL* flammable, *HF* high flammability, *EF* extremely flammable, *fr* absolute frequency, *N* native, *NN* non-native

Species	Flammability categories						fr
	LF	SF	MF	FL	HF	EF	
Acacia dealbata (NN)	0	0	0	1	0	1	2
Acacia melanoxilon (NN)	0	0	0	1	0	0	1
Araucana araucaria (N)	2	0	0	0	0	0	2
Aristotelia chilensis (N)	1	1	0	0	0	0	2
Austrocedrus chilensis (N)	0	2	2	0	0	0	4
Berberis darwinii (N)	0	0	0	1	1	0	2
Chusquea culeou (N)	0	0	0	0	2	2	4
Cryptocarya alba (N)	0	0	0	0	0	1	1
Cytisus scoparius (NN)	0	1	0	0	0	0	1
Embothrium coccineum (N)	1	0	0	0	0	0	1
Eucalyptus globulus (NN)	0	0	0	0	0	2	2
Fabiana imbricata (N)	0	1	0	0	1	0	2
Lomatia hirsuta (N)	0	1	1	2	0	0	4
Maytenus boaria (N)	0	1	0	1	0	0	2
Mulinum spinosum (N)	0	1	0	0	0	1	2
Nothofagus antartica (N)	0	1	0	3	0	0	4
Nothofagus dombeyi (N)	1	0	0	0	2	0	3
Nothofagus pumilio (N)	0	0	0	2	0	0	2
Persea lingue (N)	0	1	0	0	0	0	1
Pinus contorta (NN)	0	1	0	0	2	0	3
Pinus ponderosa (NN)	0	0	0	0	2	0	2
Pinus radiata (NN)	0	1	1	0	2	1	5
Populus nigra (NN)	2	0	0	0	0	0	2
Pseudotsuga menziessi (NN)	1	0	0	0	1	0	2
Quillaeja saponaria (N)	0	0	1	0	0	0	1
Ribes magellanicum (N)	2	0	0	0	0	0	2
Rosa rubiginosa (NN)	0	0	1	0	0	0	1
Schinus patagonico (N)	1	1	2	0	0	0	4

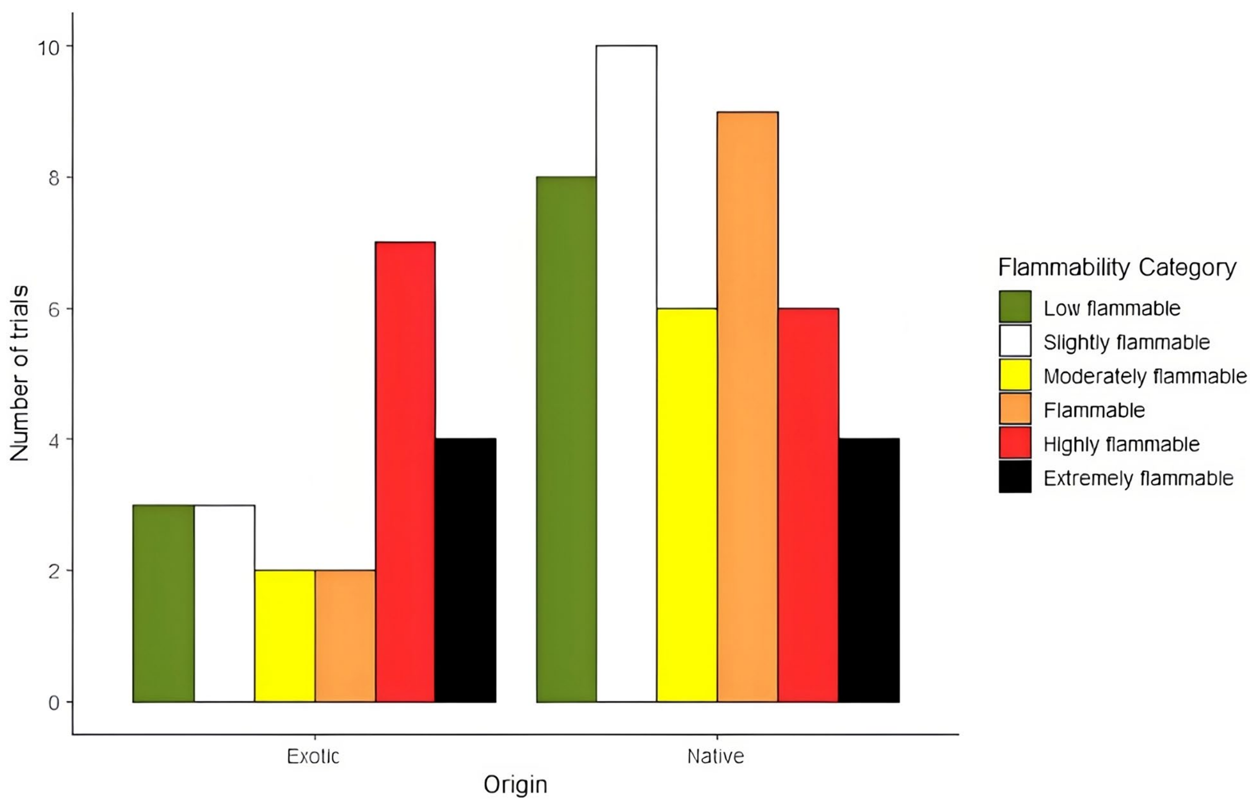

Fig. 4 Categories of flammability of the different experiments and studies examined according to the geographical origin of the species being tested

flammability; 21% flammable; 14% high flammability, and 9% classify the native species as extremely flammable (Fig. 4). With respect to the experiments conducted with non-native species, the results differ in their higher categories of flammability, where 14% classified these species as low flammability; 14% slightly flammable; 10% moderately flammable; 10% flammable; 33% highly flammable; and 19% extremely flammable (Fig. 4). According to the above mentioned, it is inferred that native species have lower flammability values compared to non-native species. This may be explained because the non-native species analyzed are almost entirely tree coniferous species, and according to several studies, these species present higher flammability traits, which could be the first indication that geographic origin has an impact on the flammability of a species. It is well known that conifers have attributes in their morphology and physiology that could be positively related with higher flammability indexes, such as the shape of the leaf, internal chemical compounds (i.e., resins), and other volatile chemicals in this type of vegetation (Murray et al. 2013; Dewhirst et al. 2020; Popović et al. 2021). This is important to consider in the analysis since it could create an imbalance when a contrast of flammability is made according to the geographic origin of the species. In fact, the results analyzed in this review revealed that native plant species might be as flammable (or even more in some cases) as non-native species, not supporting the generally-accepted hypothesis that native species are less flammable than non-native species.

The native species of the southern cone that were identified and classified exclusively in higher flammability indices (i.e., extreme, high, and flammable) were *Chusquea culeou*, *Cryptocarya alba*, *Mulinum spinosum*, and *Berberis darwinii* (Fig. 5). By contrast, some of the species that were exclusively in lower categories (low, slightly, and moderately) were *Araucaria araucana*, *Aristotelia chilensis*, *Austrocedrus chilensis*, *Embothrium coccineum*, and *Ribes magellanica*. With respect to the non-native species, *Acacia dealbata*, *Eucalyptus globulus*, *Pinus ponderosa*, and *Acacia melanoxylon* were cataloged exclusively in indices of greater flammability (Fig. 5). Some of the non-native species cataloged exclusively in indices of low flammability are *Populus nigra*, *Rosa rubiginosa*, and *Cytisus scoparius* (Fig. 5). However, caution is advised when interpreting these results as some species may present high or low flammability

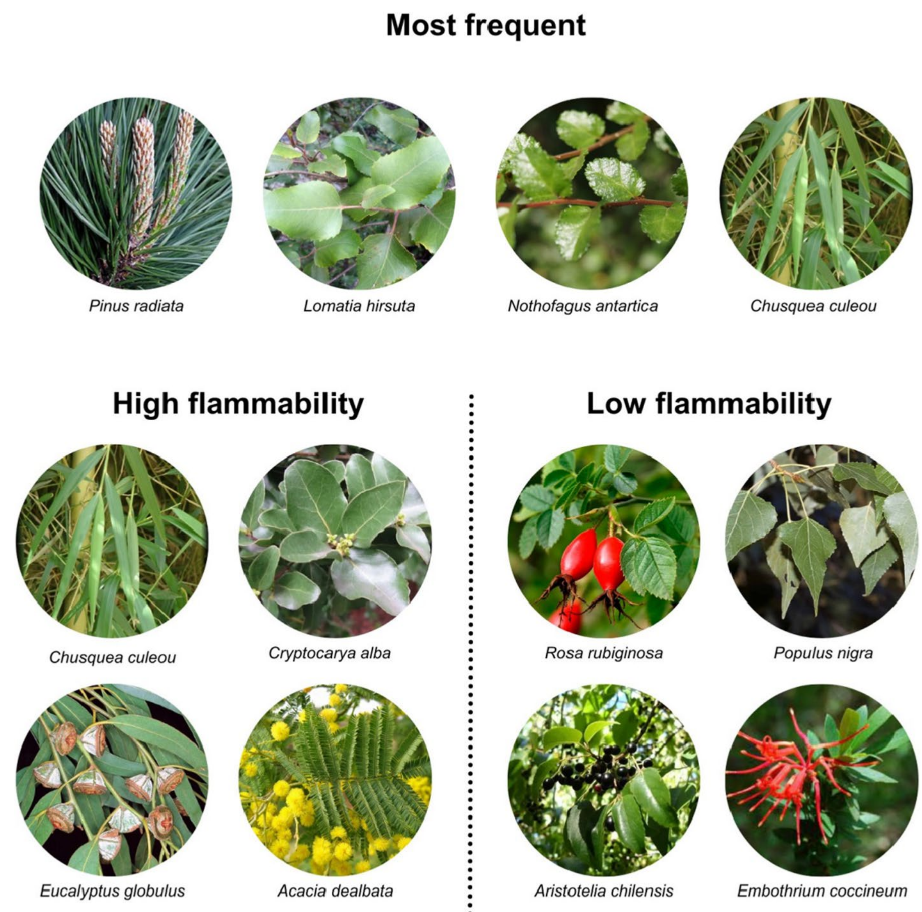

Fig. 5 Plant species highlighted in the review, either by the frequency in different articles (top row), and by being categorized as high (left) or low (right) flammability in the southern cone of South America

attributes depending how these were variables measured. For instance, the non-native trees *Pinus radiata, Pseudotsuga menziessi*, and native tree *Nothofagus dombeyi*, which are classified as highly flammable (Bianchi et al. 2019), but other studies (using other methodologies) classify these same species as being of low flammability (Blackhall and Raffaele 2019; Franzese et al. 2020). Thus, some approaches define a species to be flammable only by measuring its ignition values, but discarding all the variables, since a species may ignite very fast, but its combustion may be slow and not as hot, decreasing its flammability values (Murray et al. 2020). Furthermore, these results again indicate that leaf morphology would have a greater influence on leaf flammability than the geographic origin, which does not seem to be strongly related to the level of flammability of vegetation (i.e., thicker leaves seem to be present in a higher scale of flammability than species with thinner leaves).

Another way to analyze and discuss the results is by using the families of the studied species, where 19 families were analyzed (Table 2). *Pinaceae* was the botanical family with the greatest frequency in the tests, present in 12 articles, of which 8 classified the species with higher flammability indices. The family *Nothofagaceae*, which is the most relevant from the forest point of view in the southern cone (i.e., Chile and Argentina), also had a large number of reported tests, with a total of 9, of which 7 cataloged the species with higher flammability indices. It must be emphasized that in this case, all the species belonging to the family *Pinaceae* correspond to non-native species, and *Nothofagaceae* are all native species. This result is relevant because it indicates that families that have exclusive native and non-native species, in both cases most of the species exhibit high flammable indexes, being the geographical origin factor irrelevant in this point, since it would be expected that species belonging to the *Nothofagaceae* family would present a lower number of flammable species because they are native, which is not the case.

These results do not allow us to determine unequivocally if there are significant differences with respect to the flammability of the vegetation due exclusively to their geographic origin, since both the non-native and native vegetation have species classified in extreme flammability indices, as well as low flammability. In addition, to make a fair comparison, all the species should be evaluated using the same methodology (see Table 4). We found that there is a high variability in the methods to evaluate flammability, yielding very contrasting results for the same species (Table 1). Therefore, to have the benefit of comparing the findings for different species and in various countries/ecosystems worldwide, certain standard criteria must be proposed for the implementation of flammability experiments.

Flammability and pyric properties

The articles reviewed indicate that the ignitability of vegetation is the most used variable in tests (88%), followed by combustibility (69%), sustainability (51%), and, finally, the least measured variable in flammability tests, consumability (37%) (Table 5). These results show a great deal of variability in the features measured in flammability trials, which in some case oversimplify the classification of vegetation using only one or two variables. In fact, several authors define flammability as being determined mainly by the percentage of moisture present in the sample and that the other components of flammability are more related to the characteristics of the species in question (Curt et al. 2011; Murray et al. 2013; Bianchi and Defosse 2015; Popović et al. 2021). Due to these discrepancies (both methodological and conceptual), this review recommends that when performing flammability tests, all or most of the variables that define the flammability concept (Anderson 1970; Martin et al. 1993) should be evaluated. Each of these variables provides relevant information when cataloging a species according to its degree of flammability and makes possible a more objective comparison between different species and different places/ecosystems in the world. It is important to emphasize the need for standardized protocols to determine in the first instance the probability of ignition and fire spread through flammability experiments. The main objective of this standardization is to produce comparable and consistent results in similar geographic areas that share comparable climatic and environmental variables. Establishing a more standardized methodology better ensures that flammability assessments are consistent and comparable across locations and species. This will generate reliable data to understand and address the risks of forest fires and other events related to the combustion of vegetation in different ecosystems.

With respect to the pyric properties of the vegetation, which go together with the flammability tests (Popović et al. 2021), the moisture content of the biomass is the most considered variable in flammability tests (80%). This is followed to a lesser extent by the morphological attributes of the plants (41%), which primarily consider the length, height, and leaf width. Finally, calorimetry/calorific value tests and chemical analyses of the vegetation are the least used (29% and 27%, respectively). Several studies show that moisture (Fletcher et al. 2007; Bianchi and Defosse 2015; Livingston and Varner 2016; Bianchi et al. 2019) and the morphology of the vegetation (Dimitrakopoulos 2001; Curt et al. 2011; Kauf et al. 2015; Mason et al. 2016; Ganteaume 2018) are highly relevant when studying flammability, especially moisture, since it will be decisive of the time and frequency of ignition of the different species (Fletcher et al. 2007; Shan et al. 2008; Hernández et al. 2018; Safdari et al. 2018; Rosavec et al. 2022). With respect to the chemical analyses, although they are related to flammability, this happens with specific vegetation (i.e., that have high contents of secondary metabolites, phenols, terpenes, and others); therefore, it cannot be generalized for all species (Liodakis et al. 2002; Alam et al. 2020; Dewhirst et al. 2020; Guerrero et al. 2021, 2022).

Concluding remarks

This review shed light on the flammability features of native and non-native plant species of the southern cone of South America. It is one of the first systematization attempts to discuss this topic, and by means of the various analyses presented above, we can conclude that the geographic origin of plant species does not necessarily determine the degree of flammability of the species, as this might depend on other much more relevant variables, such as type of fuel, moisture content, and internal chemical compounds in plant tissues. Although it is difficult to compare the different species because the data

Table 5 Number and percentage of flammability tests with the variables that make up the concept of flammability. *Igni* ignition, *Cons* consumability, *Comb* combustibility, *Sust* sustainability, *Mois* moisture, *Chem* chemistry, *Morp* morphology, *Cal.* calorimetry

	Measurements							
	Igni	**Cons**	**Comb**	**Sust**	**Mois**	**Chem**	**Morf**	**Cal**
Total	45	19	35	26	42	15	21	16
Percentage	88%	37%	69%	51%	82%	29%	41%	31%

analyzed in this review are collected by different methodologies, a trend can be indeed observed, which does not relate the flammability to the geographical origin of the species.

The synthesis of this review revealed that the evaluation of the flammability of woody plant species is carried out by different methods. Among them, the methodology of Jaureguiberry and the use of epiradiators are the more frequent procedures for assessing ignitions. However, the lack of consistency was noted in the results of the studies that use the same methodology, which makes it difficult to generalize the results, interpret them correctly, or compare them with similar studies. These discrepancies limit the scope of this review as it can cause confusion in the interpretation of the results and limit the ability to establish predictions beyond the experimental laboratory scale. We believe, however, that it is relevant to approach this issue and move forward by unifying criteria and standardizing the measurement protocols, so that we can conduct comparative studies to generate more extensive and more reliable databases with a scientific foundation, both globally and within areas with vegetation and geographic characteristics similar to those of the area considered in this review.

We believe that it is essential to coin a concept of flammability that is linked to fires, particularly with what is currently happening in the southern cone of South America, where these fires originate mostly due to human related ignitions, whether accidental or intentional. What can really vary is the sustainability, combustibility and consumability of the affected vegetation and thus, its ability to spread fire. The challenge here is to move forward into a more complete characterization of fuel properties at the community scale, with both field and lab-based approaches. Therefore, vegetation variables related to fire (i.e., flammability) must be taken into account when deciding which species are the most useful for forest landscape planning aiming at creating less-fire-prone environments. These advances are expected to provide greater uniformity of results, improve our understanding of the flammability of woody plant species, and strengthen the basis for more effective forest fire management and prevention. This will enable informed decision-making supported by scientific evidence for better forest planning, fire prevention, and fuel management, specially within the wildland-urban interface zones around populated areas. Finally, the need for more exhaustive and comparative studies between native and non-native vegetation is highlighted in this review to better understand the flammability features of the vegetation in the southern cone of South America within the global context of increased wildfires.

Acknowledgements
OTO and AFR are funded by ANID/Basal FB210015 (CENAMAD) and are thankful for the support received from ANID SCIA-Anillo ACT210052. AFR acknowledges grants DIUFRO PP23-0016 and Capital Semilla PCS 2021/017 CENAMAD. RAG thanks to ANID/Basal FB210006. Two reviewers made a number of comments and suggestions that greatly improved the manuscript.

Authors' contributions
Conceiving the idea and defining objectives were done by OTO and AFR. Data research and analyses were done by OTO. Writing and editing the manuscript were done by OTO, AFR, VPS, RAG, KAM, RD, and AFC.

Funding
Funding was provided by grants ANID/Basal FB210015 (CENAMAD), ANID SCIA-Anillo ACT210052, DIUFRO PP23-0016, and Capital Semilla PCS 2021/017.

Availability of data and materials
Not applicable.

Declarations

Consent for publication
All authors reviewed the final version of the manuscript and agreed to submission.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Laboratorio de Ecosistemas y Bosques (EcoBos), Departamento de Ciencias Forestales, Universidad de La Frontera, Temuco, Chile. [2]Programa de Magister en Manejo de Recursos Naturales, Facultad de Ciencias Agropecuarias y Medioambiente, Universidad de La Frontera, Temuco, Chile. [3]Centro Nacional de Excelencia para la Industria de la Madera (CENAMAD), Pontificia Universidad Católica de Chile, Santiago, Chile. [4]Laboratorio de Invasiones Biológicas (LIB), Facultad de Ciencias Forestales, Universidad de Concepción, Concepción, Chile. [5]Instituto de Ecología y Biodiversidad (IEB), Concepción, Chile. [6]Department of Ecology, Evolution and Organismal Biology (EEOB), Iowa State University, Ames, IA 50010, USA. [7]Departamento de Industrias, Universidad Técnica Federico Santa María, Valparaíso, Chile.

Received: 14 September 2023 Accepted: 2 January 2024
Published online: 15 February 2024

References
Alzate-Guarín, F., L. Muñoz, and A. Amell. 2022. Evaluación preliminar de la inflamabilidad de algunas especies de plantas cultivadas en Colombia. *Hoehnea* 49. https://doi.org/10.1590/2236-8906-49/2021.
Ammerman, C. 2022. Lessons from fire: the displaced radiata pine on Mapuche homelands and the California roots of Chile's climate crisis. *Annals of the American Association of Geographers* 112 (3): 692–705. https://doi.org/10.1080/24694452.2021.2008225.
Anderson, H. E. 1970. Forest fuel ignitibility. *Fire Technology* 6(4): 312–319. https://doi.org/10.1007/BF02588932.
Archibald, S., C.E.R. Lehmann, J.L. Gómez-Dans, and R.A. Bradstock. 2013. Defining pyromes and global syndromes of fire regimes. *Proceedings of the National Academy of Sciences* 110 (16): 6442–6447. https://doi.org/10.1073/pnas.1211466110.
Arroyo-Vargas, P., A. Holz, and T.T. Veblen. 2022. Fire effects on diversity patterns of the understory communities of Araucaria-Nothofagus forests. *Plant Ecology* 223 (7, SI): 883–906. https://doi.org/10.1007/s11258-022-01247-4.
Balch, J.K., B.A. Bradley, J.T. Abatzoglou, R.C. Nagy, E.J. Fusco, and A.L. Mahood. 2017. Human-started wildfires expand the fire niche across the United States. *Proceedings of the National Academy of Sciences* 114 (11): 2946–2951. https://doi.org/10.1073/pnas.1617394114.

Barnes, A.G., J.M. Kane, D.A. McKenzie, and B.A. Koerner. 2022. Invasion of a non-native forb reduces flammability in a fire-dependent ecosystem. *Ecosphere* 13 (3): e3995. https://doi.org/10.1002/ecs2.3995.

Batista, A.C., D. Biondi, and A. Martini. 2021. Flammability of ornamental species for fire management in wildland-urban interface in paraná state. *Floresta* 51 (1): 192–200. https://doi.org/10.5380/rf.v51i1.67938.

Beckage, B., W. J. Platt, and L. J. Gross. 2009. Vegetation, fire, and feedbacks: a disturbance-mediated model of Savannas. *The American Naturalist* 174(6): 805–818. https://doi.org/10.1086/648458.

Behm, A., M. Duryea, A. Long, and W. Zipperer. 2004. Flammability of native understory species in pine flatwood and hardwood hammock ecosystems and implications for the wildland-urban interface. *International Journal of Wildland Fire* 13(3): 355–365. https://doi.org/10.1071/WF03075.

Bianchi, L. O., and G. E. Defosse. 2014. Ignition probability of fine dead surface fuels in native Patagonia forests of Argentina. *Forest Systems* 23(1): 129–138. https://doi.org/10.5424/fs/2014231-04632.

Bianchi, L. O., and G. E. Defosse. 2015. Live fuel moisture content and leaf ignition of forest species in Andean Patagonia, Argentina. *International Journal of Wildland Fire* 24(3): 340–348. https://doi.org/10.1071/WF13099.

Bianchi, L.O., F.J. Oddi, M. Munoz, and G.E. Defosse. 2019. Comparison of leaf moisture content and ignition characteristics among native species and exotic conifers in Northwestern Patagonia. *Argentina Forest Science* 65 (4): 375–386. https://doi.org/10.1093/forsci/fxy054.

Blackhall, M., and E. Raffaele. 2019. Flammability of Patagonian invaders and natives: when exotic plant species affect live fine fuel ignitability in wildland-urban interfaces. *Landscape and Urban Planning* 189: 1–10. https://doi.org/10.1016/j.landurbplan.2019.04.002.

Blackhall, M., E. Raffaele, and T. T. Veblen. 2012. Is foliar flammability of woody species related to time since fire and herbivory in northwest Patagonia. *Argentina? Journal of Vegetation Science* 23(5): 931–941. https://doi.org/10.1111/j.1654-1103.2012.01405.x.

Bowman, D. M. J. S., J. K. Balch, P. Artaxo, W. J. Bond, J. M. Carlson, M. A. Cochrane, C. M. D'Antonio, R. S. DeFries, J. C. Doyle, S. P. Harrison, F. H. Johnston, J. E. Keeley, M. A. Krawchuk, C. A. Kull, J. B. Marston, M. A. Moritz, I. C. Prentice, C. I. Roos, A. C. Scott, …, and S. J. Pyne. 2009. Fire in the Earth System. *Science* 324(5926): 481–484. https://doi.org/10.1126/science.1163886.

Bowman, D. M. J. S., J. Balch, P. Artaxo, W. J. Bond, M. A. Cochrane, C. M. D'Antonio, R. DeFries, F. H. Johnston, J. E. Keeley, M. A. Krawchuk, C. A. Kull, M. Mack, M. A. Moritz, S. Pyne, C. I. Roos, A. C. Scott, N. S. Sodhi, and T. W. Swetnam. 2011. The human dimension of fire regimes on Earth. *Journal of Biogeography* 38(12): 2223–2236. https://doi.org/10.1111/j.1365-2699.2011.02595.x.

Bowman, D. M. J. S., A. Moreira-Muñoz, C. A. Kolden, R. O. Chávez, A. A. Muñoz, F. Salinas, Á. González-Reyes, R. Rocco, F. de la Barrera, G. J. Williamson, N. Borchers, L. A. Cifuentes, J. T. Abatzoglou, and F. H. Johnston. 2019. Human–environmental drivers and impacts of the globally extreme 2017 Chilean fires. *Ambio* 48(4): 350–362. https://doi.org/10.1007/s13280-018-1084-1.

Brando, P. M., D. C. Nepstad, J. K. Balch, B. Bolker, M. C. Christman, M. Coe, and F. E. Putz. 2012. Fire-induced tree mortality in a neotropical forest: the roles of bark traits, tree size, wood density and fire behavior. *Global Change Biology* 18(2): 630–641. https://doi.org/10.1111/j.1365-2486.2011.02533.x.

Brennan, K., C. Christie, Fiona., and Alan. York. 2009. Global climate change and litter decomposition: more frequent fire slows decomposition and increases the functional importance of invertebrates. *Global Change Biology* 15(12): 2958–2971. https://doi.org/10.1111/j.1365-2486.2009.02011.x.

Brohez, S., G. Marlair, and C. Delvosalle. 2006. Fire calorimetry relying on the use of the fire propagation apparatus. Part II: burning characteristics of selected chemical substances under fuel rich conditions. *Fire and Materials* 30(1): 35–50. https://doi.org/10.1002/fam.897.

Brooks, M. L., C. M. D'Antonio, D. M. Richardson, J. B. Grace, J. E. Keeley, J. M. DiTomaso, R. J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54(7): 677–688. https://doi.org/10.1641/0006-3568(2004)054[0677:EOIAPO]2.0.CO;2.

Burger, N., and W. J. Bond. 2015. Flammability traits of Cape shrubland species with different post-fire recruitment strategies. *South African Journal of Botany* 101: 40–48. https://doi.org/10.1016/j.sajb.2015.05.026.

Calitz, W., A. J. Potts, and R. M. Cowling. 2015. Investigating species-level flammability across five biomes in the Eastern Cape, South Africa. *South African Journal of Botany* 101: 32–39. https://doi.org/10.1016/j.sajb.2015.07.005.

Carmona, A., M. E. Gonzalez, L. Nahuelhual, and J. Silva. 2012. Spatio-temporal effects of human drivers on fire danger in Mediterranean Chile. *BOSQUE* 33(3): 321–328. https://doi.org/10.4067/S0717-92002012000300016.

Cobar-Carranza, A. J., R. A. Garcia, A. Pauchard, and E. Pena. 2014. Effect of Pinus contorta invasion on forest fuel properties and its potential implications on the fire regime of Araucaria araucana and Nothofagus Antarctica forests. *Biological Invasions* 16(11): 2273–2291. https://doi.org/10.1007/s10530-014-0663-8.

Cubino, J. P., H. L. Buckley, N. J. Day, R. Pieper, and T. J. Curran. 2018. Community-level flammability declines over 25years of plant invasion in grasslands. *Journal of Ecology* 106(4): 1582–1594. https://doi.org/10.1111/1365-2745.12933.

Cui, X., A. M. Paterson, M. A. Alam, S. V. Wyse, K. Marshall, G. L. W. Perry, and T. J. Curran. 2020. Shoot-level flammability across the Dracophyllum (Ericaceae) phylogeny: evidence for flammability being an emergent property in a land with little fire. *New Phytologist* 228(1): 95–105. https://doi.org/10.1111/nph.16651.

Curran, T.J., G.L.W. Perry, S.V. Wyse, and M.A. Alam. 2018. Managing fire and biodiversity in the wildland-urban interface: a role for green firebreaks. *Fire-Switzerland* 1 (1): 3. https://doi.org/10.3390/fire1010003.

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

Defosse, G.E. 2015. *¿Conviene seguir fomentando las plantaciones forestales en el norte de la Patagonia?*

Della Rocca, G., C. Hernando, J. Madrigal, R. Danti, J. Moya, M. Guijarro, A. Pecchioli, and B. Moya. 2015. Possible land management uses of common cypress to reduce wildfire initiation risk: a laboratory study. *Journal of Environmental Management* 159: 68–77. https://doi.org/10.1016/j.jenvman.2015.05.020.

Dewhirst, R.A., N. Smirnoff, and C.M. Belcher. 2020. Pine species that support crown fire regimes have lower leaf-level terpene contents than those native to surface fire regimes. *Fire-Switzerland* 3 (2): 17. https://doi.org/10.3390/fire3020017.

Dibble, A. C., R. H. White, and P. K. Lebow. 2007. Combustion characteristics of north-eastern USA vegetation tested in the cone calorimeter: invasive versus non-invasive plants. *International Journal of Wildland Fire* 16(4): 426–443. https://doi.org/10.1071/WF05103.

Dimitrakopoulos, A. P. 2001. A statistical classification of Mediterranean species based on their flammability components. *International Journal of Wildland Fire* 10(2): 113–118. https://doi.org/10.1071/WF01004.

Dimitrakopoulos, A. P., and K. K. Papaioannou. 2001. Flammability assessment of Mediterranean forest fuels. *Fire Technology* 37(2): 143–152. https://doi.org/10.1023/A:1011641601076.

Essaghi, S., M. Hachmi, M. Yessef, M. Dehhaoui, and F. El Amarty. 2017. Assessment of flammability of Moroccan forest fuels: new approach to estimate the flammability index. *Forests* 8 (11): 443. https://doi.org/10.3390/f8110443.

Fares, S., S. Bajocco, L. Salvati, N. Camarretta, J.-L. Dupuy, G. Xanthopoulos, M. Guijarro, J. Madrigal, C. Hernando, and P. Corona. 2017. Characterizing potential wildland fire fuel in live vegetation in the Mediterranean region. *Annals of Forest Science* 74(1): 1. https://doi.org/10.1007/s13595-016-0599-5.

Fenesi, A., S. Saura-Mas, R. R. Blank, A. Kozma, B.-M. Lózer, and E. Ruprecht. 2016. Enhanced fire-related traits may contribute to the invasiveness of Downy Brome (Bromus tectorum). *Invasive Plant Science and Management* 9(3): 182–194. https://doi.org/10.1614/IPSM-D-16-00006.1.

Fernandes, P. M. 2009. Combining forest structure data and fuel modelling to classify fire hazard in Portugal. *Annals of Forest Science* 66(4): 415–415. https://doi.org/10.1051/forest/2009013.

Fernandes, P. M., and M. G. Cruz. 2012. Plant flammability experiments offer limited insight into vegetation–fire dynamics interactions. *New Phytologist* 194(3): 606–609. https://doi.org/10.1111/j.1469-8137.2012.04065.x.
Fletcher, T. H., B. M. Pickett, S. G. Smith, G. S. Spittle, M. M. Woodhouse, E. Haake, and D. R. Weise. 2007. Effects of moisture on ignition behavior of moist California chaparral and Utah leaves. *Combustion Science and Technology* 179(6): 1183–1203. https://doi.org/10.1080/00102200601015574.
Franzese, J., E. Raffaele, M. Blackhall, J. Rodriguez, and A. Y. Soto. 2020. Changes in land cover resulting from the introduction of non-native pine modifies litter traits of temperate forests in Patagonia. *Journal of Vegetation Science* 31(2): 223–233. https://doi.org/10.1111/jvs.12847.
Franzese, J., E. Raffaele, M.C. Chiuffo, and M. Blackhall. 2022. The legacy of pine introduction threatens the fuel traits of Patagonian native forests. *Biological Conservation* 267: 109472. https://doi.org/10.1016/j.biocon.2022.109472.
Fuentes, N., A. Marticorena, A. Saldaña, V. Jerez, J. C. Ortiz, P. Victoriano, R,A, Moreno, J. Larraín, C. Villaseñor-Parada, G. Palfner, P. Sánchez, and A. Pauchard. 2020. Multi-taxa inventory of naturalized species in Chile. *Neobiota* 60: 25–41.
Fuentes-Ramírez, A., A. Pauchard, A. Marticorena, and P. Sánchez. 2010. Relación entre la invasión de Acacia dealbata Link (Fabaceae: Mimosoideae) Y La Riqueza De especies vegetales en El centro-sur de Chile. *Gayana Botánica* 67: 188–197. http://www.scielo.cl/scielo.php?script=sci_arttext. &pid=S0717-66432010000200004&nrm=iso.
Fuentes-Ramirez, A., J. W. Veldman, C. Holzapfel, and K. A. Moloney. 2016. Spreaders, igniters, and burning shrubs: plant flammability explains novel fire dynamics in grass-invaded deserts. *Ecological Applications* 26(7): 2311–2322. https://doi.org/10.1002/eap.1371.
Ganteaume, A. 2018. Does plant flammability differ between leaf and litter bed scale? Role of fuel characteristics and consequences for flammability assessment. *International Journal of Wildland Fire* 27(5): 342–352. https://doi.org/10.1071/WF17001.
García, R. A., M. L. Engler, E. Peña, F. W. Pollnac, and A. Pauchard. 2015. Fuel characteristics of the invasive shrub Teline monspessulana (L.) K. Koch. *International Journal of Wildland Fire* 24(3): 372–379. https://doi.org/10.1071/WF13078.
Gibson, R. K., R. A. Bradstock, T. Penman, D. A. Keith, and D. A. Driscoll. 2016. Determinants of growth of the flammable grass, Triodia scariosa: consequences for fuel dynamics under climate change in the Mediterranean region of South Eastern Australia. *Austral Ecology* 41(6): 594–603. https://doi.org/10.1111/aec.12348.
Goodwin, K.M., and R.L. Sheley. 2001. What to do when fires fuel weeds: a step-by-step guide for managing invasive plants after a wildfire. *Rangelands* 23 (6): 15–21 https://www.scopus.com/inward/record.uri?eid=2-s2.0-0035713125&partnerID=40&md5=c4f27160d1af8811dc18b762be76608a.
Grootemaat, S., I. J. Wright, P. M. van Bodegom, J. H. C. Cornelissen, and W. K. Cornwell. 2015. Burn or rot: leaf traits explain why flammability and decomposability are decoupled across species. *Functional Ecology* 29(11): 1486–1497. https://doi.org/10.1111/1365-2435.12449.
Guerrero, Carmona, and C., C. Hernandez, M. Toledo, A. Arriagada, L. Espinoza, J. Bergmann, L. Taborga, K. Yanez, Y. Carrasco, and A. A. Munoz. 2022. Drivers of flammability of Eucalyptus globulus Labill leaves: terpenes, essential oils, and moisture content. *Forests* 13 (6): 908. https://doi.org/10.3390/f13060908.
Guerrero, Hernández, and C., M. Toledo, L. Espinoza, Y. Carrasco, A. Arriagada, A. Muñoz, L. Taborga, J. Bergmann, and C. Carmona. 2021. Leaf thermal and chemical properties as natural drivers of plant flammability of native and exotic tree species of the Valparaíso Region, Chile. *International Journal of Environmental Research and Public Health* 18 (13): 7191. https://doi.org/10.3390/ijerph18137191.
Guerrero, Toledo, M., N. Ripoll, L. Espinoza, Rodrigo Morales, A. Munoz, L. Taborga, and Y. Carrasco. 2020. Thermo- and physicochemical properties of native and exotic forest species of Valparaiso, Chile, as essential information for fire risk management. *International Journal of Wildland Fire* 29(8): 675–685. https://doi.org/10.1071/WF19086.
Hernández, N., A. Fuentes, J. L. Consalvi, and J. C. Elicer-Cortés. 2018. Spontaneous ignition of wildland fuel by idealized firebrands. *Experimental Thermal and Fluid Science* 95: 88–95. https://doi.org/10.1016/j.expthermflusci.2018.01.037.
Holz, A., and T. T. Veblen. 2011. The amplifying effects of humans on fire regimes in temperate rainforests in western Patagonia. *Palaeogeography Palaeoclimatology Palaeoecology* 311(1): 82–92. https://doi.org/10.1016/j.palaeo.2011.08.008.
Jaureguiberry, P., G. Bertone, and S. Díaz. 2011. Device for the standard measurement of shoot flammability in the field. *Austral Ecology* 36(7): 821–829. https://doi.org/10.1111/j.1442-9993.2010.02222.x.
Jolly, W. M., M. A. Cochrane, P. H. Freeborn, Z. A. Holden, T. J. Brown, G. J. Williamson, and D. M. J. S. Bowman. 2015. Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications* 6(1): 7537. https://doi.org/10.1038/ncomms8537.
Kane, J. M., J. M. Varner, and M. R. Saunders. 2019. Resurrecting the lost flames of American Chestnut. *Ecosystems* 22(5): 995–1006. https://doi.org/10.1007/s10021-018-0318-1.
Kane, J. M., M. R. Gallagher, J. M. Varner, and N. S. Skowronski. 2022. Evidence of local adaptation in litter flammability of a widespread fire-adaptive pine. *Journal of Ecology* 110(5): 1138–1148. https://doi.org/10.1111/1365-2745.13857.
Kauf, Z., A. Fangmeier, R. Rosavec, and Ž. Španjol. 2015. Seasonal and local differences in leaf litter flammability of six Mediterranean tree species. *Environmental Management* 55(3): 687–701. https://doi.org/10.1007/s00267-014-0427-3.
Kinoshita, A.M., R. Becerra, M. Mileti, and N. Mladenov. 2022. Upland and riparian surface soil processes in an urban creek with native and non-native vegetation after fire. *Fire-Switzerland* 5 (2): 32. https://doi.org/10.3390/fire5020032.
Kraaij, T., S.T. Msweli, and A.J. Potts. 2022. Fuel trait effects on flammability of native and invasive alien shrubs in coastal fynbos and thicket (Cape Floristic Region). *PeerJ* 10: e13765. https://doi.org/10.7717/peerj.13765.
Krawchuk, M. A., and M. A. Moritz. 2011. Constraints on global fire activity vary across a resource gradient. *Ecology* 92(1): 121–132. https://doi.org/10.1890/09-1843.1.
Krix, D. W., M. L. Murray, and B. R. Murray. 2022. Increasing radiant heat flux affects leaf flammability patterns in plant species of eastern Australian fire-prone woodlands. *Plant Biology* 24(2): 302–312. https://doi.org/10.1111/plb.13381.
Lara, A., M.E. Solari, M. Rutherford, P. Thiers, and O. Trecaman. 1999. R. Technical Report. In *Coverage of the Original Vegetation in Forests of the Valdivian Ecoregion around 1550*. Valdivia: Universidad Austral de Chile and World Wildlife Foundation.
Lavorel, S., M. D. Flannigan, E. F. Lambin, and M. C. Scholes. 2007. Vulnerability of land systems to fire: interactions among humans, climate, the atmosphere, and ecosystems. *Mitigation and Adaptation Strategies for Global Change* 12(1): 33–53. https://doi.org/10.1007/s11027-006-9046-5.
Liodakis, S., D. Bakirtzis, and A. Dimitrakopoulos. 2002. Ignition characteristics of forest species in relation to thermal analysis data. *Thermochimica Acta* 390(1): 83–91. https://doi.org/10.1016/S0040-6031(02)00077-1.
Liu, Y., J. Stanturf, and S. Goodrick. 2010. Trends in global wildfire potential in a changing climate. *Forest Ecology and Management* 259(4): 685–697. https://doi.org/10.1016/j.foreco.2009.09.002.
Livingston, A. C., and J. M. Varner. 2016. Fuel moisture differences in a Mized native and non-native grassland: implications for fire regimes. *Fire Ecology* 12(1): 73–87. https://doi.org/10.4996/fireecology.1201073.
Martin, R.E., D.A. Gordon, M.A. Gutierrez, D.S. Lee, D. Molina, R. Schroeder, D. Sapsis, and S. Stephens. 1993. Assessing the flammability of domestic and wildland vegetation. In *12th Conference on Fire and Forest Meteorology*, 26–28. Jekyll Island. https://doi.org/10.13140/RG.2.1.3999.3680.
Mason, N. W. H., C. Frazao, R. P. Buxton, and S. J. Richardson. 2016. Fire form and function: evidence for exaptive flammability in the New Zealand flora. *Plant Ecology* 217(6): 645–659. https://doi.org/10.1007/s11258-016-0618-5.
Massuque, J., C. E. Matavel, T. de Protasio P., and P. F. Trugilho. 2021. Combustion performance of charcoal: a comparative study on Miombo Woodland native species and Eucalyptus grandis. *Biomass Conversion and Biorefinery*. https://doi.org/10.1007/s13399-021-02109-1.
Moreira, F., D. Ascoli, H. Safford, M. A. Adams, J. M. Moreno, J. M. C. Pereira, F. X. Catry, J. Armesto, W. Bond, M. E. González, T. Curt, N. Koutsias, L. McCaw, O. Price, J. G. Pausas, E. Rigolot, S. Stephens, C. Tavsanoglu, V. R. Vallejo, …, and P. M. Fernandes. 2020. Wildfire management in Mediterranean-type regions: paradigm change needed. *Environmental Research Letters* 15(1): 011001. https://doi.org/10.1088/1748-9326/ab541e.
Moriondo, M., P. Good, R. Durao, M. Bindi, C. Giannakopoulos, and J. Corte-Real. 2006. Potential impact of climate change on fire risk in the Mediterranean area. *Climate Research* 31(1): 85–95. https://doi.org/10.3354/cr031085.

Msweli, S.T., A.J. Potts, H. Fritz, and T. Kraaij. 2020. Fire weather effects on flammability of indigenous and invasive alien plants in coastal fynbos and thicket shrublands (Cape Floristic Region). *PeerJ* 8: e10161. https://doi.org/10.7717/peerj.10161.

Murray, B. R., L. K. Hardstaff, and M. L. Phillips. 2013. Differences in leaf flammability, leaf traits and flammability-trait relationships between native and exotic plant species of dry sclerophyll forest. *Plos One* 8(11): 1–8. https://doi.org/10.1371/journal.pone.0079205.

Murray, B.R., C. Brown, M.L. Murray, D.W. Krix, L.J. Martin, T. Hawthorne, M.I. Wallace, S.A. Potvin, and J.K. Webb. 2020. An integrated approach to identify low-flammability plant species for green firebreaks. *Fire* 3 (2): 9. https://doi.org/10.3390/fire3020009.

Nepstad, D. C., A. Verssimo, A. Alencar, C. Nobre, E. Lima, P. Lefebvre, P. Schlesinger, C. Potter, P. Moutinho, E. Mendoza, M. Cochrane, and V. Brooks. 1999. Large-scale impoverishment of amazonian forests by logging and fire. *Nature* 398(6727): 505–508. https://doi.org/10.1038/19066.

North, M.P., S.L. Stephens, B.M. Collins, J.K. Agee, G. Aplet, J.F. Franklin, and P.Z. Fulé. 2015. *Reform forest fire management: agency incentives undermine policy effectiveness* https://www.scopus.com/inward/record.uri?eid=2-s2.0-84942873888&doi=10.1126%2fscience.aab2356&partnerID=40&md5=b0a52868c8bf7e9b5b4306d1fdc80032.

Ntoufas, I., S. Liodakis, and N. Tzamtzis. 2016. The effect of the extracable components of Euro-Mediterreanean vegetation species to the combsution of their foliage. *Fresenius Environmental Bulletin* 25(8): 2850–2859.

Nuñez, M. A., K. T. Davis, R. D. Dimarco, D. A. Peltzer, J. Paritsis, B. D. Maxwell, and a. Pauchard. 2021. Should tree invasions be used in treeless ecosystems to mitigate climate change? *Frontiers in Ecology and the Environment* 19(6): 334–341. https://doi.org/10.1002/fee.2346.

Núñez-Regueira, L., J. A. R. Añón, and J. P. Castiñeiras. 1996. Calorific values and flammability of forest species in Galicia. Coastal and hillside zones. *Bioresource Technology* 57(3): 283–289. https://doi.org/10.1016/S0960-8524(96)00083-1.

Page, M. J., J. E. McKenzie, P. M. Bossuyt, I. Boutron, T. C. Hoffmann, C. D. Mulrow, L. Shamseer, J. M. Tetzlaff, E. A. Akl, S. E. Brennan, R. Chou, J. Glanville, J. M. Grimshaw, A. Hróbjartsson, M. M. Lalu, T. Li, E. W. Loder, E. Mayo-Wilson, S. McDonald, …, and D. Moher. 2021. Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas. *Revista Española De Cardiología* 74(9): 790–799. https://doi.org/10.1016/j.recesp.2021.06.016.

Park, W.-H., and K.-B. Yoon. 2013. Optimization of pyrolysis properties using TGA and cone calorimeter test. *Journal of Thermal Science* 22(2): 168–173. https://doi.org/10.1007/s11630-013-0608-z.

Pausas, J. G. 2015. Bark thickness and fire regime. *Functional Ecology* 29(3): 315–327. https://doi.org/10.1111/1365-2435.12372.

Pausas, J. G., and J. E. Keeley. 2009. A burning story: the role of fire in the history of life. *BioScience* 59(7): 593–601. https://doi.org/10.1525/bio.2009.59.7.10.

Pausas, J. G., J. E. Keeley, and D. W. Schwilk. 2017. Flammability as an ecological and evolutionary driver. *Journal of Ecology* 105(2): 289–297. https://doi.org/10.1111/1365-2745.12691.

Popović, Z., S. Bojović, M. Marković, and A. Cerdà. 2021. Tree species flammability based on plant traits: a synthesis. *Science of the Total Environment* 800: 149625. https://doi.org/10.1016/j.scitotenv.2021.149625.

Potts, E., D. Tng, D. Apgaua, T. J. Curran, J. Engert, and S. G. W. Laurance. 2022. Growth form and functional traits influence the shoot flammability of tropical rainforest species. *Forest Ecology and Management* 522: 120485. https://doi.org/10.1016/j.foreco.2022.120485.

Quan, Y., Z. Zhang, R. N. Tanchak, and Q. Wang. 2022. A review on cone calorimeter for assessment of flame-retarded polymer composites. *Journal of Thermal Analysis and Calorimetry* 147(19): 10209–10234. https://doi.org/10.1007/s10973-022-11279-7.

Radhaboy, G., M. Pugazhvadivu, P. Ganeshan, and P. Ramshankar. 2019. Analysis of Thermo chemical behaviour of Calotropis procera parts for their potentiality. *International Journal of Ambient Energy.* https://doi.org/10.1080/01430750.2019.1630309.

Rasilla, D. F., J. C. García-Codron, V. Carracedo, and C. Diego. 2010. Circulation patterns, wildfire risk and wildfire occurrence at continental Spain. *Physics and Chemistry of the Earth Parts A/B/C* 35(9): 553–560. https://doi.org/10.1016/j.pce.2009.09.003.

Rasooli, S. B., S. Rashidi, and N. Shabanian. 2021. Fire sensitivity of broadleaf tree species in plantations of Kurdistan, Iran. *Journal of Forestry Research* 32(3): 1167–1176. https://doi.org/10.1007/s11676-020-01185-9.

Reszka, P., and A. Fuentes. 2015. The great Valparaiso Fire and fire safety management in Chile. *Fire Technology* 51(4): 753–758. https://doi.org/10.1007/s10694-014-0427-0.

Reszka, P., J. J. Cruz, J. Valdivia, F. González, J. Rivera, C. Carvajal, and A. Fuentes. 2020. Ignition delay times of live and dead pinus radiata needles. *Fire Safety Journal* 112: 102948. https://doi.org/10.1016/j.firesaf.2020.102948.

Riis, T., M. Kelly-Quinn, F. C. Aguiar, P. Manolaki, D. Bruno, M. D. Bejarano, N. Clerici, M. R. Fernandes, J. C. Franco, N. Pettit, A. P. Portela, O. Tammeorg, P. Tammeorg, P. M. Rodríguez-González, and S. Dufour. 2020. Global overview of ecosystem services provided by riparian vegetation. *BioScience* 70(6): 501–514. https://doi.org/10.1093/biosci/biaa041.

Rivera, J., N. Hernández, J. L. Consalvi, P. Reszka, J. Contreras, and A. Fuentes. 2021. Ignition of wildland fuels by idealized firebrands. *Fire Safety Journal* 120: 103036. https://doi.org/10.1016/j.firesaf.2020.103036.

Rosavec, R., D. Barčić, Ž Španjol, M. Oršanić, T. Dubravac, and A. Antonović. 2022. Flammability and combustibility of two Mediterranean species in relation to forest fires in Croatia. *Forests* 13 (8): 1266. https://doi.org/10.3390/f13081266.

Safdari, M.-S., M. Rahmati, E. Amini, J. E. Howarth, J. P. Berryhill, M. Dietenberger, D. R. Weise, and T. H. Fletcher. 2018. Characterization of pyrolysis products from fast pyrolysis of live and dead vegetation native to the Southern United States. *Fuel* 229: 151–166. https://doi.org/10.1016/j.fuel.2018.04.166.

Santacruz-García, A. C., S. Bravo, F. del Corro, and F. Ojeda. 2019. A comparative assessment of plant flammability through a functional approach: the case of woody species from Argentine Chaco region. *Austral Ecology* 44(8): 1416–1429. https://doi.org/10.1111/aec.12815.

Shan, Y., N. Liu, and L. Shu. 2008. Flammability ranking of foliage species by factor analysis of physical and chemical pyric properties. *Fire and Materials* 32(6): 371–382. https://doi.org/10.1002/fam.974.

Simberloff, D., M. A. Nuñez, N. J. Ledgard, A. Pauchard, D. M. Richardson, M. Sarasola, B. W. Van Wilgen, S. Zalba, R. Zenni, R. Bustamante, E. Peña, and S. R. Ziller. 2010. Spread and impact of introduced conifers in South America: lessons from other southern hemisphere regions. *Austral Ecology* 35(5): 489–504. https://doi.org/10.1111/j.1442-9993.2009.02058.x.

Simpson, K. J., B. S. Ripley, P.-A. Christin, C. M. Belcher, C. E. R. Lehmann, G. H. Thomas, and C. P. Osborne. 2016. Determinants of flammability in savanna grass species. *Journal of Ecology* 104(1): 138–148. https://doi.org/10.1111/1365-2745.12503.

Stetler, K.M., T.J. Venn, and D.E. Calkin. 2010. The effects of wildfire and environmental amenities on property values in northwest Montana, USA. *Ecological Economics* 69 (11): 2233–2243. https://doi.org/10.1016/j.ecolecon.2010.06.009.

Syphard, A.D., V.C. Radeloff, T.J. Hawbaker, and S.I. Stewart. 2009. Conservation threats due to human-caused increases in fire frequency in mediterranean-climate ecosystems. *Conservation Biology* 23 (3): 758–769. https://doi.org/10.1111/j.1523-1739.2009.01223.x.

Taylor, K. T., B. D. Maxwell, D. B. McWethy, A. Pauchard, M. A. Nuñez, and C. Whitlock. 2017. Pinus contorta invasions increase wildfire fuel loads and may create a positive feedback with fire. *Ecology* 98(3): 678–687. https://doi.org/10.1002/ecy.1673.

Ubeda, X., and P. Sarricolea. 2016. Wildfires in Chile: a review. *Global and Planetary Change* 146: 152–161. https://doi.org/10.1016/j.gloplacha.2016.10.004.

Valette, J. C. 1990. Inflammabilités Des espèces forestières méditerranéennes. Conséquences sur la combustibilité des formations forestières. *Revue Forestiére Francaise* 42(S): 76–92.

White, R. H., and W. C. Zipperer. 2010. Testing and classification of individual plants for fire behaviour: plant selection for the wildland urban interface. *International Journal of Wildland Fire* 19: 213227. https://doi.org/10.1071/WF07128.

Wyse, S. V., G. L. W. Perry, D. M. O'Connell, P. S. Holland, M. J. Wright, C. L. Hosted, S. L. Whitelock, I. J. Geary, K. J. L. Maurin, and T. J. Curran. 2016. A quantitative assessment of shoot flammability for 60 tree and shrub species supports rankings based on expert opinion. *International Journal of Wildland Fire* 25(4): 466–477. https://doi.org/10.1071/WF15047.

Alam, M.A., S.V. Wyse, H.L. Buckley, G.L.W. Perry, J.J. Sullivan, N.W.H. Mason, R. Buxton, S.J. Richardson, and T.J. Curran. 2020. Shoot flammability is decoupled from leaf flammability, but controlled by leaf functional traits. *Journal of Ecology* 108 (2): 641–653. https://doi.org/10.1111/1365-2745.13289.

R Core Team. 2023. *R: a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing https://www.R-project.org/.

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.