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DATA ARTICLE

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FLAMITS: A global database of plant flammability traits

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Abstract

Motivation: The propensity of plant tissues to burn (i.e. their flammability) is a key trait to understand fire regimes in many ecosystems across the globe. Measuring plant flammability under laboratory conditions allows us to improve both our understanding of plant evolutionary processes and modelling tools for simulating fire hazard and behaviour. Plant flammability has been studied from different but complementary disciplines (e.g. physics, chemistry, ecology, evolution, forestry). However, information is scattered and standardized terminology is lacking, which slows down the progress of research on plant flammability. Here we provide an open access global database on plant flammability traits measured under laboratory conditions aiming to: (a) identify the diversity of methodologies to measure plant flammability under laboratory conditions; (b) standardize the associated terminology; and (c) find geographical, ecological, and taxonomic gaps in our knowledge on plant flammability. We hope this database will stimulate transdisciplinary research and provide useful information to better cope with an increasingly flammable planet.

Main Types of Variables Contained: The FLAMITS database contains 19,972 records of 40 flammability variables (classified according to the measured component of flammability). For each record, relevant details of the flammability experiment are given, such as the burning device, the ignition source, and the burnt plant part. In addition, FLAMITS compiles taxonomic and functional data of the studied species and information on the study site (i.e. locality, geographic coordinates, biome, biogeographic realm, and fire activity).

Spatial Location and Grain: We compiled data from 295 studies in 39 countries and distributed across 12 biomes worldwide.

Time Period and Grain: The last 62.5 years (1961 to 15th May 2023).

Major Taxa and Level of Measurement: 1790 plant taxa from 186 families, 883 genera, and 1784 species.

Software Format: Five text files (.csv), relationally linked.

KEYWORDS
biogeography, burning experiments, combustibility, consumability, fire, ignitability, macroecology, plant traits, sustainability

1 | INTRODUCTION

Fire is a natural disturbance that has shaped the distribution of ecosystems, influenced plant evolution and community assembly, and affected biogeochemical cycles across the globe (Archibald et al., 2018; Pausas & Keeley, 2009). This is because, in the presence of an ignition source, most terrestrial plants can burn under a given range of weather conditions (Pausas et al., 2017). However, some plants are more flammable than others under the same conditions, that is, they burn more readily, promoting fire initiation and spread (Mutch, 1970). This ability to burn in the presence of an ignition source is called flammability; in other words, flammability is how easily fuel burns and spreads the fire (Pausas et al., 2017), with the fuel being a plant organ, a whole plant, or a plant community (Gill & Zylstra, 2005). Wildland fuel flammability is not a single metric and has been traditionally determined through four components that describe (i) how easily a fuel ignites (ignitability), (ii) how intensely it burns (combustibility), (iii) how much it burns (consumability), and (iv) for how long it burns (sustainability) (Anderson, 1970; Gill & Zylstra, 2005; Martin et al., 1993). These components of flammability are not always independent, nor can they be easily framed in a unified ecological and evolutionary context (Pausas et al., 2017; Varner et al., 2015). However, many recent investigations still consider these components in the selection of plant flammability metrics (e.g. Cui et al., 2020), because different flammability components have distinct implications for fire behaviour and ecological responses. Therefore, selecting the most relevant ones for a specific purpose has become a challenge, making the standardization of terminology and methodologies increasingly relevant (Cawson et al., 2023; Varner et al., 2015).

Flammability has been assessed with both field and laboratory experimental tests. Field burning experiments may more realistically simulate the fire behaviour, but performing such experiments is complex and the conditions are difficult to standardize (Pausas & Moreira, 2012; Popović et al., 2021; White & Zipperer, 2010). Flammability tests conducted under laboratory conditions permit accurate, standardized, and repeatable measures for selected species and plant parts. This approach allows identification of the ecophysiological traits that explain variability in plant flammability and their evolutionary drivers. For instance, the combination of different flammability metrics (ignitability, flame spread rate, and heat release) has differentiated alternative flammability strategies in fire prone-ecosystems (i.e. non-flammable, fast-flammable, and hot-flammable species; Pausas et al., 2017). Similarly, plant flammability measurements allow understanding the fire-vegetation feedbacks that underlie mesophication processes or fire-driven biological invasions (Murray et al., 2013; Varner et al., 2021). In addition, laboratory tests permit a better control of the conditions during ignition (e.g. fuel amount and moisture), which are relevant to interpret flammability data. Finally, these flammability tests provide, in a relatively easy way, valuable data for the construction of fuel models that feed many fire risk simulators (Krix et al., 2022; Popović et al., 2021; Weir & Scasta, 2014). In fact, species' flammability rankings based on experimental laboratory approaches have been found to be in line with that obtained from expert opinion, which encourages the use of these methods in fire management planning (Wyse et al., 2016).

Due to the complexity of the flammability concept, a plethora of metrics and methodologies have been developed over time (Gill & Zylstra, 2005; Jaureguiberry et al., 2011; Liodakis et al., 2002; Weise et al., 2005). However, the lack of a standardized terminology hinders progress in plant flammability research. For instance, the term "maximum temperature" has been applied to refer to both the maximum temperature of the burning fuel and the maximum temperature of the flames (Jaureguiberry et al., 2011; Padullés-Cubino et al., 2018), the latter being typically lower than the former (Msweli et al., 2020). Beyond whether it is more relevant to measure fuel or air temperature during burning, it should be noted that these metrics are very sensitive to factors such as the recording device (e.g. infrared camera or thermocouple wires of different materials and diameters), the recording frequency, among others (Bova & Dickinson, 2008; Brundage et al., 2005; Kremens et al., 2010). Therefore, the instrument used (and its configuration) should depend on what it is intended to measure, as it is difficult to capture spatial variability with thermocouple probes, but infrared sensors do not adequately measure the temperature of thin flames (Àgueda et al., 2010). Similarly, the time to ignition could vary depending on the intensity of the ignition source, which in turn changes according to the burning device (e.g. radiative heat in an epiradiator or a flame in a burning bench). Therefore, any attempt to assess global patterns of plant flammability will require a systematization of the existing information. Against this background, we set out to generate an open access global database of plant flammability traits measured under laboratory conditions. With this database, we specifically aimed to: (a) identify the diversity of methodologies to measure plant flammability under laboratory conditions; (b) standardize the terminology associated to plant flammability research; and (c) to find geographical, ecological, and taxonomic gaps in our knowledge on plant flammability taken from laboratory experiments. To our knowledge, this is the first worldwide database on plant flammability traits. We hope that this database will stimulate synergistic research on plant evolutionary ecology and provide useful information for a better mechanistic understanding of plant flammability to better cope with an increasingly flammable planet.

2 | METHODS

2.1 | Data sources and compilation

We compiled the plant flammability traits database FLAMITS by searching peer-reviewed publications, academic theses, technical reports, and books that provided quantitative data (at the specific or intraspecific level) on the flammability of individual organs or tissues of terrestrial plants (or lichens) obtained through experiments conducted under laboratory conditions. For the review, we used the Google Scholar search engine entering the following keyword combinations: “flammab” AND “plant”, “flammab” AND “trait”, “fire behaviour” AND “plant”, “fire behaviour” AND “trait”, “burning” AND “plant” AND “trait”. The search in Google Scholar was repeated using the Spanish translations of the keywords: “inflamab” AND “planta”, “inflamab” AND “rasgo”, “comportamiento del fuego” AND “planta”, “comportamiento del fuego” AND “rasgo”, “quema” AND “planta” AND “rasgo”. We also searched in two academic databases (i.e. Web of Science and SciELO) using the combination of the following keywords: “flammabl*” AND “plant*”, “fire behaviour” AND “plant”, “fire behaviour” AND “trait”, “burning” AND “plant” AND “trait” (also in Spanish: “inflamab*” AND “planta*”, “comportamiento del fuego” AND “planta”, “comportamiento del fuego” AND “rasgo”, “quema” AND “planta” AND “rasgo”). This search returned a total of 992 publications. We had access to most of the articles derived from this search, except for 68 publications. The studies included in FLAMITS had to meet the following criteria: (a) to be laboratory-controlled experiments; (b) to include quantitative data on flammability attributes (e.g. time to flaming, calorific value); (c) to provide the data at specific or intraspecific level (subspecies, or variety), therefore excluding data from interspecific mixtures of fuels; and (d) to provide details of the ignition methodology, including the part of the plant burnt (e.g. whole plant, leaves). A total of 629 publications did not meet these criteria (84% of them, peer reviewed articles), mostly because they did not provide quantitative data on plant flammability (criterion b). Publications that collected data from original research papers already included in FLAMITS were discarded to avoid pseudoreplication. Twenty-two studies were discarded for this reason.

2.2 | Database structure

FLAMITS comprises five tables that are interconnected by unique identifiers (Figure 1; Table 1): “Data”, which includes the main data values and key information for their interpretation; “Taxon”, with the taxonomic and ecological description of the taxa included in the database; “Synonymy”, to relate the taxa names used in the database to the synonymous names used in the data source; “Site”, that includes details on the geographical location and ecological characteristics of the study sites; “Source”, with the references used. Each table is provided as a text file with coma-separated values (.csv).

In the “Data” file, each record consists of one flammability trait data (column: *var_value*) measured on a given taxa (*taxon_name*) obtained in a particular study (*source_ID*), usually for a specific location (*site_ID*) and a specific sampling time (*sampling_time*), with some indicated exceptions (i.e. averaged data from several locations or sampling times). Quantitative data were collected directly from the tables or extracted from graphs using the DataThief software (Tummers, 2006). The names of the flammability traits (and their units) were homogenized based on the description of the measurement, and assigned to one of the four flammability dimensions (*flam_dimension*): ignitability, combustibility, sustainability, and consumability (see Table 1). In addition, we included records of a semi-quantitative variable integrating the abovementioned flammability dimensions, which was classified as “integrated” in the flam_diension column (see Table 1). Relevant information on the flammability experiment was also systematized and included in the database (Table 1): the type of device used for the experimental burning (*burning_device*; e.g. muffle furnace, grill; see descriptions in Table 2),

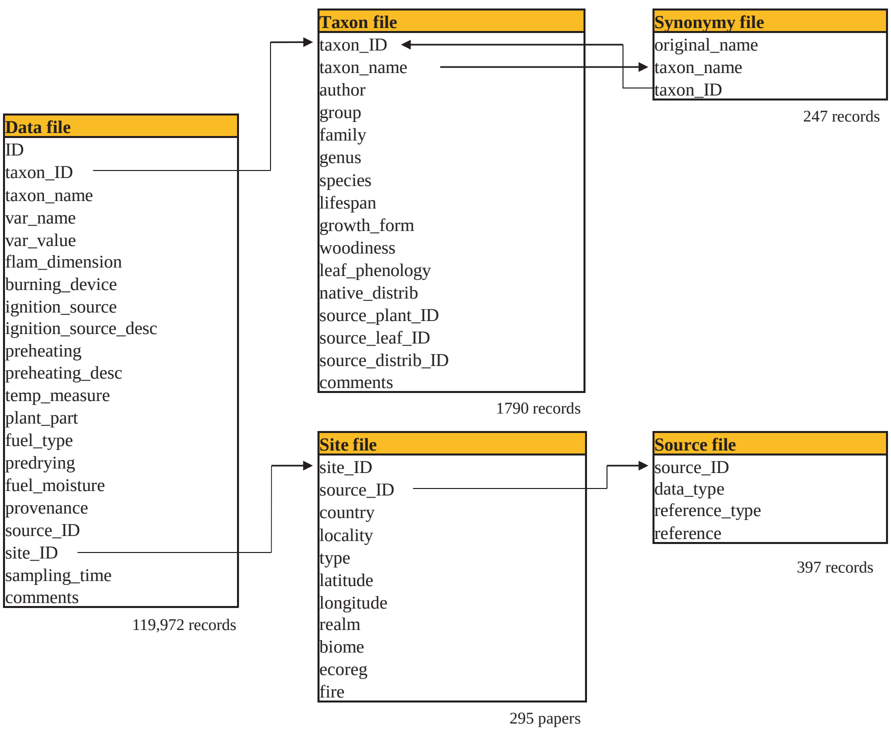

FIGURE 1 Structure of the FLAMITS database. The boxes represent the five files that make up the database and include the column names of each field as well as the number of rows (at the bottom of each box). For all files, the first field is a unique identifier. Black arrows link files.

TABLE 1 Description of the fields (columns) for the five files that compose the FLAMITS database: Data, Taxa, Synonymy, Site, and Source file.

Column name	Description
Data file	
ID	Unique record identifier (numeric)
taxon_ID	Unique taxon identifier used in the "Taxa" file
taxon_name	Taxon name without authority names. Complete names are provided in the "Taxa" file
var_name	Flammability variable name (see definitions in Table 2)
var_value	The numerical value of the flammability variable
flam_dimension	Measured flammability component (see definitions in Table 2): ignitability; combustibility; sustainability; consumability; integrated
burning_device	Type of device used for the flammability test (see definitions in Table 2): burning bench; calorimeter; epiradiator; flat flame burner; ignition temperature tester; grill; infrared burner; muffle furnace; thermal analyser; wind tunnel
ignition_source	Type of ignition source: flame; heater; flame + heater; sparkler
ignition_source_desc	Description of the characteristics of the ignition source. ND = no data available
preheating	Whether or not the samples were preheated before the combustion experiment: no; yes
preheating_desc	Description of the procedures of preheating the sample before the exposure to the ignition source
temp_device	Temperature measurement device: infrared camera; infrared thermometer; thermocolour pyrometer; thermocouple; ND (= no data available); NA (= not applicable)
plant_part	Part of the plant burnt (see definitions in Table 2): bark; branches; cones; outer bark; inner bark; leaves; litter; roots; stems; twigs; whole plant; wood
fuel_type	Type of fuel burnt: all; dead; live; ND (= no data available)
predrying	Whether or not the samples were dried before the combustion experiment: no; yes
fuel_moisture	Fuel moisture (in %) before the flammability test
origin	Type of distribution range of the burnt specimens: non-native; native
source_ID	Unique identifier used in the "Source" file to label the source from which the data were obtained. Complete references are listed in the "Source" file
site_ID	Unique identifier used in the "Site" file to label the study sites. A description of the study sites is provided in the "Site" file
sampling_time	Period, season, or month of sampling. ND = no data available
comments	Relevant comments
Taxa file	
taxon_ID	Unique taxon identifier (numeric)
taxon_name	Currently accept species, subspecies, or variety names in World Flora Online (WFO) or the Taxonomic Name Resolution Service (TNRS)
author	Authority for the taxon name
group	Suprafamily taxonomic group: bryophyte; dicot; gymnosperm; lichen; monocot; pteridophyte
family	APG IV and PPG I family
genus	Genus, that is, the first part of the species binomial name
species	The specific epithet, that is, the second part of the species binomial name
lifespan	The period during which an individual of a species is alive and physiologically active: annual; perennial; variable (see definitions in Table 2)
growth_form	Morphology of the whole plant related to its size (see definitions in Table 2): bambusoid; climber; epiphyte; fern; forb; graminoid; large shrub; lichen; moss; palm-like; shrub; subshrub; tree
woodiness	Presence and distribution of wood in the plant (see definitions in Table 2): fibrous; herbaceous; suffrutex; woody
leaf_phenology	Phenology of leaves (see definitions in Table 2): deciduous; evergreen; semideciduous
native_distrib	Known native distribution of the taxon by state, city, or country
source_plant_ID	Unique identifier used in the "Source" file to label the source from which the lifespan and the growth form were obtained. Complete references are listed in the "Source" file
source_leaf_ID	Unique identifier used in the "Source" file to label the source from which the leaf phenology was obtained. Complete references are listed in the "Source" file

TABLE 1 (Continued)

Column name	Description
source_distrib_ID	Unique identifier used in the "Source" file to label the source from which the native range of the species was obtained. Complete references are listed in the "Source" file
comments	Relevant comments
Synonymy file	
original_name	Name given to the taxon in the data source
taxon_name	Currently accept species, subspecies, or variety names in World Flora Online (WFO) or the Taxonomic Name Resolution Service (TNRS)[a]
taxon_ID	Unique taxon identifier used in the "Taxa" file
Sites file	
site_ID	Unique identifier for the study sites (alphanumeric)
source_ID	Unique identifier used in the "Source" file to label the data source. Complete references are listed in the "Source" file
country	Country where the study was conducted
locality	Location of the study site. ND = no data available
type	Whether the location corresponds to the sampling site or to the site where the burning experiment was carried out: sampling; burning
latitude	Latitude (in decimal degrees) of the study site
longitude	Longitude (in decimal degrees) of the study site
realm	Code for the corresponding biogeographical realm where the study area was located (cf. Olson et al., 2001) (see definitions in Table 2)
biome	Code for the corresponding terrestrial biome where the study area was located (cf. Olson et al., 2001) (see definitions in Table 2)
ecoreg	Code for the corresponding terrestrial ecoregion where the study area was located (cf. Olson et al., 2001) (see definitions in Table 2)
fire	A dimensionless measurement of the average fire activity of the ecoregion of the study site (cf. Pausas & Ribeiro, 2013)
Source file	
source_ID	Unique identifier for the data source (alphanumeric)
data_type	Data type obtained from the source: flammability; complementary (e.g. life form, leaf phenology, species distribution)
reference_type	Reference type: book; book section; conference paper; peer-reviewed article; preprint; technical report; thesis; web page
reference	Full reference

[a]Except two species: *Phebalium sylvaticum* and *Populus × tomentiglandulosa*.

the ignition source (*ignition_source*; e.g. flame, heater), the preheating method (i.e. treatment prior to exposure to the ignition source; *preheating*), the device used for measuring the temperature (*temp_device*), and the part of the organism burnt (*plant_part*). When available, FLAMITS also includes whether the fuel was alive or dead (*fuel_type*), whether the sample was pre-dried before the burning experiment or not (*predrying*), as well as the moisture content of the fuel (*fuel_moisture*) and the sampling period (*sampling_time*; Table 1). In addition, it was indicated whether the specimens studied were taken from the native or from the non-native distribution range of the species (*origin*) according to the information of the study site and corroborated with global databases (i.e. Plants of the World Online). Finally, each record was linked to a unique identifier for the study site (*site_ID*) and another for the reference of the data source (*source_ID*).

Taxon names were first checked for misspellings and then we searched for synonymous names using the World Flora Online (WFO, 2022) and the Taxonomic Name Resolution Service (TNRS; Boyle et al., 2013). Notice that in some cases, the taxa were only determined at the genus level. The "Synonymous" file includes the accepted name and the name used in the corresponding reference. The "Taxon" file also includes the accepted taxa name and the taxonomic family following the APG IV and PPG I systems (APG IV et al., 2016; PPG I et al., 2016). In addition, we classified species according to the family group (monocot, dicot, gymnosperm, pteridophyte, bryophyte) following the criteria of Kew Royal Botanic Gardens (KEW, 2022). Information on the life-history traits of each taxon, particularly lifespan, growth form, and leaf phenology, was consulted using databases such as Encyclopedia of Life (EOL, 2018), Plants of the World Online (POWO, 2019), World Species Website (WSW, 2022), and Wikipedia (2022), among others. The woodiness was classified following Pausas et al. (2018) and Kattge et al. (2020). The categories used for lifespan, growth form, leaf phenology, and woodiness are defined in Table 2.

TABLE 2 Definitions for the categorical fields of the following FLAMITS files: Data (*var_name*, *flam_dimension*, *burning_device*), Taxon (*growth_form*), and Site (*biome*, *realm*). The flammability variables (*var_name*) were assigned to one of the five flammability dimensions (*flam_dimension*): ignitability, combustibility, sustainability, consumability, and integrated (see main text for details).

DATA FILE	
Flammability variable (var_name; for flam_dimension = Ignitability)	
Categories	**Description**
Ignition frequency (%)	Percentage of samples that ignited during the experimental burning. A sample is considered to be ignited when a flame appears after being exposed to an ignition source during a limited period of time (e.g., 10 s in Jaureguiberry et al., 2011 or 60 s in Americo et al., 2021) and if the sample sustains the flame after the ignition source has been removed (Valette, 1990)
Flammability value	Index defined as a function of the ignition frequency and the mean ignition time score. A flammability of this type is declared low when the scores are 0 and 1, medium for scores 2 and 3, and high for scores 4 and 5 (Valette, 1990)
Temperature at flaming (°C)	Temperature of the sample (or of the surrounding air) at the beginning of the flame phase (i.e., when the flames appear and are maintained; Saura-Mas et al., 2010)
Temperature at smoke (°C)	Temperature of the sample (or of the surrounding air) at the beginning of the smoke phase (i.e., when the smoke appears; Saura-Mas et al., 2010)
Temperature at smouldering (°C)	Temperature of the sample (or of the surrounding air) at the beginning of the smouldering phase (i.e., when glowing occurs; Saura-Mas et al., 2010)
Time to flaming (s)	Time to the beginning of the flaming phase (i.e., when the flames appear and are maintained; Saura-Mas et al., 2010). Time measurements start when the sample is exposed to an ignition source (Cui et al., 2020; Krix et al., 2019) or when the sample reaches a given temperature (e.g., 60°C; Saura-Mas et al., 2010)
Time to maximum heat release rate (s)	Time elapsed since the beginning of the flaming phase up until the maximum heat release rate is reached (Dupuy et al., 2003)
Time to maximum smoke density (s)	Time elapsed since the exposure to the ignition source up until the maximum smoke density is reached (King, 1975)
Time to smoke (s)	Time to the beginning of the smoke phase (i.e., when the smoke appears; Saura-Mas et al., 2010). Time measurements start when the sample is exposed to an ignition source (Krix et al., 2019) or when the sample reaches a given temperature (e.g., 60°C; Saura-Mas et al., 2010)
Time to smouldering (s)	Time to the beginning of the smouldering phase (i.e., when the glowing occurs; Saura-Mas et al., 2010). Time measurements start when the sample is exposed to an ignition source (Krix et al., 2019) or when the sample reaches a given temperature (e.g., 60°C; Saura-Mas et al., 2010)
Flammability variable (var_name; for flam_dimension = Combustibility)	
Categories	**Description**
Calorific value (kcal/kg)	The amount of energy released per unit of fuel biomass burnt (Shaha, 2018)
Energy flux (kW/m²)	The rate of energy release during combustion per surface area unit (see "heat release rate" definition for details; NIST, 2022)
Energy release rate (kW)	The rate of energy release during combustion. The value usually corresponded to the average heat release rate over the experimental burning (Belcher, 2016)
Flame height (cm)	Maximum flame height, estimated visually to the nearest centimeter (Santos et al., 2018)
Flame intensity (kW/m)	Maximum heat release rate per meter of fire front (Liodakis et al., 2011)
Flame propagation	Number of opposite directions in which flames spread from the center of the sample (0 to 4; Ganteaume, 2018)
Heat released per mass (°C s/g)	Energy released as heat during the flame occurrence, estimated as the area under the temperature-time curve throughout the flaming duration divided by the fresh fuel biomass (Blackhall & Raffaele, 2019)
Mass loss rate (g/s)	Burnt biomass divided by the flaming duration (i.e., since the ignition to the flame extinction; Simpson et al., 2016)
Mass loss rate per area (g/m² s)	Mass loss rate per area unit of the fuel sample (see "mass loss rate" definition for details; Ramadhan et al., 2019)
Maximum energy flux (kW/m²)	Maximum rate of energy release during combustion per surface area unit (White et al., 1996)
Maximum energy release rate (kW)	Maximum energy release rate obtained during the experimental burning (see "energy release rate" definition for details; Madrigal et al., 2011)

TABLE 2 (Continued)

Flammability variable (var_name; for flam_dimension = Combustibility)	
Categories	**Description**
Maximum flame temperature (°C)	Highest temperature measured in the flame during the sample burning (Cornwell et al., 2015)
Maximum sample temperature (°C)	Highest temperature measured in the sample during burning (Burger & Bond, 2015)
Percentage rate of mass loss (%/s)	Burnt biomass percentage divided by flaming duration (from ignition to flame extinction; de Freitas Rocha & Landesmann, 2016)
Smoke release rate (m^2/s)	Volumetric smoke flow rate through the duct of a cone calorimeter (Dowbysz & Samsonowicz, 2021)
Smoke specific extinction area (m^2/kg)	Instantaneous amount of smoke produced per mass unit of burnt sample in a cone calorimeter (Babrauskas, 2016)
Temperature increase rate (°C/s)	Maximum rate of temperature increase during flaming combustion (Page et al., 2012)

Flammability variable (var_name; for flam_dimension = Sustainability)	
Categories	**Description**
Burning duration (s)	Amount of time that the combustion is sustained; can be restricted to the flaming duration or it can also include the smouldering phase (Pausas et al., 2017)
Flaming duration (s)	Time elapsed from the appearance of the first visible flame until no more flames were seen (Grootemaat et al., 2015)
Flaming duration per mass (s/g)	Flaming duration standardized by the dry, pre-burning fuel mass (Grootemaat et al., 2017)
Frequency of sustained flaming (%)	Percentage of samples that maintained flames for (at least) a given time (e.g., 10 s in Weir & Scasta, 2014) or that propagated fire over (at least) a given distance (of 125 mm in Santana & Marrs, 2014)
Rate of burning spread (cm/s)	It expresses the speed of burning (by smouldering or flaming). It can be calculated by dividing the length of the sample that was burnt by the burning time (Jaureguiberry et al., 2011) or the time interval between the flaming front passage at two points of the sample (Pausas et al., 2017)
Smoke duration (s)	Amount of time over which smoke is emitted (Krix et al., 2019)
Smouldering duration (s)	Amount of time during which glowing occurs, usually measured as the time from the end of the last visible flame until the glowing phase died out (Grootemaat et al., 2015) or by subtracting flaming duration from the total burning duration (Gabrielson et al., 2012)
Smouldering duration per mass (s/g)	Smouldering duration standardized by the dry, pre-burning fuel mass (Grootemaat et al., 2017)

Flammability variable (var_name; for flam_dimension = Consumability)	
Categories	**Description**
Burnt biomass (%)	Post-burning sample weight related to its weight before the experimental burning (Liodakis & Antonopoulos, 2006). Note that the initial change in weight of a burnt sample corresponds to the evaporation of water and other gases
Estimated burnt biomass (%)	Visually estimated percentage of the fuel biomass or volume consumed by the fire (Burger & Bond, 2015)
Total heat release (MJ/m^2)	Total heat produced by the burning fuel over the entire period of the experiment calculated by integrating the heat release rate curve *vs.* the time (Madrigal et al., 2009)
Total smoke release (m^2/m^2)	Smoke production in a cone calorimeter standardized by the burnt specimen's area unit (Östman et al., 1992)

Flammability variable (var_name; for flam_dimension = Integrated)	
Categories	**Description**
Flammability index	Compound value of flammability obtained by adding standardized scores of the maximum sample temperature, the rate of burning spread, and the burnt biomass. It has a minimum possible value of 0 (no flammability) and a maximum value that would rarely exceed 3 (maximum flammability) (Jaureguiberry et al., 2011)

(Continues)

TABLE 2 (Continued)

Burning device (burning_device)	
Categories	**Description**
Burning bench	Device to perform flammability assays under laboratory conditions, where the samples are located on a surface or container (frequently a steel mesh) and exposed to a flame (e.g., from a lit, alcohol-soaked cotton, a Bunsen burner, etc.). Fireproof rings are included here (Cornwell et al., 2015)
Calorimeter	Device for the measurement of the heat produced by a chemical reaction or a physical change, as well as its heat capacity. Types of calorimeters included are: bomb calorimeter, scanning calorimeter, microcalorimeter, mass loss calorimeter, and cone calorimeter (Toppr, 2022). The type of calorimeter used is specified in the "Comments" field
Epiradiator	Device consisting of an electrical heating resistor (typically powered by 500 W) placed inside an opaque and impermeable silica case. The resistor is fixed to a refractory surface at the top of the case (i.e., the heating plate). The fuel is placed lying on the heating plate or at a certain distance above it to test the flammability initiated by (respectively) heat conduction or radiative heat, boosted (Valette, 1997) or not (Pausas et al., 2012) by a pilot flame
Flat flame burner	Device with a movable platform where a radiating heating panel simulates the radiative heating ahead of the flame front in a wildfire and a flat blame burner provides the heat transfer by convection (Engstrom et al., 2004)
Grill	Propane–butane gas barbecue for flammability measurements of large plant samples up to 70 cm in length: the sample is exposed to a blowtorch (10 s) after preheating at 150°C for 2 min (Jaureguiberry et al., 2011)
Ignition temperature tester	A device equipped with a hot plate with a non-corrosive abrasion resistant surface (usually an aluminum plate) on which a layer of solid particles or powder of a specified thickness is deposited. It allows measurement of the minimum temperature of the hot plate that will result in combustion of the sample (i.e., resulting in a flame or incandescence; NRC, 1979)
Infrared burner	A device that focuses a flame of a standard gas burner onto a ceramic tile with thousands of microscopic holes; this converts the heat of the flame into infrared energy (Dove, 2011)
Muffle furnace	Furnace built with refractory materials that can reach temperatures above 350°C (Gilbson, 2022)
Radiant panel	A device in which the sample (placed on a metal plate) is exposed to the heat flux emitted by a radiant panel and uses a pilot flame as ignition source (Overholt et al., 2014)
Thermal analyzer	A device to study the properties of materials as they change with temperature using a set of techniques collectively known as thermal analysis. Thermal gravimetric analysis (TGA) is one of those techniques frequently used to assess fuel flammability (Espectrometria, 2020)
Outdoor wind tunnel	Device consisting of a fan and a tunnel several metres long placed in the ground, which is covered with sand. The fuel is placed on the sand and ignited from one end of the tunnel. The fan (controlled by an electronic system) is used to create an airflow that simulates the action of the wind inside the tunnel (cf. Madrigal et al., 2011)
Scale wind tunnel	Device designed according to the Forced Ignition and Flame Spread Test (FIST), where samples are heated from above by a radiant panel. The pyrolyzates produced by the heated sample are carried to a Kanthal wire ignitor by a fixed airflow. Ignition occurs, when sufficient pyrolyzates are accumulated (Jolly et al., 2012)
TAXON FILE	
Growth form (growth_form)	
Categories	**Description**
Bambusoid	Perennial plant with fibrous stems arising from belowground, clonal structures (usually rhizomes). The stems lack or have only weak secondary growth, but their rapid vertical growth sometimes forms tree-sized canopies (Pérez-Harguindeguy et al., 2013)
Climber	Plant that roots in the soil but relies, at least initially, on external support for its upward growth and leaf positioning (Pérez-Harguindeguy et al., 2013)
Epiphyte	Plant that grows attached to the trunk or branch of a shrub or tree (or to anthropogenic supports) by aerial roots, usually without contact to the ground (Pérez-Harguindeguy et al., 2013)
Forb	Broad-leaved herbaceous plant (Tavşanoğlu & Pausas, 2018). Herbaceous ferns, mosses, and lichens are included here
Graminoid	Herbaceous plant with a grass-like morphology (Tavşanoğlu & Pausas, 2018)

TABLE 2 (Continued)

TAXON FILE	
Growth form (growth_form)	
Categories	**Description**
Large shrub	Tall, woody plant that, under optimal conditions, may reach an arborescence structure (Tavşanoğlu & Pausas, 2018). It includes large shrubs or small trees
Palmoid	Plant of variable size with a rosette-shaped canopy of typically large (often compound) leaves atop a thick, columnar, unbranched (or small-branched) stem of fibrous consistency (Pérez-Harguindeguy et al., 2013)
Shrub	Dwarf woody plant (typically <50 cm), including suffruticose (suffrutescent) plants (Tavşanoğlu & Pausas, 2018). Includes most chameaphytes
Subshrub	Plant with usually multiple, ascending, woody stems less than 0.5 m tall (Pérez-Harguindeguy et al., 2013)
Tree	Very tall woody plant, frequently with one main, primary stem and a green canopy rarely touching the ground (Tavşanoğlu & Pausas, 2018)

SITE FILE	
Terrestrial biomes[a] (biome)	
Categories	**Description**
1	Tropical and subtropical moist, broadleaf forests (tropical and subtropical, humid)
2	Tropical and subtropical dry, broadleaf forests (tropical and subtropical, semihumid)
3	Tropical and subtropical coniferous forests (tropical and subtropical, semihumid)
4	Temperate broadleaf and mixed forests (temperate, humid)
5	Temperate coniferous forests (temperate, humid to semihumid)
6	Boreal forests/taiga (subarctic, humid)
7	Tropical and subtropical grasslands, savannas, and shrublands (tropical and subtropical, semiarid)
8	Temperate grasslands, savannas, and shrublands (temperate, semiarid)
9	Flooded grasslands and savannas (temperate to tropical, fresh or brackish water inundated)
10	Montane grasslands and shrublands (alpine or montane climate).
11	Tundra (arctic climate)
12	Mediterranean forests, woodlands, and scrub or sclerophyll forests (temperate warm, semihumid to semiarid with winter rainfall)
13	Deserts and xeric shrublands (temperate to tropical, arid)
14	Mangrove (subtropical and tropical, salt water inundated)
Biogeographic realms[a] (realm)	
Categories	**Description**
NA	Neartic
PA	Paleartic
AT	Afrotropic
IM	Indomalay
AA	Australasia
NT	Neotropic
OC	Oceania
AN	Antarctic

[a]cf. Olson et al. (2001).

The geographical description of each sampling site was compiled in the "Site" file, including latitude, longitude, country, and locality. Coordinates were either collected directly from the source or estimated from the sampling site. When the source did not provide detailed information on the sampling site (such as location or coordinates), the location (and the associated geographic data) where the burning experiment took place was included instead. The column named *type* was used to report whether the location corresponded to the sampling or the burning site. Using the coordinates, we specified the corresponding ecoregion (cf. Olson et al., 2001) and the fire activity of the location (cf. Pausas & Ribeiro, 2013).

2.3 | Technical validation

In all records, the original reference is indicated, so that users can verify the accuracy of the data themselves. In addition, the type of data source is specified, with peer-reviewed articles being the main data source (85%). All data sources have their own data validation mechanism, except for technical reports and the three preprints included (which together account for 1% of the data sources). In all cases, each data source was carefully checked for the quality of its data and its fit to the corresponding fields of the FLAMITS database. Lastly, for quantitative data, extreme values were identified using histograms of the frequency distribution; the original source of these extreme values was revised and eliminated if likely to be erroneous.

3 | DESCRIPTION OF THE DATA

We identified 295 eligible data sources published between 1961 and May 15th, 2023. Altogether, the FLAMITS database includes 19,972 records for 1790 taxa belonging to 1784 species, 883 genera, and 186 families. Most of the data corresponds to perennial plants (99% of the taxa), mainly woody species (88%) and especially trees (61%). Forty different flammability variables were registered. Records of time to flaming (4140 records), calorific value (2048 records), burning duration (1623 records), flaming duration (1471 records), and maximum flame temperature (°C) (923 records) are the most represented flammability variables, accounting for 51% of the records in the database. Accordingly, variables related to combustibility (36%) and ignitability (35%) are the most represented variables.

Several methodologies have been used to study plant flammability under laboratory conditions. We identified 12 types of devices, of which the use depends on the part of the plant assessed (see Appendix S1 in Supporting Information). The first experiments were performed with small plant parts such as leaves (43%) and twigs (15%), using instruments such as calorimeters (26%), epiradiators (20%), and burning benches (17%). In 2011, a shoot flammability device was developed (henceforth the grill), in which typically 70 cm long branches are burnt (Jaureguiberry et al., 2011). This new approach, which accounts for 15% of FLAMITS' records, allowed for more realistic values of plant flammability (Wyse et al., 2016), because it takes into account (at least partially) the effect that plant architecture has on fuel connectivity as well as the airflow through the fuel, both of which significantly influence flammability (Schwilk, 2003).

The FLAMITS records are distributed across 129 ecoregions. The best-represented ecoregions were those with intermediate to high fire activity (Figure 2), corresponding to Mediterranean forests, woodlands, and shrublands forest of the Palearctic (22% of the records) and temperate broadleaf and mixed forests of Australasia (13%). In general, seasonal tropical ecosystems were underrepresented, despite being globally the most fire-prone ecosystems (Pausas & Ribeiro, 2013). Information from the taiga is absent, even though wildfires largely contribute to the dynamics of boreal forests, in both the Palearctic and the Nearctic (Archibald et al., 2018). Most species were assessed exclusively within their native distribution range (73.9%), whereas 349 species (19.5%) were studied only in their non-native distribution range, and 118 species (6.6%) were studied in both their native and non-native distribution ranges.

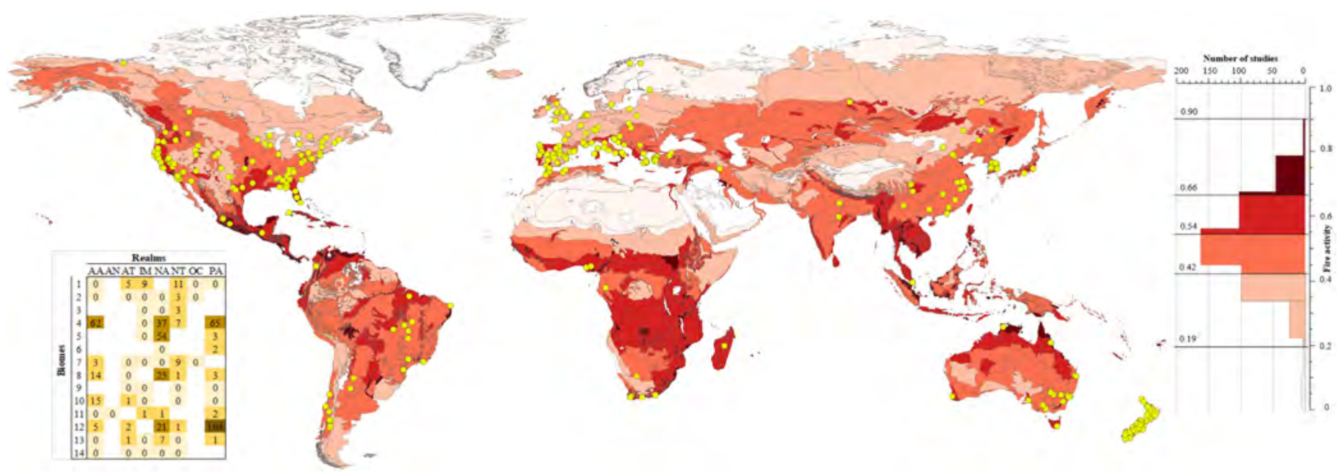

FIGURE 2 Geographical distribution of the study sites compiled in FLAMITS. Yellow circles indicate the locations of the study sites. The intensity of the red colours is related to the fire activity index of the ecoregions (cf. Pausas & Ribeiro, 2013). The inset on the right shows the frequency distribution of fire activity of the FLAMITS' study sites estimated from the fire activity of the corresponding ecoregions. The fire activity classes were defined via the Jenks natural break optimization method to minimize value differences among data within the same class, and to emphasize the differences among the classes (McMaster & McMaster, 2002). The heat map (left) indicates the number of study sites per biome and biogeographical realm (cf. Olson et al., 2001). The darker the colour, the greater the number of study sites. White cells in the heat map indicate that such a combination of realm and biome does not exist in any ecoregion. For more details and abbreviations, see Table 2.

4 | CONCLUDING REMARKS

Flammability is a complex characteristic of plants that have drawn attention to both evolutionary biologists and land managers. The former were interested in the evolution of a character that may seems lethal for the plant, yet it may increase their fitness (Bond & Midgley, 1995; Pausas et al., 2017). However, most research on flammability has been focused on ways to for reducing fire hazard. Thus, much of the research on plant flammability has been conducted in highly human-populated areas, such as the Mediterranean basin, and is scarce in highly flammable but low human-populated regions, such as seasonal tropical ecosystems and boreal forests. Little is also known about the flammability of species outside their native range, which hampers our understanding of how biological invasions altered fire-vegetation feedbacks in various regions of the world (Brooks et al., 2004).

The plethora of metrics used to measure plant flammability highlights the complexity of this phenomenon. Moreover, flammability is measured differently depending on the type of fuel used, making it difficult to scale flammability from small tissues and organs to large branches or whole plants (Alam et al., 2020); even harder is to scale plant flammability at the community scale (the scale at which fire spreads). In any case, variables related to combustibility and ignitability are the most represented in FLAMITS, probably due to their applicability in fuel reduction planning (Hogenbirk & Sarrazin-Delay, 1995) or for predicting fire behaviour and its impacts on vegetation (Cardoso et al., 2018). Advancing the understanding of plant flammability through transdisciplinary research would help to generate standardized data, easily applicable for the management of the Anthropocene fire regimes.

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CONFLICT OF INTEREST STATEMENT

None of the co-authors has a conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The five text files composing the database are openly available in DRYAD at https://doi.org/10.5061/dryad.h18931zr3.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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