Comparative Shoot Flammability of Tree Species in the Barrington Tops Region

Molly Irene Wallace

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Master of Science (Research)

Under the supervision of Associate Professor Brad Murray, Dr Megan Murray, and Dr Dan Krix

University of Technology Sydney Faculty of Science, School of Life Sciences

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Molly Irene Wallace declare that this thesis, is submitted in fulfilment of the requirements for the award of Master of Science, in the Faculty of Science, School of Life Science at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

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Statement of thesis format

This thesis is submitted as a conventional thesis. Chapter 1 provides an introduction to wildfires, the Barrington Tops region, plant flammability, and my research questions. Chapter 2 details the various methods used in my research. Chapter 3 provides my results. Chapter 4 provides a synthesis of my research, highlights the contribution my research has on flammability, and provides details on future directs on the topic.

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Abstract

Although wildfires are natural ecosystem events, particularly in Australia, climate-change research is predicting increases in the severity and length of fire seasons, resulting in more intense and frequent wildfire events worldwide. These wildfires have the potential to greatly impact human life, infrastructure, and biodiversity. As such, it is important to further our understanding of plant flammability in an ecological context to make informed decisions and predictions that can assist fire management and modelling. Based on recent evidence that measurements of shoot-level flammability provide robust assessments of whole-plant flammability, a growing number of studies have been investigating flammability at the shoot level, and this thesis contributes new knowledge to this field of endeavour.

I employed a bespoke shoot flammability apparatus to assess shoot flammability patterns in 38 tree species of wet habitats in the Barrington Tops region of New South Wales, Australia. To better understand inter-species variation in shoot flammability, I also explored how this variation is influenced by various plant functional traits, including the leaf-scale and shoot-scale traits of leaf area, leaf mass per area, leaf number (i.e. leafing intensity), leaf energy content, shoot mass, shoot bulk density, shoot water content, and the number of branches on a shoot. I measured ignitability (time-to-flame, TTF), sustainability (flame duration, FD), combustibility (flame height, FH; maximum flame temperature, FT) and consumability (burnt biomass, BB) in shoots of each of these species, and examined pairwise relationships between the flammability attributes.

I found significant variation across all flammability attributes among the species tested in this study. There were significant positive pairwise correlations between FD, FH, FT, and BB. Indicating, species which burned for shorter periods, with shorter flames at lower flame temperatures also did not consume much of their shoots in the fire. These correlations demonstrated alignment of these four flammability attributes in a way that matches the expectations of an 'ideal' low-flammability species. Conversely, however, TTF was negatively correlated with all other flammability attributes, such that low-flammability species in the dimension of ignitibility (i.e. slow TTF) were actually high-flammability species in the other dimensions (i.e. long FD, tall FH, high FT, large BB). Leaf energy content was a primary predictor of flammability across the attributes of FD, FH, FT, and BB, with increasing energy content associated with an increase across each of these attributes. An elevated number of leaves in the shoot resulted in faster TTF and longer FD. Larger shoot mass led to an Increase in FD, while higher bulk density and lower shoot water content resulted in higher FT. Additionally, I found that Myrtaceous species exhibited significantly higher flammability in the dimensions of FD, FH, BB.

This thesis seeks to understand the flammability of widely available wet habitat plant species of the Barington Tops region at the shoot level, as well as the traits that drive this flammability. My study is the first to detail the flammability of wet habitat plants from Barrington and will help enhance our knowledge of how plants burn in these typically non-fire prone habitats. This research in turn will help to advise and develop effective fire management strategies, predict fire behaviour, and conserve ecosystems, particularly in landscapes that due to climate change are likely to become more fire prone.

Chapter 1 | Introduction

1.1 Wildfires and the Australian context

Wildfires are large, uncontrolled and destructive fires that spread rapidly through wildland vegetation (McKenzie et al. 2004; Pausas et al. 2008). While wildfires are important ecological and evolutionary drivers of ecosystem structure and function (Stevens-Rumann & Morgan 2016; Pausas & Keeley 2019; Santos et al. 2023), recent changes in fire regimes and climatic conditions have resulted in rapid increases in the frequency of intense wildfires across the world (Westerling & Bryant 2008; Krawchuk et al. 2009; Vardoulakis et al. 2020; Cardil et al. 2021; van Oldenborgh et al. 2021). Such changes bring with them heightened risks to human lives, homes, infrastructure, and agriculture, and can ultimately lead to ecological consequences including reductions in native biodiversity and deleterious alterations to ecosystem function (Holmes et al. 2008; Westerling & Bryant 2008; Berry et al. 2011; Durán-Medraño et al. 2017; Kramer et al. 2018; Caggiano 2020; Vardoulakis et al. 2020; Feng et al. 2021; van Oldenborgh et al. 2021). Although climate change does not directly create wildfires, it has had and will continue to have a profound influence on wildfire severity and likelihood of occurrence into the future (Running 2006; Jones et al. 2020; Pausas et al. 2021; Baker 2022; Mansoor et al. 2022). Indeed, increasingly warmer weather linked to climate change has seen an expansion in the number of days each year experiencing either high or extreme bushfire risk (Hurteau et al. 2014).

Wildfires have been an intrinsic part of the Australian landscape for hundreds of thousands of years, and shaped the nature of the current landscape (Gott 2005; Pascoe 2018). Much of Australia's historic fire occurrences were purposefully and skillfully implemented by the traditional owners of the land, with burning occurring in mosaic-like patterns that influenced plant growth and reduced ground-level plant material available during fire events (Singh et al. 1981). Supporting evidence of this comes from tree-core analysis, which has shown for example that wildfires in wet sclerophyll mountain forests were largely unknown before the arrival of Europeans (Pascoe 2018). Over the last 20 years or so, wildfires in Australia have been unparalleled in their frequency and intensity. For instance, the Victorian wildfires in February 2009 led to the loss of 173 lives, 2000 homes, and 450,000 ha of eucalypt forest (Haynes et al. 2010; Cary et al. 2012). Recently in the 2019–2020 wildfires, widespread fires resulted in four deaths, the loss of 500 homes, and the burning of over 1,000,000 ha of land (Nolan et al. 2020). In addition, wildfires pose significant threats to habitats and biodiversity, with destructive landscape effects and loss of species (Louise et al. 2011; Haque et al 2021). Large-scale wildfires create uniform burned patches, which can lead to reductions in species diversity within affected areas. To mitigate such risks, land managers employ prescribed burning, aiming to limit wildfires and enhance biodiversity. Small-scale prescribed burns, creating diverse habitats, can increase species diversity within patches and decrease turnover across them. However, fire impacts differ across taxonomic groups, hindering a universal approach (Louise et al. 2011; Calhoun et al. 2022).

1.2 Wildfires and plant flammability

Unprecedented wildfire events are predicted to become increasingly common throughout all areas of Australia in the future due to a long-term increase in extreme fire weather and the length of fire seasons (Collins et al. 2021; Shi et al. 2021). Such wildfires are complex events influenced by three major factors, including weather (e.g. temperature and rainfall), topography (e.g. position in the landscape such as ridge tops vs gullies) and fuel (e.g. vegetation type, fuel load and availability) (Fares et al. 2017; Sanderson and Fisher 2020; Filippi 2021; Van Oldenborgh et al. 2021; Twidwell et al. 2022). Complex modelling is used to examine wildfire behavior but for the most part without explicit consideration of how plant species vary in their relative flammability (Peacock et al. 1998; Lopes et al. 2002; but see Zylstra et al. 2016 for an important exception). Yet, species do vary in their flammable properties (Wyse et al. 2016; Murray et al. 2018; Cui et al. 2020), which suggests that the species' make-up of vegetation assemblages may have an important role in determining wildfire dynamics across the landscape. However, the limiting factor here is that there are few studies involving large numbers of species that can be used effectively to inform wildfire modelling in the context of capturing inter-species differences in flammable properties.

While work to understand plant species flammability has a long history (see Anderson 1970), it is only in recent times that we have begun to see growth in this research area. Indeed, published knowledge of patterns of variation in leaf flammability among plant species is steadily increasing (Massari and Leopaldi 1998; Alessio et al. 2008; Murray et al. 2013; Powell et al. 2017; Krix and Murray 2018; Krix et al. 2019; Alam et al. 2020a). Comparatively fewer studies, however, have examined inter-species patterns in shoot flammability (Wyse et al. 2016; Alam et al. 2020). Shoot-level sections of plants incorporate not only leaves but also the branching architecture of species. This branching is regarded as being important in the determination of flammability at the whole plant level of a species, along with canopy and crown fires in the field (Fernandes and Cruz 2012). Importantly, research has shown that assessments of shoot flammability can provide a robust representation of whole-plant flammability (Wyse et al. 2016), more so in fact than assessments of leaf flammability (Alam et al. 2020a). Producing data on flammability at a shoot level is imperative for future fire management, as canopy and crown fire occurrences are becoming increasingly frequent worldwide (Mitsopoulos and Dimitrakopoulos 2007; Storey et al. 2016). At present, there has been little research on shoot flammability patterns among Australian plant species (see Potts et al. 2022; Murray et al. 2023), despite Australia's long and continued history of wildfires.

Among the many factors influencing wildfire behavior within plant communities, the flammability of plant species present in a particular environment plays a vital role. These flammability properties include how quickly a plant ignites (ignitibility), how long a plant burns (sustainability), the intensity with which the plant burns (combustibility), and how much of the plant is burnt (consumability). Recent research has shown that different plant species exhibit considerable variation in their flammability (Wyse et al. 2016; Krix et al. 2019; Tumino et al. 2019; Kane et al. 2022). Understanding inter-species patterns of this flammability variation, and the underlying drivers, is crucial for developing accurate models of wildfire severity and spread, as well as for guiding future wildfire management strategies (Curran et al. 2018; Murray et al. 2020; Krix and Murray 2022).

1.3 Relationships between shoot flammability and plant traits

The flammability of plant species can be described by a diverse array of chemical, morphological and physiological plant functional traits. While there is compelling evidence linking leaf traits to wildfire behavior, these assessments often overlook the influence of plant architecture (Wyse et al. 2016; Potts et al. 2022). Research has demonstrated that plant architecture significantly impacts canopy-level fire intensity (Schwilk 2003; Fernandes and Cruz 2012). Therefore, it is crucial to incorporate considerations of plant architecture and other shoot-scale traits when studying the flammability of species at a broader level (Calitz et al. 2015; Santacruz- García et al. 2019; Kraaij et al. 2022). Ultimately, it is important to determine relationships between shoot flammability and and plant functional traits, as the ability to use traits which can be measured relatively easily as reliable indicators of flammability could make it easier to distinguish low-flammability from high-flammability species. This would allow ecologists to produce larger datasets of low-flammability and high-flammability species spanning a broad range of geographic regions for use in managing wildfires.

At a shoot level, numerous plant traits have been found to correlate with plant flammability (Burger and Bond 2015; Alam et al. 2020a; Cui et al. 2020a; Zanzarini et al. 2022). The sustainability of a species has a strong positive correlation to the availability of fuel, number of leaves and branches a species has (Dimitrakopoulos and Papaioannou 2001; Wyse et al. 2016). These findings suggest that the more fuel available for combustion the longer it will burn. The consumability of a plant is found to be influenced by the size of leaves, small leaves tend to have a lower surface area exposed to potential fire, reducing their flammability. Conversely, large leaves can act as fuel and increase flammability (Calitz et al. 2015; Tumino et al. 2019; Alam et al. 2020a). In 2015, a study by Calitz et al. compared various traits like leaf size, leaf texture, leaf density, and the number of twigs per unit volume to shoot flammability. They discovered that shoots with small leaves and higher number of twigs tended to exhibit greater flammability, however, there were other unmeasured traits that were more effect predictors of flammability. As Leaves are typically the initial part of plants to catch fire, leaf traits are anticipated to play a significant role in determining plant flammability (Murray et al., 2013; Alam et al. 2020a). Leaf traits can mirror the overall shoot structure and chemical composition of a plant, where a slender, extensively branched shoot often bears numerous small leaves with higher volatile components, while robust shoots tend to support fewer, larger leaves of higher water content (Westoby & Wright, 2003; Alam et al. 2020a). Leaf traits have a notable influence on the burning behaviour of plants at a shoot level and uncovering this relationship will help facilitate the understanding of fire behaviour across diverse ecosystems (Schwilk 2015; Archibald et al. 2018; Alam et al. 2020).

1.4 Research aims and thesis outline

In this thesis, I aim to better understand shoot flammability patterns in common tree species native to wet forests in the Barrington Tops region of New South Wales, Australia. This region of eastern Australia provides a highly appropriate opportunity to examine shoot flammability patterns in native tree species that are predominant in the upper canopies of vegetation assemblages such as rainforests, riparian forests, and wet sclerophyll forests. In Chapter 2, I present the methods I used to perform my research. I performed fieldwork to collect fresh shoot samples for flammability experiments and for measurement of a wide range of plant functional traits, including leaf energy content. This is a trait that has yet to be explored for its relationship with inter-species variation in shoot flammability. I performed laboratory work to measure the plant traits, and used a bespoke flammability device to assess shoot flammability. To analyse my data, I built a series of models that included the use of phylogenetic comparative methods for relating shoot flammability to plant traits among species (e.g. Murray et al. 2023). In Chapter 3, I present the results of my assessments of inter-species patterns in shoot flammability, and my analyses of trait correlates of shoot flammability. Chapter 4 provides a synthesis of my research findings, places them in the broader context of ecological studies of intrinsic plant flammability, and explores future avenues of research suggested by my findings. My research aims were:

(1) To compare inter-species variation in five shoot flammability attributes, including time to flame, flame duration, flame height, flame temperature, and biomass burnt. As a first step to understanding patterns in shoot flammability, it is essential to explore the range of variation in each of these flammability attributes among the study species.

(2) To quantify pairwise, inter-species relationships between each of the five flammability attributes. These quantifications allowed me to determine whether the flammability attributes were aligned with each other such that ideal low-flammability species (sensu Murray et al. 2020) were characterised by slow time-to-flame, short flame duration, short flame height, low flame temperature, and small biomass burnt.

(3) To compare inter-species variation in eight shoot traits, which included the shoot traits of mass, bulk density, water content, and branch number, as well as the leaf traits of area, mass per area, intensity (i.e. number of leaves on a shoot), and energy content. I selected these traits to explore their potential roles in driving variation in shoot flammability. Some of these traits have been examined previously in shoot flammability studies (e.g. shoot water content, Murray et al. 2023), while others have yet to be considered for their relationship with the five shoot flammability

attributes examined in this study (e.g. leaf energy content). At present, it is difficult to establish a priori hypotheses for how many of these leaf and shoot traits will dictate inter-species variation in shoot flammability. As such, my analyses described below were performed in an exploratory capacity, without a priori predictions.

(4) To determine inter-species relationships between shoot flammability attributes and the shoot and leaf traits. Relationships were examined using phylogenetically-informed analyses to account for evolutionary relatedness among species. I sought to identify those traits correlated with each of the flammability attributes, first to better understand whether variation in plant traits underpins variation in flammability among species, and second to produce a list of candidate traits that can be tested in future studies for their generality in driving shoot flammability patterns in other plant assemblages.

(5) To assess how shoot flammability differs between species in the family Myrtaceae and species in all other families assessed in this study. Here, I sought empirical support at the shoot scale for long-held notions that Myrtaceous trees in Australia are more flammable than non-Myrtaceous families (Bradstock et al. 2012).

Chapter 2 | Methods

2.1 Study region and sites

The study focused on the flammability of common tree species of the Barrington Tops region (-32.06448° N, 151.5143° E). The Barrington Tops National Park covers an area of 67,530 ha, and forms part of the Great Dividing Range in New South Wales, Australia (Fig. 2.1). The National Park is located 100 km north-west of Newcastle, set between the towns of Scone and Gloucester, and is of international significance for its biodiversity. Rainforests form part of the Gondwana Rainforests of Australia World Heritage Site and the National Park's soils provide an insight to a pre-human world and a record of the past, including evidence of climate change through fossilized pollen (Zoete 2000; Department of Planning and Environment 2010). The Barrington Tops rise from near sea level to over 1500 m and the region is host to ecologically diverse flora and fauna (Binns 1995; Zoete 2000; Dungog Biodiversity Report 2012; Bell 2014).

The annual maximum temperature of the region is 20.6°C and the annual minimum temperature is 12.2°C (BOM 2022). The region's climate is typically sub-humid, with an average annual rainfall of 1308 mm (BOM 2022), although rainfall varies with altitude and longitude. Areas on the lower slopes are generally drier, with a mean annual rainfall of approximately 1000 mm, while areas in the rain shadow of the plateau further inland experience the driest conditions with a mean annual rainfall of less than 700 mm. The majority of precipitation at higher elevations comes from heavy fog or snow during winter months (Zoete et al. 2000; Sweller et al. 2001), and the mean annual rainfall at high elevations (1549 m above sea level) is 1576 mm (BOM 2023).

There are 106 threatened animal species and 116 threatened plant species that occur in the Barrington Tops (Department of Planning and Environment 2010; Winn et al. 2022). The Barrington Tops is a popular recreational area that attracts many tourists and locals with many bushwalking, cycling, four-wheel driving and camping opportunities. This attraction to the Barrington Tops in turn provides surrounding communities with income and growth opportunities. The Barrington Tops region is the traditional country of the Biripi, Worimi, Geawegal, Wonaaruah, and Ungooroo people. It contains many significant cultural sites such as Mount Mackenzie, camping areas, spiritual places and medicinal plant and animal species, all of which are intrinsic to Aboriginal cultural wellbeing (Department of Planning and Environment 2010; Hunter Community Environment Centre 2022). The ancient and isolated nature of the Barrington Tops area makes it an area of exceptional world heritage, natural heritage and Aboriginal cultural heritage.

Esri, CGIAR | Sources: Esri, USGS | Esri, HERE, Garmin, Foursquare, FAO, METI/NASA, USGS

Fig. 2.1 Barrington Tops National Park is located in NSW in eastern Australia in the Dungog Local Government Area.

2.2 Study sites and species

In this study, I assessed shoot flammability of tree species characteristic of moist forest habitats in the Barrington Tops region. This included species common to three vegetation associations, including rainforest, riparian forests, and wet sclerophyll forests. Rainforest is characterized by being a warm and moist biome where rain occurs throughout the year, and by dense canopies that occur in ground, mid and upper plant strata (National Geographic 2023). Riparian forests occur along the banks of rivers or large creeks and are rich in organic matter, and are often inundated with water (Department of Sustainability and Environment 2005). Wet sclerophyll forest occurs in areas of high rainfall and has an open and tall tree canopy, with soft-leaved understories populated by shrubs, ferns, and herbs (Office of Environment and Heritage 2023). Plant samples for flammability experiments were collected from a total of 20 study sites spread across the region (Fig. 2.2). Most of the collection sites were in the National Park (16 sites), with four other sites located in areas of remnant vegetation adjacent to the National Park. Each site was defined by an area measuring 50 m x 50 m, which contained species representative of the vegetation types mentioned above, and sites were identified prior to field collections using the NSW State Vegetation Type Map (2022).

A total of 38 widespread and abundant tree species (Table 2.1) were identified using two published vegetation surveys of the flora of the region (Zoete 2000; McCauley 2006). The study species represented a wide range of plant families, 19 in total, which included characteristic families of the region such as Myrtaceae, Fabaceae, and Rutaceae (Table 2.1). I collected plant samples of 26 species from the 16 sites within Barrington Tops National Park and 12 species from the four remnant vegetation sites adjacent to the National Park. All collection of plant samples was conducted under National Parks Permit SL102508. For each species, plant samples were collected from three separate sites, with no more than three plants per species sampled at a single site. All sites were located a minimum of 100 m apart. This sampling design was established to ensure that for each species, there was a relatively wide representation of individual plants sampled across the region. Sampling of plants was performed in sites that were situated at least 10 m from any roads or foot paths to ensure consistency among samples in terms of minimizing the likelihood of samples being influenced by disturbances (Stenhouse 2005). All shoot collection and flammability assessments were conducted across three months during July, August, and September of 2021.

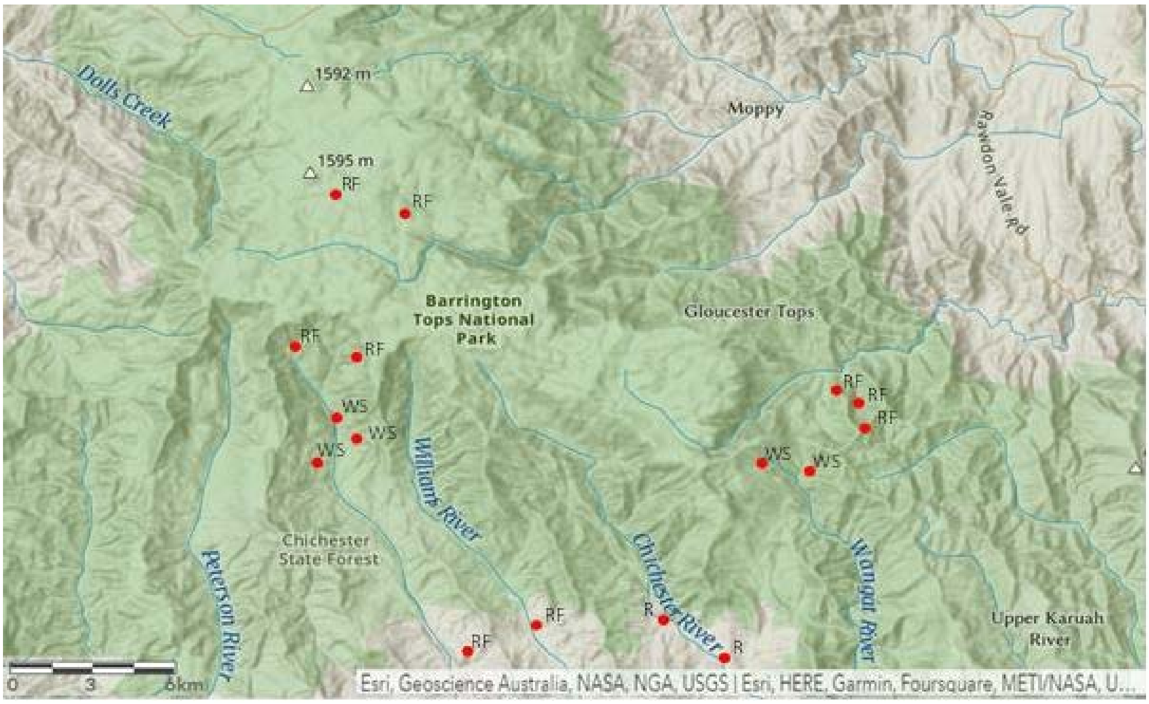

Fig. 2.2 Locations of the 20 sites of plant shoot collection within and adjacent to the Barrington Tops National Park (RF: Rainforest, WS: Wet Sclerophyll, R: Riparian).

Table 2.1 The 38 native Australian tree species assessed in this study. Species and family taxonomies are consistent with PlantNET, The Plant Information Network System of The Royal Botanic Gardens and Domain Trust Version 2.0 (https://plantnet.rbgsyd.nsw.gov.au).

Species	**Family**	**Vegetation**
Acacia barringtonensis	Fabaceae	Riparian forest
Acacia irrorata	Fabaceae	Wet sclerophyll forest and rainforest
Acacia implexa	Fabaceae	Riparian forest
Acacia maidenii	Fabaceae	Wet sclerophyll forest and rainforest
Acacia melanoxylon	Fabaceae	Wet sclerophyll forest and rainforest
Ackama paniculata	Cunoniaceae	Wet sclerophyll forest and rainforest
Acmena smithii	Myrtaceae	Rainforest and riparian forest
Acronychia oblongifolia	Rutaceae	Rainforest
Alphitonia excelsa	Rhamnaceae	Rainforest
Callistemon salignus	Myrtaceae	Riparian forest
Casuarina	Casuarinaceae	Riparian forest
Ceratopetalum apetalum	Cunoniaceae	Rainforest
Croton verreauxii	Euphorbiaceae	Rainforest
Cryptocarya glaucescens	Lauraceae	Rainforest
Diospyros pentamera	Ebenaceae	Rainforest
Dysoxylum fraserianum	Meliaceae	Rainforest
Elaeodendron australe	Celastraceae	Rainforest
Eucalyptus campanulata	Myrtaceae	Wet sclerophyll forest
Eucalyptus fibrosa	Myrtaceae	Wet sclerophyll forest
Eucalyptus	Myrtaceae	Riparian forest
Eucalyptus saligna	Myrtaceae	Wet sclerophyll forest
Eucalyptus siderophloia	Myrtaceae	Wet sclerophyll forest
Eucalyptus paniculata	Myrtaceae	Wet sclerophyll forest
Eucalyptus resinifera	Myrtaceae	Wet sclerophyll forest
Ficus obliqua	Moraceae	Rainforest
Ficus coronata	Moraceae	Rainforest and riparian forest
Grevillea robusta	Proteaceae	Wet sclerophyll forest
Lophostemon confertus	Myrtaceae	Wet sclerophyll forest and rainforest
Melicope micrococca	Rutaceae	Rainforest
Mischocarpus australis	Sapindaceae	Rainforest
Neolitsea dealbata	Lauraceae	Rainforest
Olearia argophylla	Asteraceae	Wet sclerophyll forest and rainforest
Pittosporum undulatum	Pittosporaceae	Wet sclerophyll forest and rainforest
Planchonella australis	Sapotaceae	Rainforest
Psychotria loniceroides	Rubiaceae	Wet sclerophyll forest and rainforest
Myrsine variabilis	Primulaceae	Riparian forest
Syzygium australe	Myrtaceae	Rainforest and riparian forest
Tristaniopsis laurina	Myrtaceae	Rainforest and riparian forest

2.3 Collection, preparation, and measurement of plant samples

At each study site and for each species, three mature sun-exposed shoots were collected from three different individual trees to obtain a total of nine replicate shoot samples per species (Pérez-Harguindeguy et al. 2013; Murray et al. 2023). All individuals sampled were not visibly unhealthy or damaged. Handheld pruners and a tree-pruner saw and pole were used to cut shoot samples of 70 cm in length (Alam et al. 2019). In cases where samples could not be cleanly detached, the saw was used to obtain a slightly longer sample that was then cut to 70 cm using the pruners to ensure a clean and even cut across all species and replicates. Shoots containing multiple leaves, twigs and small branches were collected to ensure the inclusion of key factors that influence the flammability of vegetation, including fuel arrangement, continuity and quantity (Martin et al. 1994; Alam et al. 2020a). A 10-cm shoot sub-sample was also collected from one randomly-selected plant of the three individuals at each location to allow determination of shoot water content for each species. The ends of the shoots were wrapped in a damp cloth to ensure that minimal moisture loss would occur during transport from the study site to the laboratory. The collection and return of the shoot samples took place on the same day and shoot samples were stored in large, sealed plastic bin bags. In the laboratory, all shoot samples were spaced out on a bench without overlap in an indoor area for approximately 24 hours (Cubino et al. 2018; Wyse et al. 2018; Alam et al. 2019; Murray et al. 2023). This dry-down procedure was used to match the ignition source to the moisture content of these samples (White and Zipperer 2010; Wyse et al. 2016, 2018).

2.4 Shoot flammability experiments

Shoot flammability was measured using a portable, custom-built shoot flammability device (Figs 2.3, 2.4). The device was built to match the specifications and methodology of Jaureguiberry et al. (2011), modified by Wyse et al. (2016), and to comply with Australian safety standards. The device was constructed using an 85 x 60 cm metal barrel cut in half and reattached on hinges to form a lid and wind breaker. The barrel was mounted on a trolley for ease of portability and functionality, with two parallel burners positioned inside the barrel below a metal mesh grill. During flammability experiments, each shoot sample was placed on the grill and there was no contact with the open flame. The LPG-powered flammability device provided heat when lit to radiate from below and through the shoot sample.

At the start of each series of shoot flammability assessments, a strip of metal was placed inside the device to measure the temperature before shoots were placed onto the grill. Once the temperature of the device reached a constant 180°C, shoot samples were weighed and then laid horizontally onto the grill for 2 min to simulate the conditions of an approaching bushfire (Wyse et al. 2016). During this pre-heating phase Jaureguiberry et al. 2011), the shoot sample's length, width and height were measured with a tape measure. At the conclusion of the 2 min, a blowtorch directed at the shoot was turned on for 10 s. During the 10 s, observers determined the time-point at which the shoot ignited to assess time to flaming combustion (TTF, in s). The torch was turned off after the full 10 s and subsequently the time over which flaming combustion occurred was recorded as flame duration (FD, in s). The maximum flame height (FH, in cm) was measured using a ruler setup on a stand next to the flammability device. A handheld infrared laser thermometer (Digitech QM 7226) was used at a distance of 50 cm from the sample to measure the maximum temperature (FT, in °C) reached by the external flame plume (Jir-Ming and Jun-Hsien 1996; Pérez- Harguindeguy et al. 2013; Calitz et al. 2015; Wyse et al. 2016). The proportion of biomass consumed by combustion (BB, measured as a %) was visually estimated by at least two observers, following Burger and Bond (2015). After each shoot burn, the shoot sample was placed into a tub of water to ensure the sample was completely extinguished before being placed into a green composting bin.

Fig. 2.3 The shoot flammability device used in this research: (a) gas cylinder, (b) gas flow tap, (c) device tub housing grill, (d) moveable wind protection hood, (e) butane blowtorch, (f) portable stand on lockable wheels, (g) tub filled with water to

extinguish samples, (h) safety equipment (fire extinguisher, fire blanket, gloves, tongs, sunscreen, water bucket), and (i) low flammability mat.

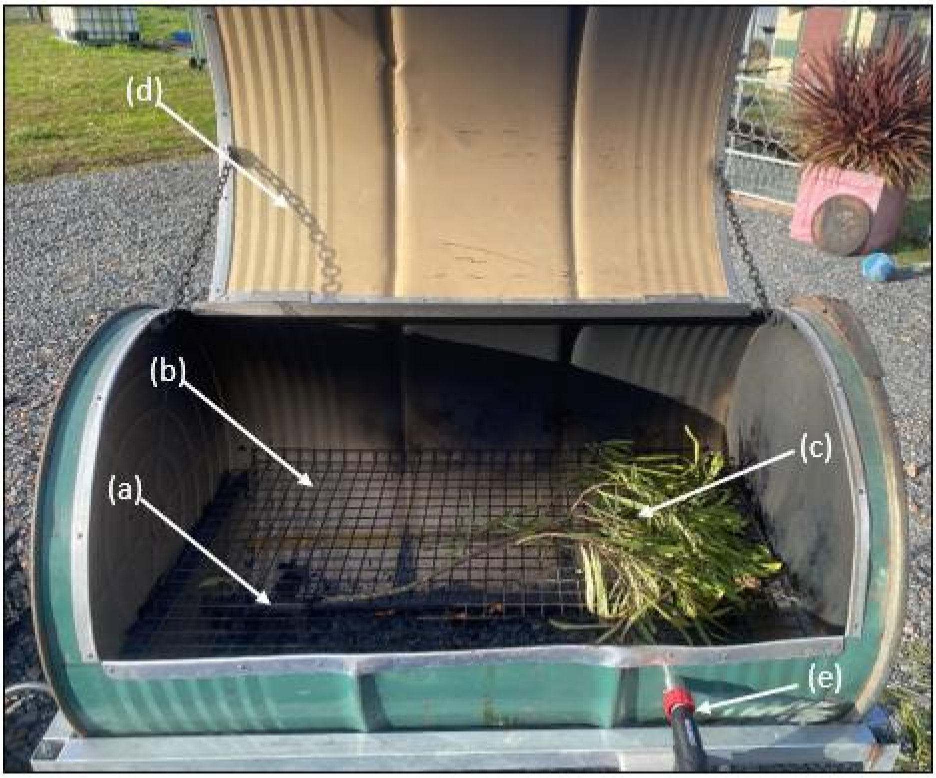

Fig. 2.4 Alternate view of shoot flammability device with (a) flame rods, (b) grill, (c) horizontally laid shoot sample (*Acacia maidenii*), (d) moveable wind protection hood, and (e) butane blowtorch.

2.5 Shoot and leaf traits

A total of eight shoot and leaf traits were measured, including shoot mass, shoot bulk density, shoot water content, the number of branches on a shoot; as well as leaf area, leaf mass per area, leaf number, and leaf energy content. These traits were measured to determine their relative roles in driving variation in shoot flammability. The air-dried mass of each shoot was measured using a portable spring balance just prior to burning. Shoot length, height, and width measurements were used to calculate shoot bulk density (BD), using the equation $BD = \frac{ADSM}{\pi \times LENGTH \times WIDTH \times 0.5 \times HEIGHT \times 0.5}$, where ADSM is air-dried shoot mass (measured directly before burning), which is divided by the shoot volume. To measure shoot water content, the replicate 10 cm sub-samples for each species were weighed using a CGOLDENWALL 500G / 0.001G High Precision Analytical Electronic Balance to determine fresh shoot mass (FSM), then placed in an oven for 48 h at 70°C. The subsamples were then reweighed to obtain their dry shoot mass (DSM) and shoot water content (SWC) was calculated using the equation $SWC = \frac{ADSM - DSM}{ADSM}$. Branch number on each shoot was calculated as the number of branches (or nodes) along the main stem line per m of branch (Santacruz-García et al. 2019).

Five leaves from each replicate shoot were detached, including the intact petiole, and scanned using a Brother HL-L3230CDW Wireless A4 Duplex Color Laser Printer to determine leaf area. The leaves were dried in an oven at 70°C for 48 h and then weighed to determine leaf dry mass. Leaf mass per area was then determined as the leaf dry mass divided by leaf area. The total number of leaves on each replicate shoot was counted to determine leafing intensity.

I used an IKA C1 bomb calorimeter to measure leaf energy content. At least 10 g of leaves were collected from all three 10-cm shoot subsamples for five replicate runs per species in the calorimeter. The leaves were placed in paper bags and placed into a drying oven at 70°C for 48 hours to prepare the samples so that they were completely devoid of moisture, as the grinding and pelleting process requires the samples to form a powder. The leaves were then ground using a coffee grinder into a fine powder with about 1.4 g of the leaf powder compressed into pellet form using a dye. The use of 1.4 g of powder per run was determined during the standardization process, as 1.4 g provided a known value (q) consistent with calibration of a known heat capacity. The pellets were placed in a crucible connected by a cotton thread to the ignition source (Basu 2015). The calorimeter was closed, and then the exact weight of the pellet was entered into the bomb calorimeter before starting the ignition. The bomb calorimeter consists of a pressurized oxygen container with a fuse wire connected to two electrodes that is kept in contact with the leaf pellet inside the bomb. The cylinder is surrounded by water during a test, during which a thermocouple measures the exact change in water temperature after a sample is ignited. This change in temperature is used to calculate the exact amount of heat released by combustion of the sample. Once the bomb calorimeter completed combustion and calculated the heat capacity of the sample, the energy content of the leaf was expressed as J per g. The test was repeated five times per species and an average leaf energy content for each species was then calculated.

2.6 Data Analysis

To determine whether there was significant variation among species in shoot flammability, I fitted a linear model on each flammability attribute, using species as a categorical factor. For these models, TTF was ln transformed, FD, FH and FT were sqrt transformed, and BB was logit transformed, and all replicate observations were used (nine replicates per species). To explore bivariate relationships between flammability attributes, I tested the pairwise associations among attributes (TTF, FD, FH, FT and BB) using phylogenetic generalised least squares (PGLS). To allow me to conduct phylogenetically informed analyses, a phylogenetic tree for the study species was pruned from a published megatree (Smith and Brown 2018; see further detail below on the PGLS analyses). Following this, relationships between each of the flammability attributes and the leaf and shoot traits were tested, using multiple regression PGLS models. Initially, saturated models were built using all leaf and shoot traits as predictors (Appendix 2.1), which were then simplified on the basis of statistical significance (Crawley 2013), to uncover the leaf and shoot traits which best explain shoot flammability. Finally, to test if flammability attributes, as well as the leaf and shoot traits that emerged as important predictors of inter-species variation in flammability, differed between the Myrtaceae family and other non-Myrtaceae families, I fitted PGLS models to each response variable (i.e. flammability attributes, leaf traits and shoot traits) using a binary categorical factor as the sole predictor (Myrtaceae family vs other families).

For each PGLS model, the optimal branch length transformation and type was selected by fitting each model four times under Brownian motion, and with lambda, kappa and delta branch length transformations, with the transformation value for each estimated using maximum likelihood. The best fitting model was then determined on the basis of it having the lowest Akaike's information criterion, and this transformation used to fit the model used in the analysis (Appendix 2.2). In all models, TTF, leaf mass per area and bulk density were ln transformed, FD, FH and FT were sqrt transformed, BB and water content were logit transformed, and the negative reciprocal taken for leaf and branch number. Leaf energy content and shoot mass were not transformed.

All analyses were performed in R 4.2.1 (R Core Team 2022) with ape (Paradis and Schliep 2019), caper (Orme et al. 2019) and V.PhyloMaker (Jin and Qian 2019). Flammability, shoot trait and leaf trait data for the tree species are presented in Appendices 2.3, 2.4, and 2.5. Simplified PGLS models for flammability attributes as a function of the leaf and shoot traits are in the Appendix 2.6. The PGLS models comparing flammability attributes and leaf and shoot traits between Myrtaceous and non-Myrtaceous families can be found in Appendix 2.7.

Chapter 3 Results

3.1 Inter-species variation in shoot flammability

I found that TTF varied significantly among the study species ($F_{36,279} = 9.42$, $P < 0.001$; Fig. 3.1), ranging from fast ignitions of 1 s for species such as *Acacia maidenii*, *Eucalyptus resinifera*, and *Callistemon salignus*, to comparatively slower ignition times of 7.7. s for *Croton verreauxii* and 6.4 s for *Cryptocarya glaucescens*. Mean TTF across all species was 2.6 s. I also found that FD varied significantly among species ($F_{36,279} = 7.31$, $P < 0.001$; Fig. 3.2), with *Ficus coronata* (2.0 s) and *Croton verreauxii* (5.3 s) exhibiting the shortest FD compared to all other species, and several Myrtaceae species having relatively long FD, e.g. *Callistemon salignus* at 63.4 s and *Eucalyptus campanulata* at 57. 5 s. Mean FD across all species was 28.6 s.

There was significant variation among species in FH ($F_{36,279} = 9.72$, $P < 0.001$; Fig. 3.3). I found that FH was shortest in *Ficus coronata* (5.0 cm) and tallest in *Eucalyptus campanulata* (65 cm). Mean FH across all species was 30.4 cm. I found significant variation in FT among species ($F_{36,279} = 7.31$, $P < 0.001$; Fig. 3.4), with species such as *Ficus coronata* (270.6°C), *Croton verreauxii* (377.3°C), and *Psychotria loniceroides* (378.9°C) burning at the lowest temperatures, and species such as *Grevillea robusta* (624.4°C), *Eucalyptus campanulata* (766.0°C), *Eucalyptus siderophloia* (649.6°C), and *Callistemon salignus* (622.0°C) at the highest temperatures. Mean FT across all species was 551.8°C. I also found that BB varied significantly among species ($F_{36,279} = 7.86$, $P < 0.001$; Fig. 3.5). The amount of shoot consumed was small in species such as *Ficus coronata* (< 5%), while much larger in species such as *Eucalyptus campanulata* (94%). Mean BB across all species was 45.3%.

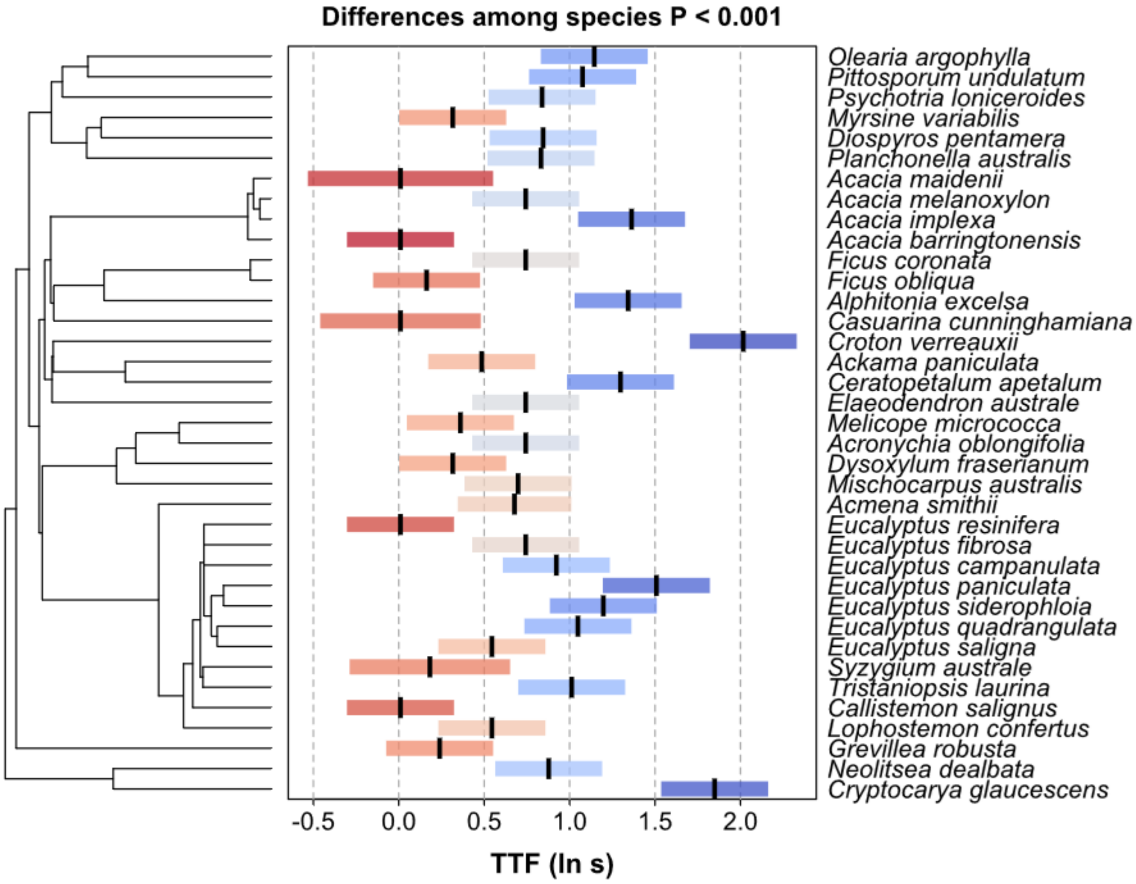

Fig. 3.1 Variation among species in time to flame (TTF) for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There was a significant difference among species in TTF (P < 0.001).

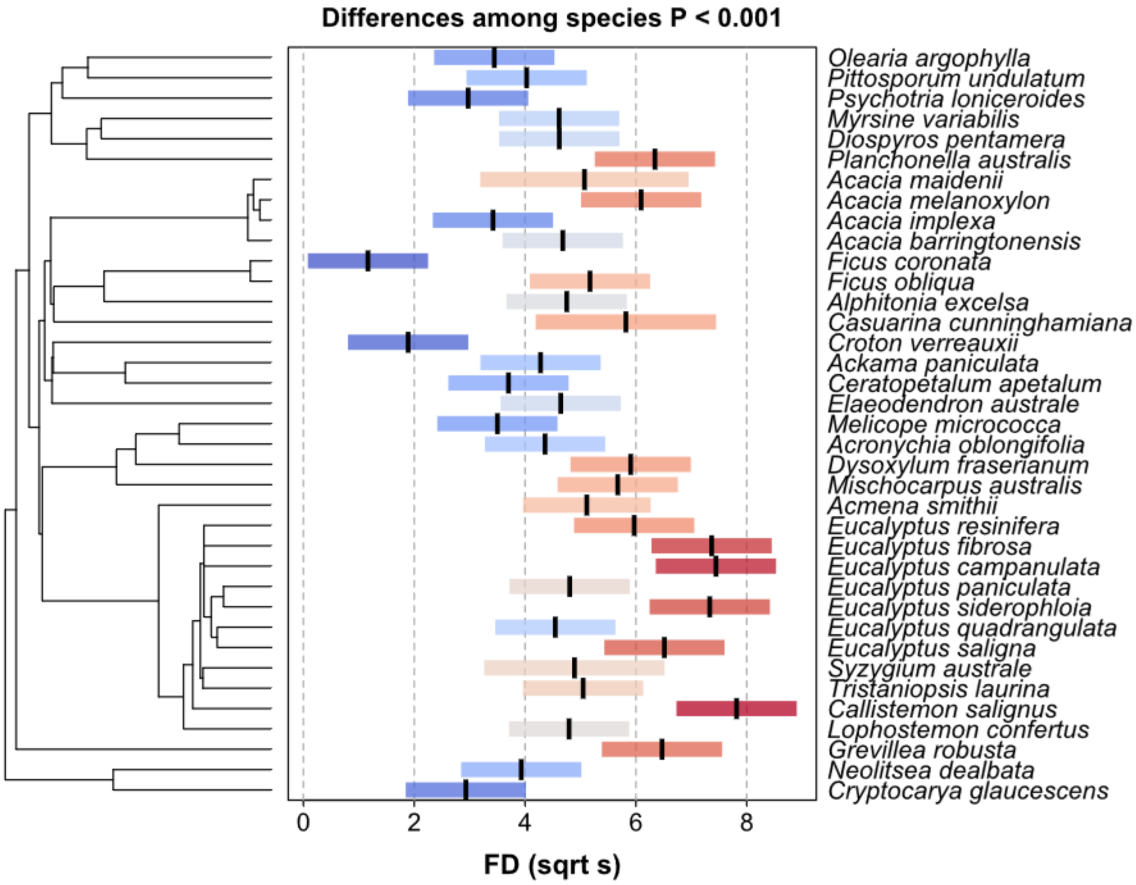

Fig. 3.2 Variation among species in flame duration (FD) for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There was a significant difference among species in FD (P < 0.001).

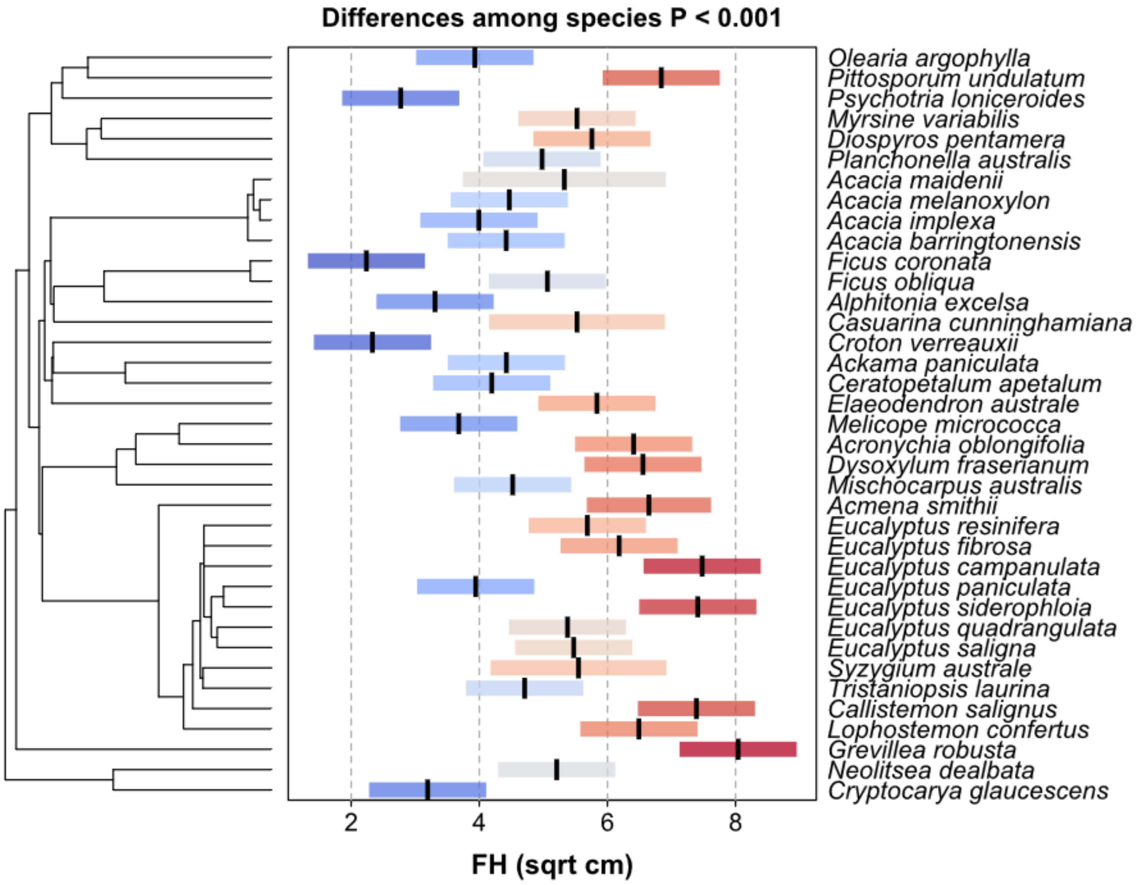

Fig. 3.3 Variation among species in flame height (FH) for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There was a significant difference among species in FH (P < 0.001).

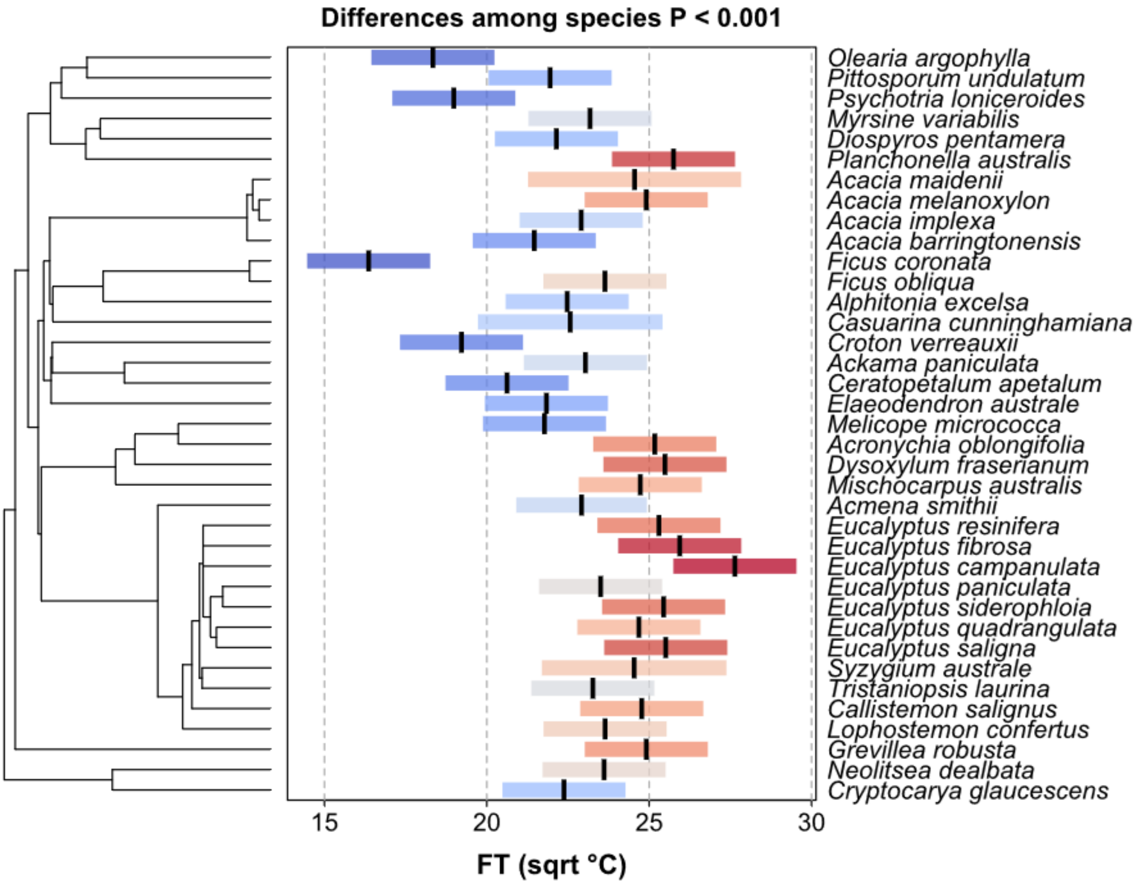

Fig. 3.4 Variation among species in flame temperature (FT) for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There was a significant difference among species in FT (P < 0.001).

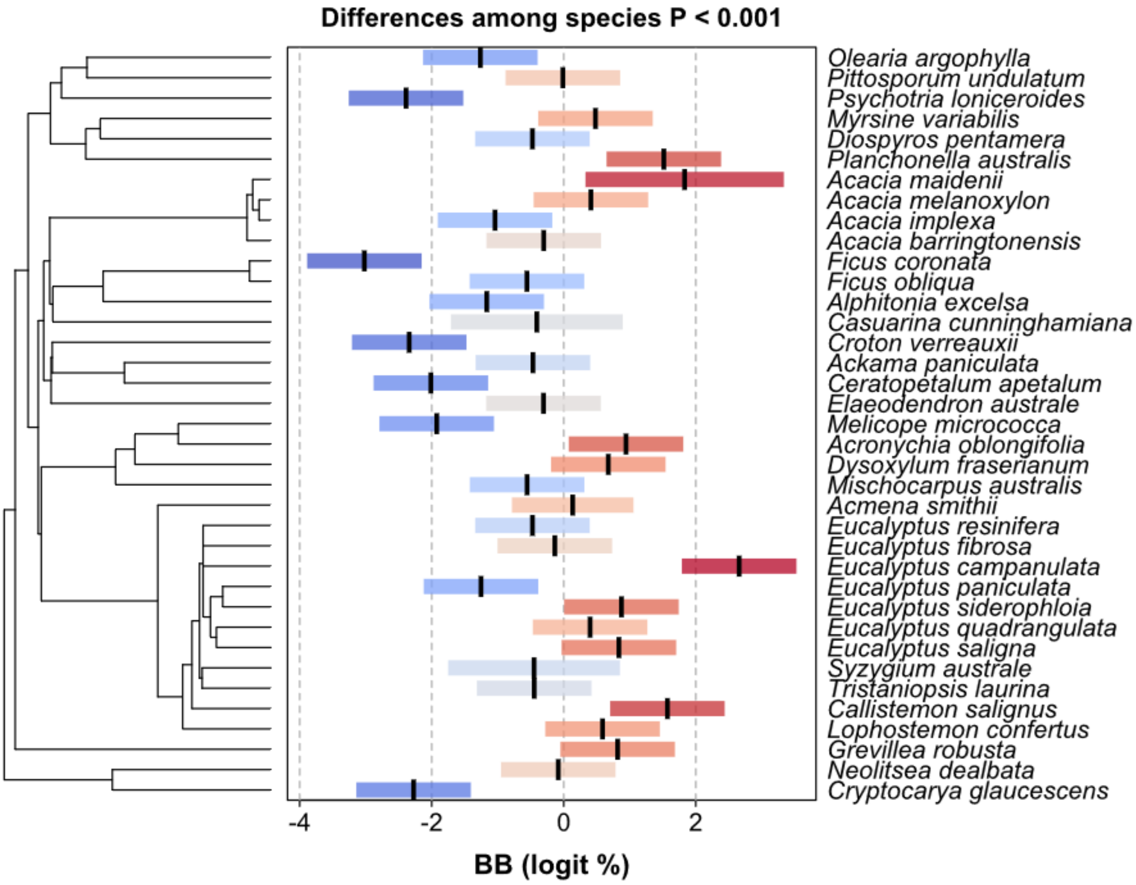

Fig. 3.5 Variation among species in biomass burnt (BB) for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There was a significant difference among species in BB (P < 0.001).

3.2 Relationships between shoot flammability attributes

Significant inter-species relationships emerged between all pairs of flammability attributes (Fig. 3.6). I found that TTF was negatively related to each of the other flammability attributes, such that faster TTF was related to significantly longer FD ($t_{1,35} = -3.18$, $P = 0.003$), taller FH ($t_{1,35} = -3.22$, $P = 0.003$), higher FT ($t_{1,35} = -2.17$, $P = 0.036$), and larger BB ($t_{1,35} = -2.79$, $P = 0.008$). In contrast, there were significant and positive pairwise relationships between all the other four flammability attributes. I found that longer FD was related to taller FH ($t_{1,35} = 5.87$, $P < 0.001$), higher FT ($t_{1,35} = 7.91$, $P < 0.001$), and larger BB ($t_{1,35} = 6.67$, $P < 0.001$); that taller FH was related to higher FT ($t_{1,35} = 5.23$, $P < 0.001$) and larger BB ($t_{1,35} = 9.60$, $P < 0.001$); and that higher FT was related to larger BB ($t_{1,35} = 9.30$, $P < 0.001$).

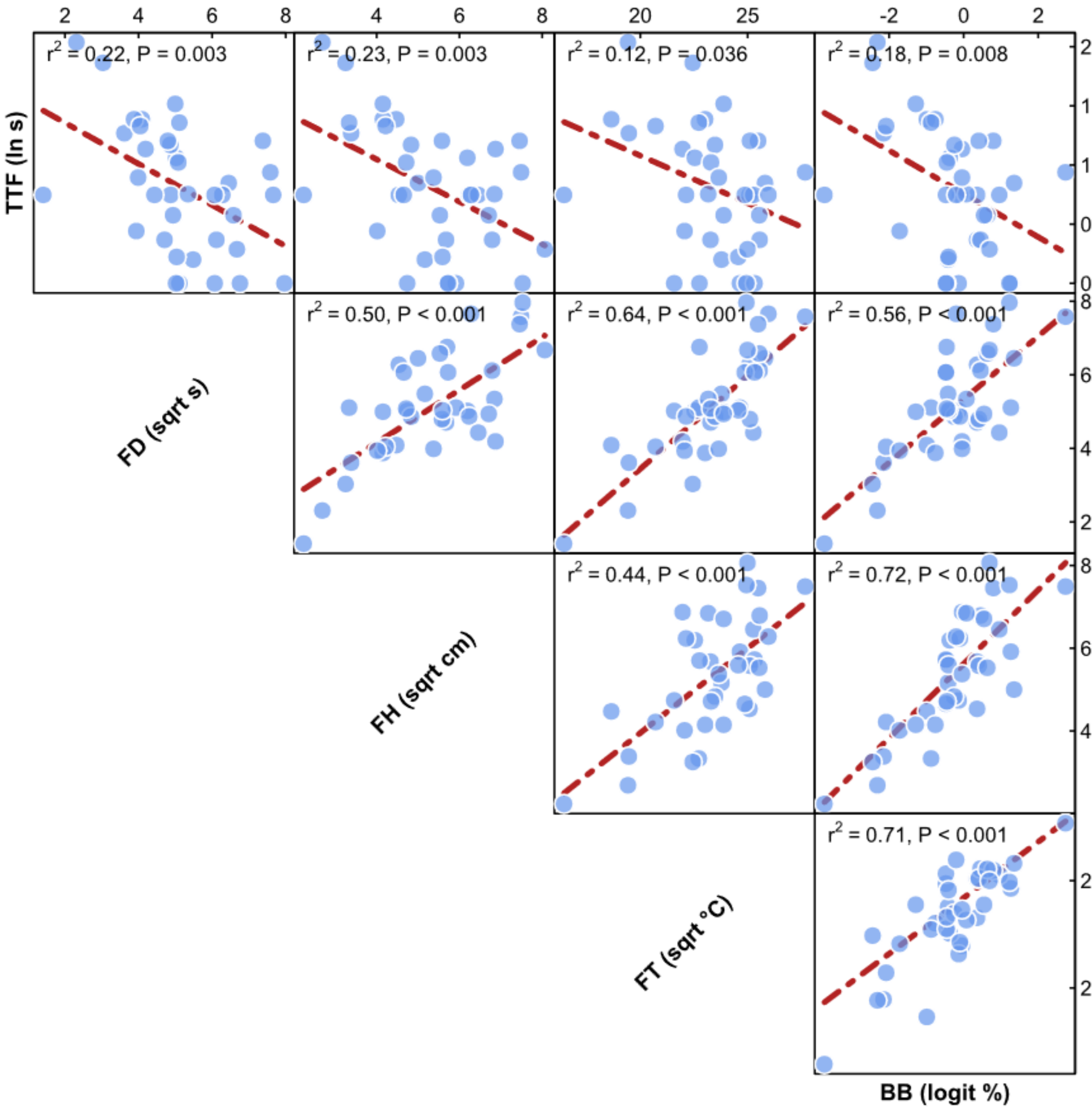

Fig. 3.6 Pairwise relationships between all shoot flammability attributes, including time to flame (TTF), flame duration (FD), flame height (FH), flame temperature (FT), and biomass burnt (BB). Each point represents a species mean value with the red lines show model best fits with R^2 and P values. All relationships are statistically significant.

3.3 Inter-species variation in leaf traits

There was significant variation among species in leaf area ($F_{36,185} = 116.62$, $P < 0.001$), leaf mass per area ($F_{36,185} = 253.58$, $P < 0.001$), leaf number ($F_{36,185} = 18.85$, $P < 0.001$), and leaf energy content ($F_{36,185} = 4115.37$, $P < 0.001$) (Fig. 3.7). Species with the largest leaf areas included *Eucalyptus resinifera* (32.4 cm^2) and *Eucalyptus siderophloia* (31.7 cm^2), and those with the smallest leaf areas included *Ackama paniculata* (6.8 cm^2), *Casuarina cunninghamiana* (7.1 cm^2), and *Alphitonia excelsa* (7.9 cm^2). I found that *Casuarina cunninghamiana* had substantially higher leaf mass per area (2174.8 g m^2) than all other species, while *Ceratopetalum apetalum* had the lowest leaf mass per area (78.4 g m^2). Leaf number was relatively high in many species including *Casuarina cunninghamiana* (612.2), *Grevillea robusta* (376.5), *Ackama paniculata* (274.3), *Alphitonia excelsa* (201.3), and *Acmena smithii* (170.3), while much lower in species such as *Cryptocarya glaucescens* (25.5). Leaf energy content was comparatively higher in several Myrtaceae species including *Eucalyptus campanulata* (5008.5 C g), *Eucalyptus quadrangulata* (5020.7 C g), and *Eucalyptus saligna* (5019.9 C g), and lowest in *Ficus coronata* (3287.5 C g) and *Acacia barringtonensis* (3465.5 C g).

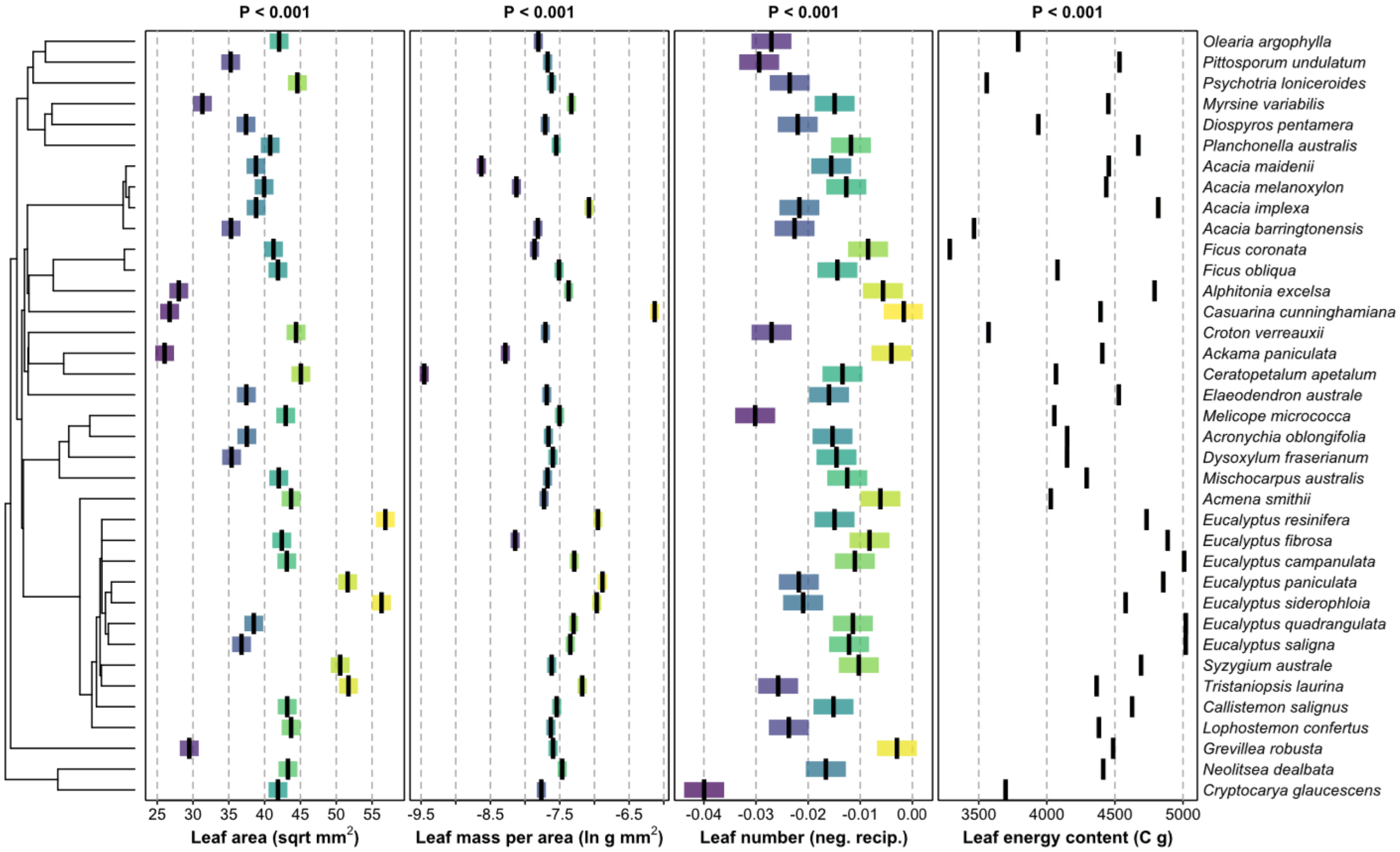

Fig. 3.7 Variation among species in leaf traits for all 38 study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There were significant inter-species differences for all traits ($P < 0.001$).

3.4 Inter-species variation in shoot traits

I found significant inter-species variation in shoot mass ($F_{36,185} = 7.41$, $P < 0.001$), branch number ($F_{36,185} = 8.71$, $P < 0.001$), bulk density ($F_{36,185} = 4.75$, $P < 0.001$), and shoot water content ($F_{36,185} = 3.00$, $P < 0.001$) (Fig. 3.8). The species with the largest shoot mass were *Dysoxylum fraserianum* (131.1 g) and *Psychotria loniceroides* (121.7 g), and those with the smallest shoot mass were *Ficus coronata* (28.3 g) and *Acacia implexa* (36.7 g). Branch number was highest in species such as *Eucalyptus fibrosa* (59.5) and *Ficus coronata* (42.0), and lowest in species such as *Olearia argophylla* (3.2), *Psychotria loniceroides* (3.3), and *Eucalyptus campanulata* (3.2). Bulk density was highest in *Planchonella australis* (5564.3 g m^3), *Neolitsea dealbata* (5110.2 g m^3), and *Casuarina cunninghamiana* (4136.5 g m^3), and lowest in *Ficus coronata* (1034.0 g m^3), *Croton verreauxii* (1158.4 g m^3), and *Olearia argophylla* (1234.4 g m^3). Shoot water content was comparatively high in several species including *Casuarina cunninghamiana* (37.2%) and *Neolitsea dealbata* (37.6%), while much lower in species such as *Eucalyptus campanulata* (10.5%) and *Diospyros pentamera* (20.7%).

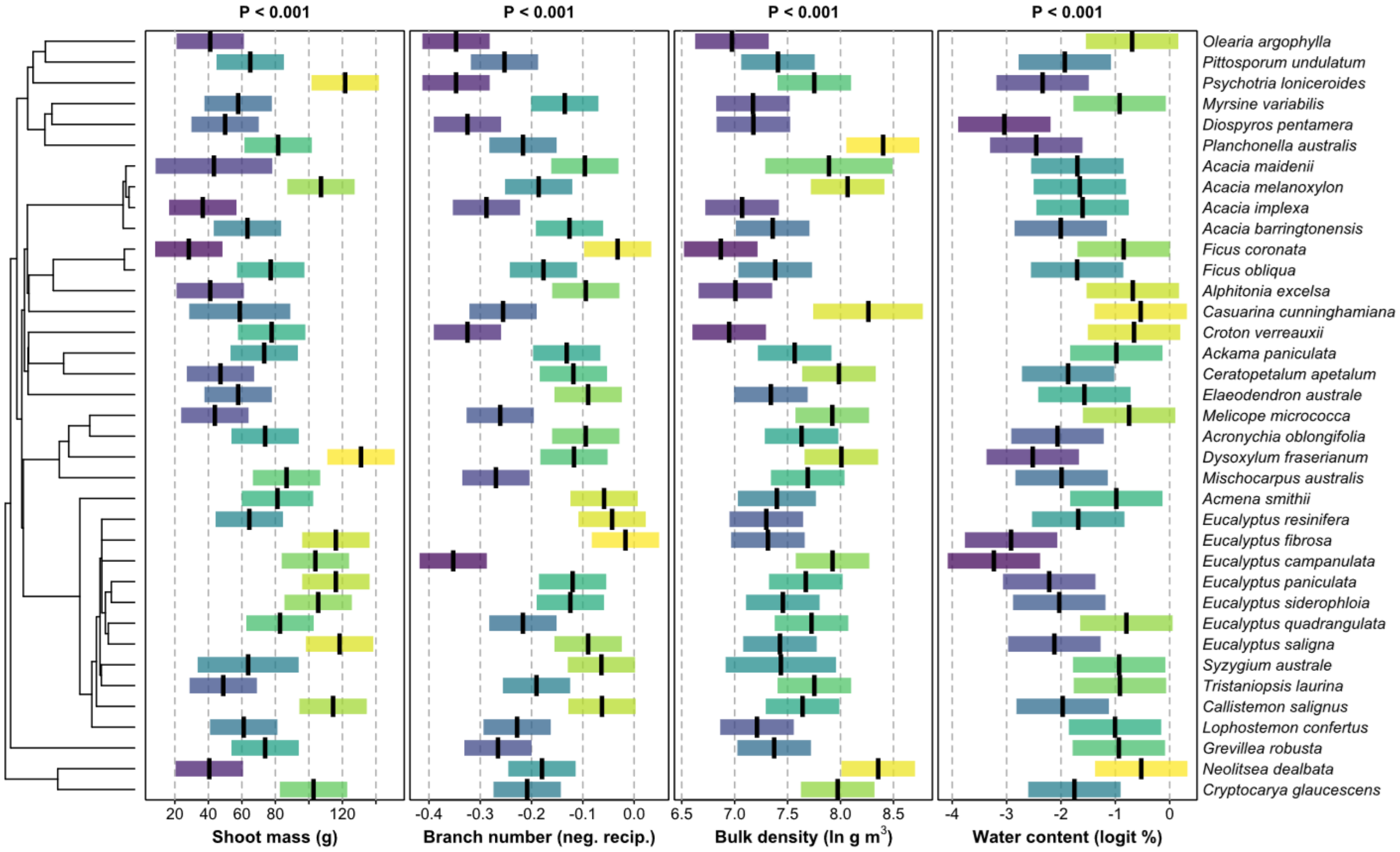

Fig. 3.8 Variation among species in shoot traits for the study species. Mean values (black lines) with 95% confidence intervals (bars) are shown for each species, with the phylogeny of the study species on the left. There were significant inter-species differences for all traits ($P < 0.001$).

3.4 Inter-species relationships between flammability and leaf and shoot traits

Multiple regression MAMs for TTF, FH and BB each retained only one significant predictor (Fig. 3.9; Appendix 3.1). The strongest predictor of TTF was the number of leaves on a shoot ($t_{1,35} = -3.22$, $P = 0.003$), with fast-igniting species having a relatively larger number of leaves (Fig. 3.9a). Leaf energy content was the strongest predictor of both FH ($t_{1,35} = 3.66$, $P < 0.001$) and BB ($t_{1,35} = 4.99$, $P < 0.001$), with species with higher leaf energy content producing taller flames (Fig. 3.9b) and burning up a large amount of shoot biomass (Fig. 3.9c). Several leaf and shoot traits were significantly related to FD and FT in the MAMs (Fig. 3.10; Appendix 4). Leaf energy content ($t_{1,33} = 3.57$, $P = 0.001$), leaf number ($t_{1,33} = 2.33$, $P = 0.026$), and shoot mass ($t_{1,33} = 3.50$, $P = 0.001$) were the best predictors of FD, while leaf energy content ($t_{1,33} = 7.73$, $P < 0.001$), bulk density ($t_{1,33} = 2.57$, $P = 0.015$), and shoot water content ($t_{1,33} = -2.83$, $P = 0.008$) were the best predictors of FT. Species that burned for longer had higher leaf energy content (Fig. 3.10a), higher leaf number (Fig. 3.10b), and larger shoot mass (Fig. 3.10c). Species that burned hotter had higher leaf energy content (Fig. 3.10d), higher bulk density (Fig. 3.10e), and lower shoot water content (Fig. 3.10f).

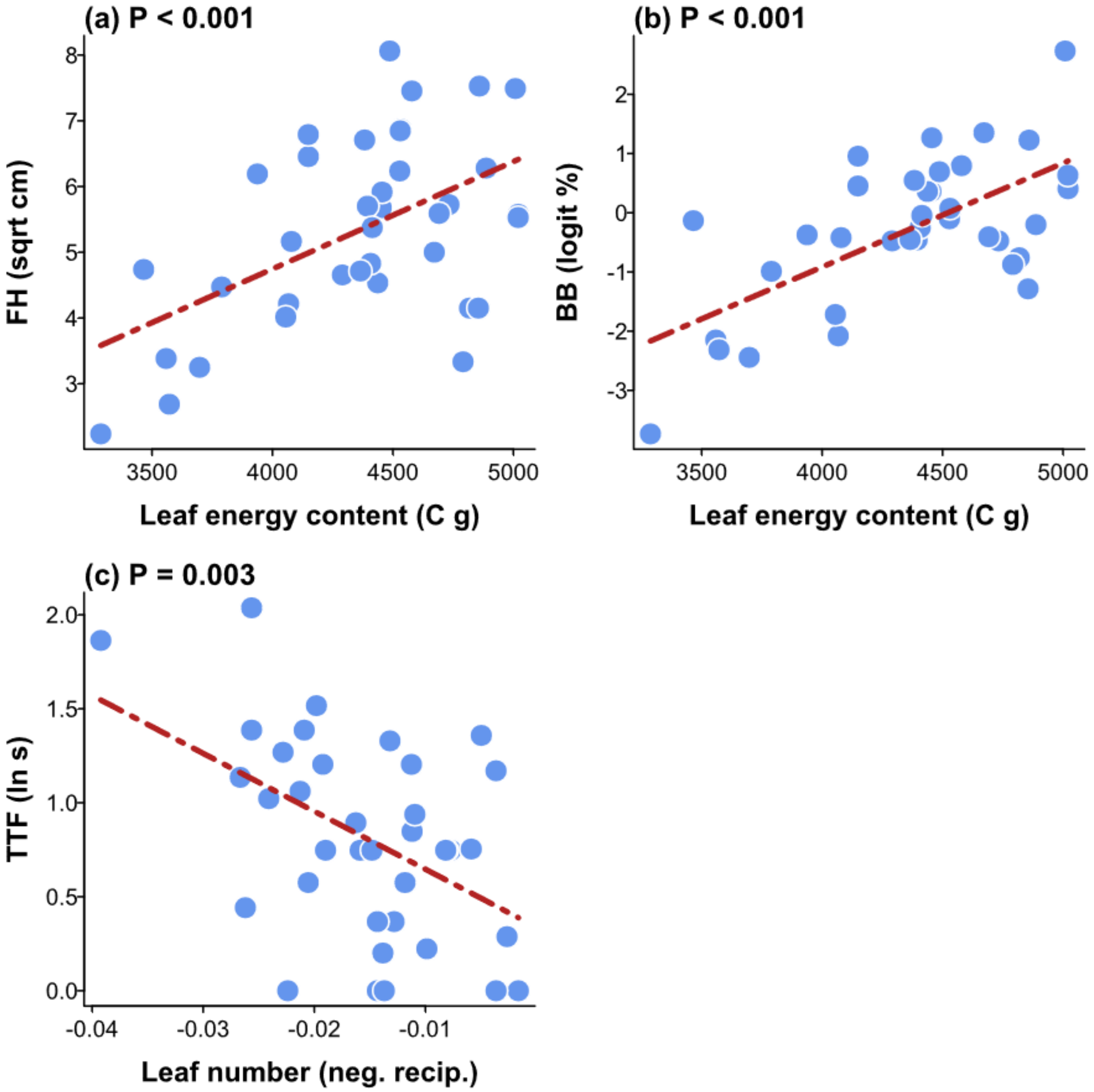

Fig 3.9 Significant relationships between (a) FH and leaf energy content, (b) BB and leaf energy content, and (c) TTF and leaf number. Broken red lines show model coefficients from PGLS MAMs.

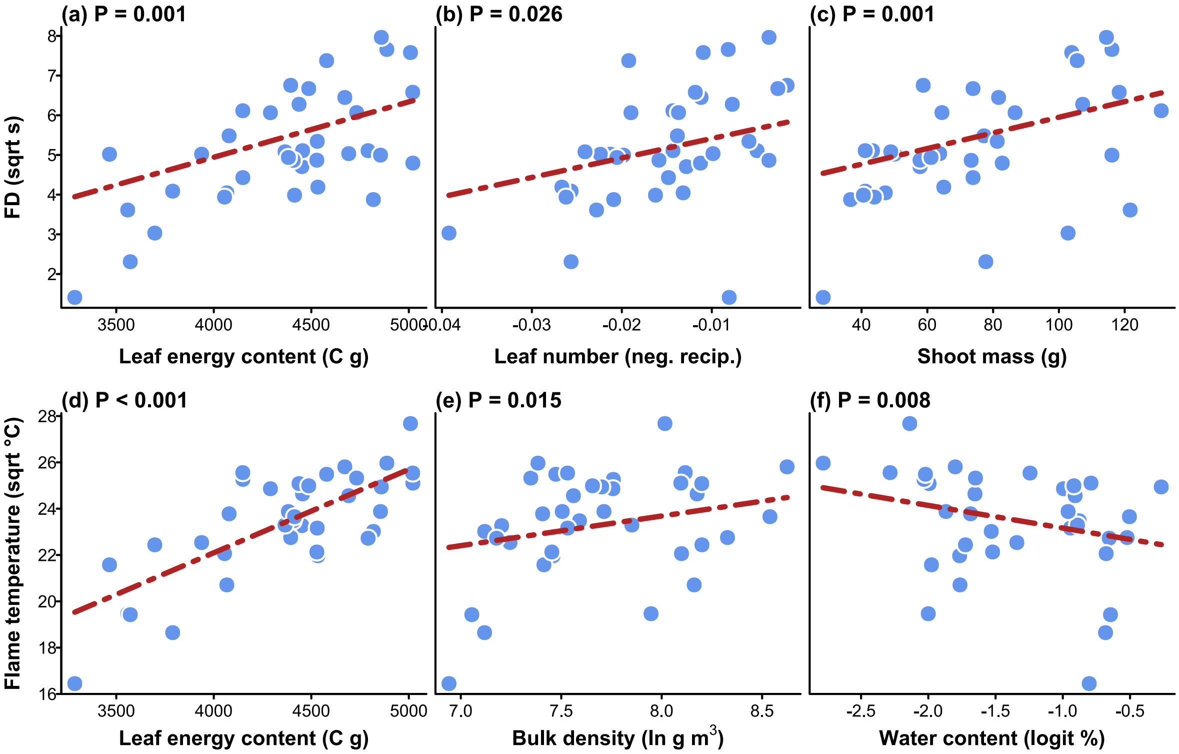

Fig 3.10 Significant relationships between FD and (a) leaf energy content, (b) leaf number, and (c) shoot mass; and between FT and (d) leaf energy content, (e) bulk density, and (f) shoot water content. Broken red lines show the coefficient for the predictor of interest while holding the other predictors at their mean value in PGLS MAMs.

3.5 Evolutionary patterns in shoot flammability, with a focus on Myrtaceae

Myrtaceous species were significantly more flammable in several flammability dimensions (Fig. 3.11), with longer FD ($F_{1,35} = 9.69$, $P = 0.004$; Fig. 3.11b), taller FH ($F_{1,35} = 6.42$, $P = 0.016$; Fig. 3.11c), higher FT ($F_{1,35} = 9.72$, $P = 0.004$; Fig. 3.11d), and larger BB ($F_{1,35} = 4.20$, $P = 0.048$; Fig. 3.11e). No significant differences were found between Myrtaceous and non-Myrtaceous species for TTF ($F_{1,35} = 0.38$, $P = 0.54$; Fig. 3.11a). Myrtaceous species had significantly higher leaf energy content ($F_{1,35} = 18.44$, $P < 0.001$; Fig. 3.12) and larger shoot mass ($F_{1,35} = 5.80$, $P = 0.021$; Fig. 3.12c). Leaf number ($F_{1,35} = 0.36$, $P = 0.55$; Fig. 3.12b), bulk density ($F_{1,35} = 0.36$, $P = 0.19$; Fig. 3.12d) and shoot water content ($F_{1,35} = 0.04$, $P = 0.85$; Fig. 3.12e) did not differ significantly between Myrtaceous and non-Myrtaceous species (Fig. 3.12).

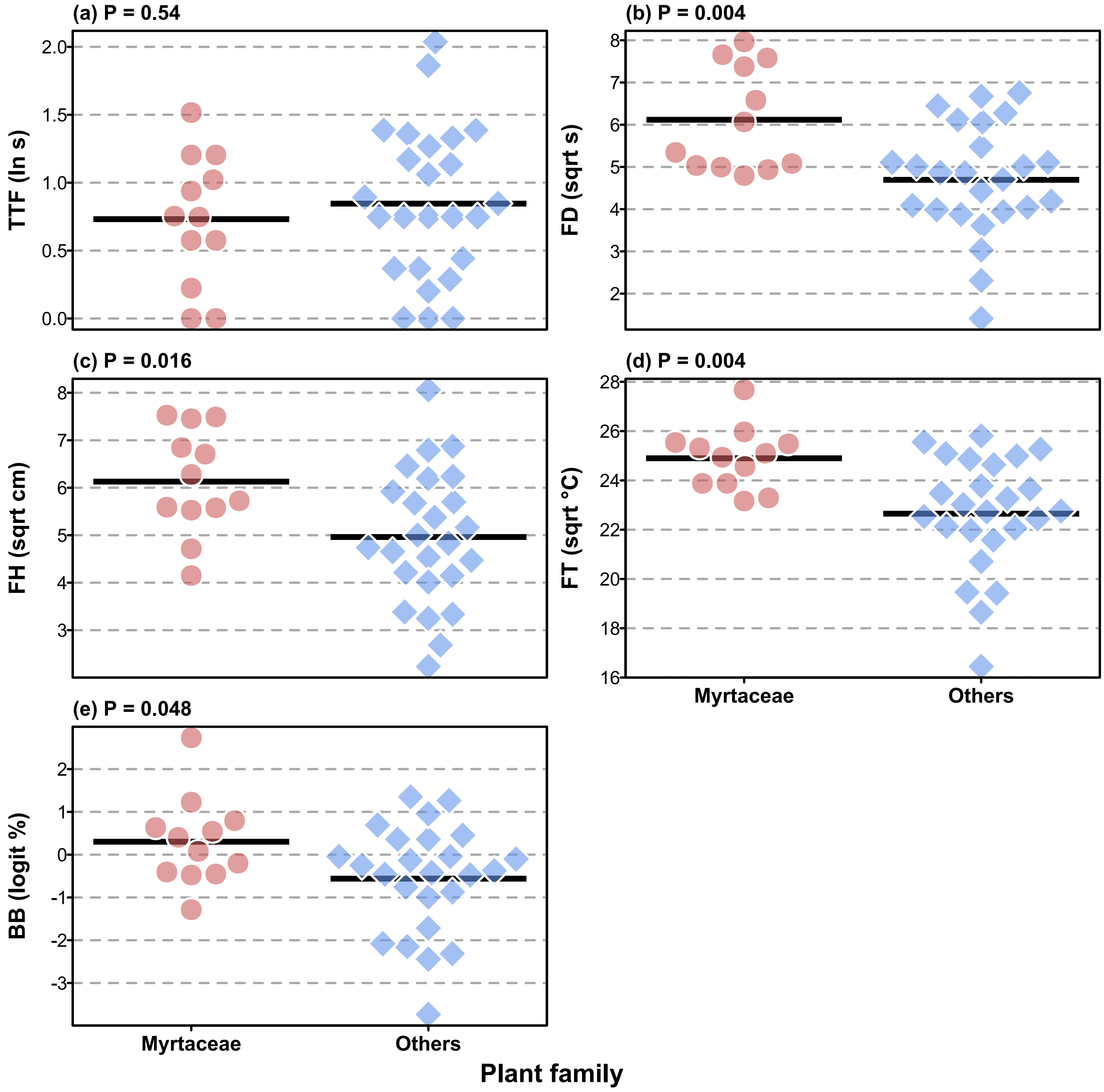

Fig. 3.11 Comparisons of the five flammability attributes (a) TTF, (b) FD, (c) FH, (d) FT, and (e) BB (y-axis), between Myrtaceous species and species in all other families. The mean (PGLS estimate, black line) for each group is shown with P values for the comparisons.

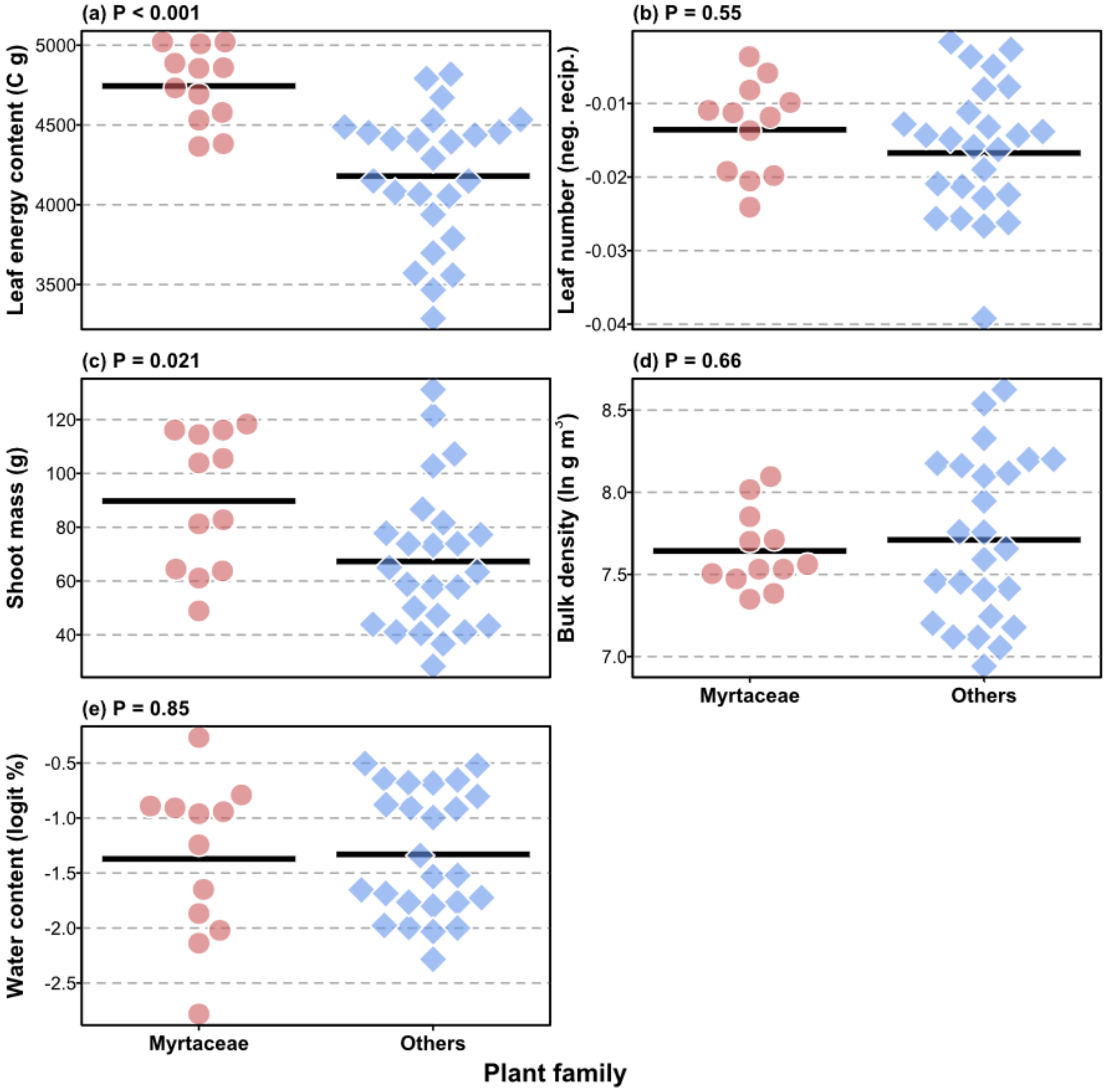

Fig. 3.12 Comparisons between Myrtaceous and non-Myrtaceous species of leaf and shoot traits that emerged as important predictors of shoot flammability. The mean (PGLS estimate, black line) for each group is shown with P values for the comparisons.

Chapter 4 | Discussion

4.1 Were the aims of this thesis met?

The research presented in this thesis, focused in common tree species of wet forests in the Barrington Tops region, aimed to (i) determine inter-species variation in five shoot flammability attributes; (ii) quantify pairwise inter-species relationships between each of the five flammability attributes; (iii) compare inter-species variation in eight shoot traits; (iv) determine relationships between shoot flammability attributes and leaf and shoot traits; and (v) compare shoot flammability between species in the Myrtaceae and non-Myrtaceous species. All of these aims were met and explored thoroughly in this thesis. In summary, I showed that (i) there were significant inter-species differences in the five shoot flammability attributes including TTF, FD, FH, FT, and BB; (ii) all pairwise relationships between flammability attributes were significant; (iii) there were significant variation in eight shoot traits including shoot mass, branch number, bulk density, water content, leaf area, leaf mass per area, leaf number and leaf energy content, (iv) found that there was significant relationships between species attributes and traits that could explain a species flammability, and (v) found that Myrtaceae were significantly higher in flammability compared to all other plant families examined in this study. In what follows, I delve into my findings, contextualise them in relation to research in plant shoot flammability, and discuss their implications for wildfire management and future research directions.

4.2 Variation in shoot flammability attributes among species

Many parts of the world including the study region of the Barrington Tops are expected to experience increased fire susceptibility as a direct result of anthropogenic activities such as land use alterations, climate change, and global warming (Boer et al. 2020; Kloss et al. 2021; Cui et al. 2023). As such, it is becoming increasingly important to obtain accurate measurements of plant flammability to understand plant responses to fire and to develop effective fire management strategies in fire-prone environments and those that are expected to become fire prone. Shoot flammability as examined in this thesis refers to the propensity of plant shoots, including leaves and twigs, to catch fire and burn under certain conditions. It is an essential aspect of fire-prone ecosystems to understand as it affects fire behaviour and can influence fire spread, intensity, and duration (Burger & Bond, 2015; Calitz et al., 2015). Research on shoot flammability at a global scale is still in its early stages, as to date, only a few hundred plant species have been tested worldwide (Jaureguiberry et al., 2011; Burger & Bond, 2015; Calitz et al., 2015; Wyse et al., 2016; Padullés Cubino et al., 2018), with no previous studies conducted in The Barrington Tops National Park or the Hunter Valley region. A landscaping approach to safeguard lives, infrastructure and biodiversity includes the selection of low-flammability plant species in a given environment, from largescale rural areas to smaller compact urban areas. Plants of low flammability have the potential to reduce the rate, spread and intensity of fires (Murray et al, 2018; Murray et al. 2020). In understanding and planting species that promote biodiversity, are non-poisonous, provide multiple benefits (e.g., cooling, pollution mitigation) and are of low flammability, it has the potential to alter the way we coexist with our environment (Detweiler and Fitzgerald 2006; Farrell et al. 2022). As these species would thrive harmoniously within diverse ecosystems, their presence would provide a sense of security and help to reshape our relationship with nature into one of cohabitation rather than conflict (Farrell et al. 2022).

Significant variation in TTF among the studied species indicates that different plant species exhibit different and distinct ignition responses when exposed to fire. This variability in TTF at a shoot level suggests that certain plant species are more prone to rapid ignition and could potentially lead to faster fire spread in ecosystems that have these quick to ignite species present (Himoto K. 2023). For example, species such as *Acacia maidenii*, *Eucalyptus resinifera*, and *Callistemon salignus* showed fast ignitions, with TTF values as short as 1 second. These quick ignition times suggest that these plants would not be suitable for use close to residential areas as they are likely to spread fire quickly leaving less time for evacuation of areas during wildfire events. On the other hand, species such as *Croton verreauxii* and *Cryptocarya glaucescens* exhibited commensurately slower ignition times of 7.7 seconds and 6.4 seconds, suggesting that they would spread fire slower and allow for greater chance of evacuation in these areas to occur.

In ecosystems that have evolved extensively with fire and require it as part of seed germination and reproduction cycles, the characteristic of longer FD might be beneficial as these species would be exposed to flames over longer periods of time (Pausas and Moreira 2012). The significant variation in FD among species reflects variations in the duration of flames after ignition. Species like *Ficus coronata* and *Croton verreauxii* had the shortest FDs, with values of 2.0 seconds and 5.3 seconds. Conversely, *Myrtaceae* species, such as *Callistemon salignus* and *Eucalyptus campanulata*, exhibited relatively long FDs, with durations of 63.4 seconds and 57.5

seconds. A study by Crisp et al. (2011) found that fire adaptive traits including epicormic sprouting is common among eucalypts and Myrtaceae, making them ideal carbon banks compared to other fire-renewing biomes. A method of carbon sequestration by allowing the growth of these species may help to offset the production of carbon dioxide, a driver of increasing global temperatures (Deyn et al. 2008; Gordon et al. 2018).

FH among species varied significantly and indicates that plant species produce flames of varying vertical extent. *Ficus coronata* had the shortest FH at 5 centimetres, while *Eucalyptus campanulata* had the tallest FH at 65 centimetres. A modelled study on flame dimensions by Zylstra et al. (2016), found that individual plant species impact flame height however, the final flame height was influenced by a complex interplay of various factors, including environmental characteristics, specific leaf traits, and the overall fire dynamics in the site being analysed. FH variability can influence fire behaviour, affecting factors such as radiant heat output and the potential for fire to reach higher vegetation or structures (Zylstra 2013; Cruz et al. 2005). Understanding how high flames reach in particular environments and species is imperative as crown fires are more difficult to control than surface fires, their rate of spread is significantly faster, it is often where animals seek refuge and spotting can occur over long distances (Scott 2001; Pausas 2019). Lower flame producing species such as *Ficus coronata* can be used to create areas of refuse and green breaks and may be able to slow the continuity of crown fires.

Variation in FT can impact fire intensity, with higher temperatures promoting more intense and severe fires while lower FT may promote less intense fires and may be effective as green fire breaks to slow the progression of wildfires (Alexander

2010; Krix et al. 2022). The FT among species was observed to vary significantly and reveals differences in the maximum temperature at which flames burn during combustion. Species like *Ficus coronata*, *Croton verreauxii*, and *Psychotria loniceroides* burned at lower temperatures (270.6°C, 377.3°C, and 378.9°C), and would be suited for inclusion in green breaks (Murray et al, 2018; Murray et al. 2020) and populated areas as fire intensity could potentially be decreased by the presence of these species. While other species such as *Grevillea robusta*, *Eucalyptus campanulata*, *Eucalyptus siderophloia*, and *Callistemon salignus* burned at significantly higher temperatures (624.4°C, 766.0°C, 649.6°C, and 622.0°C), suggesting that they would be ill suited areas of high population as they may produce intense fires of great risk to human life and infrastructure (Wotton et al 2011).

The variability in BB can influence fire severity and post-fire ecological responses, as different levels of biomass consumption may result in varying degrees of vegetation damage and recovery (Giuseppee et al. 2021; Lauk et al. 2009). The significant variation in BB among species indicates that there are differences in the amount of shoot biomass consumed during fire events. In an applied context it may be best to target species such as *Eucalyptus campanulate* that experienced significant biomass consumption of 94%, to burn greater biomass during times of backburning to quickly reduce full load under the right climatic and environmental conditions. While in areas where large burns would not be suitable species such as *Ficus coronate* that had minimal biomass burnt (less than 5%), would be appropriate to target for backburning. Information on a specific species flammability and particularly its BB may be of use for fire management plans and backburning as another factor to consider when performing these operations and provide greater outcomes not only for the environment but human health.

I found that there was considerable variation among species in all five dimensions of shoot flammability. This observation aligns with several previous studies that have demonstrated that plant shoot specific flammability varies significantly among species (Alam et al. 2019; Cornwell et al. 2015; Simpson et al. 2016; Wyse et al. 2016). My study found that *Callistemon salignus*, *Eucalyptus campanulata and Grevillia robusta* was consistently high (fast TTF, long FD, large FH, strong FT, and high BB) while *Croton verreauxii*, *Cryptocarya glaucescens and Psychotria loniceroides* was consistently low across all flammability attributes (slow TTF, sort FD, small FH, low FT, small BB). Considering this difference in flammability it would be important to next determine the abundance of each species and investigate if they pose a risk to these wet forest ecosystems. A vegetation study completed in 1995 by Binns and in 2000 by Zoete, surveyed the Barrington region and both found that *Eucalyptus campanulata* was widely abundant and frequently occurring within the region and *Callistemon salignus* was moderately abundant in certain areas. They also found that *Cryptocarya glaucescens* and *Psychotria loniceroides* was highly abundant in small areas, while *Croton verreauxii* was rare. These wet habitats have previously not been exposed to great intensity or frequent fires but under the changing climate are expected to be at greater risk (Westerling & Bryant 2008; Krawchuk et al. 2009; Vardoulakis et al. 2020; Cardil et al. 2021; van Oldenborgh et al. 2021). The abundance of the highly flammable species, *Eucalyptus campanulate*, in these habitats suggests that if and when these areas do burn, they may be exposed to fires of greater intensity and destruction.

4.3 Relationships between shoot flammability attributes

An important finding in this thesis was the strong correlations observed between pairs of these five flammability attributes, whereby, species that exhibited low flammability in one dimension (e.g., TTF as a measure of ignitability) also exhibited low flammability in all other dimensions tested in this study. This suggests that any one of the five measured attributes could serve as an indicator of plant shoot flammability. A similar finding was shown in Alam et al. (2020a), where each flammability attribute also served as an indicator of low or high flammability, and almost half of the variation in shoot flammability could be explained by the four traits measured in their study being ignition percentage, maximum flame temperature, burn time, and biomass consumed.

My findings demonstrate that TTF is inversely associated with all other flammability attributes (FD, FH, FT, BB). This negative correlation implies that as a species ignites more quickly, it is likely to have a longer-lasting flame, a greater flame height, hotter flames, and a larger burned area. In contrast, the other four flammability attributes (FD, FH, FT, BB) exhibit positive pairwise relationships. This means that longer FD is linked to taller FH, higher FT, and larger BB. Similarly, taller FH is associated with higher FT and larger BB, while higher FT corresponds to a larger BB. Considering these findings, an example of a species that possesses a fast TTF is *Callistemon salignus*. Due to its quick ignition, it experiences prolonged FD, a towering FH, intensely high FT, and a wide BB, suggesting that *Callistemon salignus*, despite being relatively slow to ignition, tends to exhibit a more intense and extended flames. This ignitability behaviour may have implications for its survival and interaction with its environment such as an increased frequency and intensity of fire, habitat destruction, production of carbon emissions, biodiversity loss and impact to human health through lowering of air quality due to smoke and particulate matter, endangerment to life and loss of infrastructure (Haque et al 2011; Bayham et al. 2022).

Understanding these inter-species relationships contributes to our comprehension of fire ecology and management strategies across various ecosystems. The ideal low-flammability species is described as taking a long time to ignite (low ignitability), burns for a short duration (low sustainability) burns at a relatively low temperature (low combustibility), and does not consume much biomass (low consumability) (Murray et al. 2020). Identifying ideal low flammability species my prove difficult as my results at a shoot scale indicate that TTF is inversely related to all these attributes. These results have been observed by several previous studies at the leaf (de Magalhaes and Schwilk 2012; Krix et al. 2019; Alam et al. 2020b) and shoot level (Padullés Cubino et al. 2018; Dent et al. 2019; Msweli et al. 2020). One possible use for species with low flammability is in the creation of green firebreaks, that are intended to slow down the spread of fires (Curran et al., 2018; Murray et al., 2018). However, the findings of this study indicate that there aren't any species with consistently low flammability across all aspects of flammability. This implies that fire managers and appropriate parties might need to make a choice between two options: a species that takes a while to catch fire, but then burns for an extended periods at high temperatures, consumes much biomass and produces high flames; or select species that ignite quickly, burn briefly, doesn't reach as high temperatures during combustion, consumes little biomass and produces small flames. This emphasizes the significance of separately assessing each attribute of flammability when categorizing the flammability attributes of plants. Combining these attributes into a single index would overlook the specific details about how each plant burns in terms of ignitability, sustainability, combustibility and consumability.

4.4 Relationships between shoot flammability and leaf and shoot traits

There was significant variation in shoot flammability between the 38 plant species researched in my study. As such I sought to understand and identify the leaf and shoot traits responsible for driving this variation. In my research the strongest predictor of TTF was the number of leaves on a shoot. With faster ignition times being associated with a relatively high number of leaves. Given that leaves commonly serve as the primary ignition site for plants (Gill & Zylstra, 2005; Murray et al., 2013), it is foreseeable that a higher leaf count on shoots amplifies the likelihood of an earlier ignition at that specific point, as opposed to shoots with fewer leaves (Alam et al. 2020). Additionally, FD was found to be heavily influenced by the number of leaves on a shoot. When there are more leaves on a shoot, the overall biomass available for combustion is greater (Burger and Bond 2015). This means that there's more material that can be heated, vaporized, and ultimately ignited by fire (Schwilk 2003; Burger and Bond 2015; Calitz et al. 2015). Additionally, a higher leaf count can lead to a denser arrangement of foliage, potentially creating a pathway for flames to propagate across the surface of the plant resulting in longer burning durations (Cowan and Ackerly 2010; Calitz et al. 2015). A study by Calitz et al. (2015) using the methodology used by Jaureguiberry et al. (2011), found that finely branched, densely packed, small and highly leaved Fynbos shrubs, where some of the highest flammability among the species they recorded across all attributes including long flaming times.

Leaf energy content was the largest predictor of both FH and BB, with higher energy contents producing larger flames and consuming more of the shoot. A higher leaf energy content can contribute to larger flames on a plant species due to the relationship between fuel availability, heat release, and combustion dynamics. The energy content of leaves refers to the amount of stored chemical energy, typically in the form of carbohydrates, fats, and other combustible compounds (Ormeño et al. 2020; Guerrero et al. 2021). When these compounds undergo combustion, they release heat energy, which drives the flames and sustains the fire. As leaves with higher energy content burn, they release more heat energy per unit of fuel. This increased heat release contributes to higher temperatures within the fire zone, promoting more vigorous combustion and larger flames (Finney et al. 2011). My study also found that leaf energy content was a primary driver of FD and FT, meaning when leaves with high energy content burn, they release enough heat to sustain the combustion of neighbouring leaves and other plant parts. These larger flames have more potential to ignite adjacent plant parts, including leaves and branches. As flames touch these new fuel sources, the fire can transition and propagate rapidly, resulting in a more expansive fire front and taller flames (Babrauskas and Peacock 1992). This interplay of fuel availability, heat release, and combustion dynamics contributes to the overall size and intensity of flames as well as how much of the shoot is consumed of individual plant species. I found that shoot mass was another strong indicator of FD. The greater number of leaves can result in a higher fuel load in the immediate vicinity of the ignition source. This can facilitate the transfer of heat and fire to adjacent leaves, promoting faster ignition across the entire plant.

The greatest predictors in my study of FT were leaf energy content, bulk density, and shoot water content. It has been observed that certain species exhibit characteristics such as high bulk density and large volume, which are associated with increased flammability in terms of sustainability, combustibility and consumability. Similar findings have been reported in various studies (Grootmaat et al. 2017; Wyse et al. 2018; Alam et al. 2019; Murray et al. 2020; Burton et al. 2021), which have established a negative correlation between fuel bulk density and volume with fire spread, but a positive correlation with burn time and maximum flame temperature. These relationships can be attributed to the influence of oxygen availability, which affects the time to ignition and maximum temperature of the shoot, as well as the availability of fuel, which impacts the duration of burning (Pausas et al. 2017). Furthermore, Pausas et al. (2017) suggested that canopies with higher volumes and bulk density might benefit species that rely on fire for seed germination and reproduction, as they can withstand exposure to flames for longer periods. At the leaf litter level, bulk density is a critical factor affecting flammability, with Burton et al. (2021) linking bulk density to predicted flame spread rate and flame duration, while the packing ratio is associated with predicted consumption. I expected plant species found in wet forest habitats to be of low flammability mainly due previous research stating that water content is a principal indicator of flammability, with numerous studies finding that species, particularly at the leaf level, with high water content were low in flammability (Alam et al. 2019; Cornwell et al. 2015; Simpson et al. 2016; Wyse et al. 2016; Krix et al. 2018; Krix et al. 2019; Krix et al. 2022).

However, my results indicate that some wet habitat species are indeed highly flammable and other traits may be a larger driver of flammability at the shoot level.

The implications stemming from the correlations between specific traits and flammability, serve as a foundation for prospective exploration on a grander scale, with implications for fire management, intricate modelling, and landscape design. Plant composition and their species-specific traits that drive flammability could be combined with existing fire management practices to lead towards more encompassing and widely adaptable prognostications concerning ecosystems (Zylstra et al. 2016; Scarff et al. 2021).

4.5 Myrtaceae evolutionary patterns in shoot flammability

My study found that Myrtaceous species exhibited significantly higher flammability in the dimensions of FD, FH, BB, leaf energy content, and shoot mass compared to other plant species tested in this study. This could be largely due to a combination of biological and ecological traits as many Myrtaceous species have small, leathery leaves containing volatile compounds like oils and resins that can quickly vaporize and ignite (Crisp et al. 2011; Grattapaglia et al. 2012; Mitra et al. 2012; Popović et al. 2021; Potts et al. 2022). In certain ecosystems, Myrtaceous species have evolved to capitalize on fire, with some producing seeds that germinate after fires (Crisp et al. 2011; Grattapaglia et al. 2012; Mitra et al. 2012). It should be noted that not all Myrtaceae have evolved in currently fire prone environments and therefore it is expected that flammability varies among the different exist genera and species within the Myrtaceae family (Crisp et al. 2011). Further research is warranted to explore the underlying mechanisms and ecological consequences of these flammability adaptations within the Myrtaceae family.

4.8 Limitations and future directions

Future research directions in the field of vegetation flammability can build upon the insights obtained from this study, which focused on shoot flammability. While this study provides valuable insights into the flammability of individual shoots, there is a pressing need to bridge the gap between shoot-level flammability and the flammability of whole plants. Addressing this challenge requires innovative methodologies that can effectively assess the fire susceptibility of entire trees, particularly in species similar to those investigated in this study. It is important to highlight that shoot level flammability, as investigated in this study, is distinct from flammability at the leaf level, as indicated by previous research (Alam et al., 2020a; Murray et al., 2013; Krix and Murray, 2018; Krix, Phillips, & Murray, 2019). The divergence between leaf-level and shoot-level attributes could potentially be attributed to branch architecture, which influences the arrangement of leaves and twigs. As such, further studies are warranted to better understand these differences and refine our understanding of plant flammability. While shoot flammability may be a closer representation of whole plant flammability care should be taken when scaling up to the whole plant level and indeed assemblages, as traits such as bark, species spacing, and numerous factors effecting whole plants and environments (e.g. weather, geography).

To validate the shoot flammability method employed, researchers could consider a comparative approach, similar to the approach undertaken by Wyse et al.

(2016). By collaborating with experts in the field, the flammability assessments of the study species and other vegetation assemblages can be cross-referenced with expert opinions. This approach could provide a more comprehensive understanding of the accuracy and reliability of the shoot flammability method, further solidifying its applicability in broader contexts. The exploration of leaf-level flammability and shoot flammability of the same species burnt at the same time presents another promising avenue for future investigation. Given that only one study (Alam et al. 2020a) has undertaken such an examination using data compilation and not fresh work, there is ample room for research in this area. Conducting controlled experiments involving the simultaneous burning of leaves and shoots using standardized protocols could yield insights into the extent to which leaf flammability can serve as an indicator of shoot flammability. This research could provide a more holistic understanding of plant fire responses and vulnerabilities.

In addition to shoot and leaf flammability, future studies should expand their focus to encompass various growth forms within the ecosystem, including shrubs and grasses. Investigating the flammability of these growth forms would enable researchers to develop a comprehensive understanding of vegetation assemblage-level flammability. The work done by Tim Curran and colleagues (Padullés Cubino et al. 2018) in assessing community-level flammability over an extended period, could serve as a model for such research. By studying how different growth forms contribute to overall flammability dynamics, researchers can better inform fire management strategies and ecosystem resilience in the face of changing fire regimes.

There is a suggestion that flammability can be influenced by factors such as fuel arrangement, fuel load, and continuity (Alam et al. 2019). The study conducted by

Alam et al. (2019) revealed significant insights indicating that leaf morphological and chemical traits are essential predictors of shoot flammability. Certain volatile organic compounds (VOCs) like terpenes, terpenoids, and leaf lignin have been extensively researched and have demonstrated an increase in leaf-level flammability (Alessio et al. 2008; Pausas et al. 2016). This observation could be partly explained by the Mutch (1970) hypothesis (Schwilk and Kerr 2002; Cowan and Ackerly 2010; Pausas et al. 2012; Burger and Bond 2015), which posits that plants in fire-dependent communities have evolved specific characteristics that may enhance their flammability.

Plant species ignitability and combustibility have been previously found to be influenced by the presence of volatile oils and leaf water content (Dickinson 1985; Dimitrakopoulos and Papaioannou 2001; Krix et al. 2019; Msweli et al. 2020; Cui et al. 2020; Kraaij et al. 2022; Zanzarini et al. 2022). The presence of volatile oils increases how quickly and how intensely a species burns (Dickinson 1985; Dimitrakopoulos and Papaioannou 2001). While higher water content increases the time a species takes to combust and lowers the temperature at which it does so (Msweli et al. 2020; Cui et al. 2020; Kraaij et al. 2022; Zanzarini et al. 2022). Future studies should look at the presence and make up of volatile oils as my study indicated leaf energy content was a significant driver of flammability, a study into the presence of volatiles could provide context as to what drives energy content.

For future investigations, it is recommended to explore these chemical traits, considering Australia's rich history of wildfire and cultural burning practices. Other traits such as leaf and twig energy content and branching structure should also be considered in further studies to determine their potential impact on species flammability. The outcomes of this research, along with ongoing studies on plant flammability, will aid fire and forest managers in making informed decisions regarding fuel management and improving vegetation fire modelling.

4.9 Conclusion

In this thesis I investigated the variation of flammability 38 wet habitat species occurring in the Barrington Tops region. I detailed the significant variation in terms of the attributes of ignitability, sustainability, combustibility and consumability and found significant pairwise relationships. I demonstrated that traits at leaf (energy content and leaf number) and shoot levels (bulk density, shoot mass and shoot water) were important predictors of shoot flammability. This variability and flammability relationships has important implications for fire management and modelling. Understanding these differences is crucial for developing effective strategies to mitigate fire risk, protect vulnerable ecosystems, and promote ecological resilience in the face of increasing fire threats due to anthropogenic activities and climate change.

Appendices

Appendix 1 | Images of Species Shoots

Fig. A1.1 Image of an example of 70 cm Shoot of *Acacia barringtonensis*.

Fig. A1.2 Image of an example of 70 cm Shoot of *Acacia irrorata.*

Fig. A1.3 Image of an example of 70 cm Shoot of *Acacia implexa*.

Fig. A1.4 Image of an example of 70 cm Shoot of *Acacia maidenii.*

Fig. A1.5 Image of an example of 70 cm Shoot of *Acacia melanoxylon.*

Fig. A1.6 Image of an example of 70 cm Shoot of *Ackama paniculate.*

Fig. A1.7 Image of an example of 70 cm Shoot of *Acmena smithii*.

Fig. A1.8 Image of an example of 70 cm Shoot of *Acronychia oblongifolia.*

Fig. A1.9 Image of an example of 70 cm Shoot of *Alphitonia excelsa.*

Fig. A1.10 Image of an example of 70 cm Shoot of *Callistemon salignus*.

Fig. A1.11 Image of an example of 70 cm Shoot of *Casuarina cunninghamiana*.

Fig. A1.12 Image of an example of 70 cm Shoot of *Ceratopetalum apetalum*.

Fig. A1.13 Image of an example of 70 cm Shoot of *Croton verreauxii*.

Fig. A1.14 Image of an example of 70 cm Shoot of *Cryptocarya glaucescens*.

Fig. A1.15 Image of an example of 70 cm Shoot of *Diospyros pentamera.*

Fig. A1.16 Image of an example of 70 cm Shoot of *Dysoxylum fraserianum*.

Fig. A1.17 Image of an example of 70 cm Shoot of *Elaeodendron australe*.

Fig. A1.18 Image of an example of 70 cm Shoot of *Eucalyptus campanulata*.

Fig. A1.19 Image of an example of 70 cm Shoot of *Eucalyptus fibrosa*.

Fig. A1.20 Image of an example of 70 cm Shoot of *Eucalyptus quadrangulata.*

Fig. A1.21 Image of an example of 70 cm Shoot of *Eucalyptus saligna*.

Fig. A1.22 Image of an example of 70 cm Shoot of *Eucalyptus siderophloia*.

Fig. A1.23 Image of an example of 70 cm Shoot of *Eucalyptus paniculata.*

Fig. A1.24 Image of an example of 70 cm Shoot of *Eucalyptus resinifera*.

Fig. A1.25 Image of an example of 70 cm Shoot of *Ficus obliqua*.

Fig. A1.26 Image of an example of 70 cm Shoot of *Ficus coronata.*

Fig. A1.27 Image of an example of 70 cm Shoot of *Grevillea robusta.*

Fig. A1.28 Image of an example of 70 cm Shoot of *Lophostemon confertus*.

Fig. A1.29 Image of an example of 70 cm Shoot of *Melicope micrococca.*

Fig. A1.30 Image of an example of 70 cm Shoot of *Mischocarpus australis*.

Fig. A1.31 Image of an example of 70 cm Shoot of *Myrsine variabilis*.

Fig. A1.32 Image of an example of 70 cm Shoot of *Neolitsea dealbata*.

Fig. A1.33 Image of an example of 70 cm Shoot of *Olearia argophylla*.

Fig. A1.34 Image of an example of 70 cm Shoot of *Pittosporum undulatum.*

Fig. A1.35 Image of an example of 70 cm Shoot of *Planchonella australis*.

Fig. A1.36 Image of an example of 70 cm Shoot of *Psychotria loniceroides*.

Fig. A1.37 Image of an example of 70 cm Shoot of *Syzygium australe.*

Fig. A1.38 Image of an example of 70 cm Shoot of *Tristaniopsis laurina*.

Appendix 2 | Results

Table A2.1 Sequence of terms dropped from PGLS models using shoot and leaf traits to explain variation in each of the flammability attributes (Response). The Order column indicates the order that terms were dropped from the models.

Response	Order	Term	Estimate	SE	t value	Res. DF	P
TTF	1	leaf area	0.000	0.011	-0.030	28	0.98
	2	shoot water content	0.101	0.170	0.593	29	0.56
	3	leaf energy content	0.000	0.000	0.765	30	0.45
	4	shoot bulk density	-0.172	0.194	-0.885	31	0.38
	5	shoot mass	0.002	0.003	0.737	32	0.47
	6	leaf mass per area	-0.108	0.145	-0.749	33	0.46
	7	branch number	-0.928	0.953	-0.975	34	0.34
FD	1	leaf area	0.000	0.022	-0.016	28	0.99
	2	shoot bulk density	0.163	0.376	0.432	29	0.67
	3	leaf mass per area	0.329	0.310	1.060	30	0.30
	4	branch number	-2.393	1.916	-1.249	31	0.22
	5	shoot water content	-0.287	0.295	-0.970	32	0.34
FT	1	leaf area	0.000	0.030	-0.013	28	0.99
	2	branch number	-0.725	2.708	-0.268	29	0.79
	3	leaf number	15.229	29.551	0.515	30	0.61
	4	leaf mass per area	0.202	0.421	0.480	31	0.63
	5	shoot mass	0.014	0.009	1.605	32	0.12
FH	1	leaf area	-0.001	0.030	-0.026	28	0.98
	2	shoot bulk density	-0.075	0.517	-0.146	29	0.89
	3	leaf mass per area	-0.134	0.425	-0.315	30	0.75
	4	shoot mass	0.004	0.009	0.430	31	0.67
	5	branch number	-2.622	2.533	-1.035	32	0.31
	6	leaf number	29.309	28.395	1.032	33	0.31
	7	shoot water content	-0.324	0.333	-0.974	34	0.34
BB	1	leaf mass per area	0.022	0.324	0.067	28	0.95
	2	shoot mass	-0.001	0.007	-0.117	29	0.91
	3	leaf number	22.410	26.789	0.837	30	0.41
	4	shoot bulk density	0.339	0.368	0.922	31	0.36
	5	branch number	-2.173	1.723	-1.261	32	0.22
	6	shoot water content	-0.427	0.256	-1.670	33	0.10
	7	leaf area	-0.028	0.018	-1.518	34	0.14

Table A2.2 Table showing PGLS models, their formulae or response variable, AIC values for BM and branch length transformations, the selected branch length used in the final models (shown in the Transform column), and model significance (P) estimated for the branch length transform in a given model.

Model	Formula or response	Brownian	Lambda	Kappa	Delta	Transform	P
Bivariate models	TTF ~ FD	138.49	127.85	132.84	129.72	lambda	< 0.001
	TTF ~ FH	138.76	127.17	131.79	129.86	lambda	< 0.001
	TTF ~ FT	143.98	130.93	136.8	134.96	lambda	< 0.001
	TTF ~ BB	134.36	125.42	131.14	126.58	lambda	< 0.001
	FD ~ FH	308.76	285.68	294.41	295.15	lambda	0.042
	FD ~ FT	296.67	275.95	287.99	284.36	lambda	< 0.001
	FD ~ BB	303.75	284.27	293.59	290.52	lambda	0.089
	FH ~ FT	299.09	290.81	296.46	292.11	lambda	< 0.001
	FH ~ BB	274.77	270.79	273.85	269.91	delta	3.000
	FT ~ BB	434.58	412.42	410.77	421.46	kappa	0.029
Flammability ~ traits	TTF	82.44	61.26	70.22	73.55	lambda	< 0.001
	FD	135.47	108.49	125.36	123.61	lambda	< 0.001
	FT	147.10	132.43	135.65	139.67	lambda	< 0.001
	FH	143.37	131.96	136.93	136.55	lambda	< 0.001
	BB	130.52	109.01	123.37	120.95	lambda	< 0.001
Flammability ~ Myrtaceous/ non-Myrtaceous	TTF	83.42	60.82	68.84	70.81	lambda	< 0.001
	FD	159.28	126.33	142.24	143.74	lambda	< 0.001
	FT	189.01	160.22	170.28	174.53	lambda	< 0.001
	FH	145.34	127.5	140.57	134.78	lambda	< 0.001
	BB	146.3	119.79	136.77	131.90	lambda	< 0.001
Traits ~ Myrtaceous/ non-Myrtaceous	Leaf energy content	574.58	545.44	560.56	559.41	lambda	< 0.001
	Leaf number	-236.23	-247.91	-241.73	-243.55	lambda	0.450
	Shoot mass	385.58	349.53	366.39	369.05	lambda	< 0.001
	Bulk density	73.28	45.29	56.94	59.90	lambda	< 0.001
	Water content	86.21	71.74	82.03	75.12	lambda	< 0.001

Table A2.3 Shoot flammability attributes for all plant species used in this study (mean values across all replicates for each species).

Species	TTF (s)	FD (s)	FT (°C)	FH (cm)	BB (%)
Acacia barringtonensis	1.0	25.2	465.6	22.4	46.7
Acacia irrorata	0.6	22.5	536.4	30.0	40.6
Acacia implexa	0.3	22.9	507.8	26.1	57.4
Acacia maidenii	2.1	39.4	629.2	20.6	58.9
Acacia melanoxylon	4.0	15.0	529.9	17.2	31.9
Ackama paniculata	3.2	23.7	551.2	23.3	43.8
Acmena smithii	1.9	27.4	540.0	46.1	56.1
Acronychia oblongifolia	2.1	19.6	638.3	41.7	72.2
Alphitonia excelsa	3.9	26.1	516.4	11.1	29.4
Callistemon salignus	1.0	63.4	622.0	56.7	77.3
Casuarina cunninghamiana	0.4	47.4	544.1	33.3	57.8
Ceratopetalum apetalum	3.8	16.4	428.9	17.8	11.1
Croton verreauxii	7.7	5.3	377.3	7.2	9.0
Cryptocarya glaucescens	6.4	9.2	503.6	10.6	8.0
Diospyros pentamera	2.9	25.2	508.0	38.3	40.8
Dysoxylum fraserianum	1.4	37.4	653.2	46.1	61.1
Elaeodendron australe	2.1	23.7	489.8	38.9	47.4
Eucalyptus campanulata	2.6	57.5	766.0	56.1	93.9
Eucalyptus fibrosa	2.1	58.7	674.3	39.4	45.0
Eucalyptus quadrangulata	3.3	23.0	630.2	31.1	60.0
Eucalyptus saligna	1.8	43.3	652.2	30.6	65.3
Eucalyptus siderophloia	3.3	54.4	649.6	55.6	68.9
Eucalyptus paniculata	4.6	25.0	570.2	17.2	21.7
Eucalyptus resinifera	1.0	36.8	641.2	32.8	38.3
Ficus obliqua	1.2	30.1	565.4	26.7	39.7
Ficus coronata	2.1	2.0	270.6	5.0	2.3
Grevillea robusta	1.3	44.5	624.4	65.0	66.7
Lophostemon confertus	1.8	24.4	570.2	45.0	63.3
Melicope micrococca	1.6	15.5	486.7	16.1	15.2
Mischocarpus australis	2.1	36.8	618.1	21.7	38.3
Myrsine variabilis	1.4	22.1	541.4	32.2	58.9
Neolitsea dealbata	2.4	15.9	559.6	28.9	48.9
Olearia argophylla	4.0	16.7	347.8	20.0	27.1
Pittosporum undulatum	3.1	17.6	482.6	47.2	48.9
Planchonella australis	2.3	41.6	666.0	25.0	79.4
Psychotria loniceroides	3.6	13.1	378.9	11.4	10.4
Syzygium australe	1.3	25.3	603.3	31.3	40.0
Tristaniopsis laurina	2.8	25.8	542.6	22.2	38.9

Table A2.4 Shoot traits for all plant species used in this study (mean values across all replicates for each species).

Species	**Mass (g)**	**Branch number**	**Bulk density (m^3)**	**Water content (%)**
Acacia barringtonensis	60.9	8.7	1658.6	12.2
Acacia irrorata	69.9	30.0	1235.3	17.8
Acacia implexa	52.6	30.7	3556.0	16.1
Acacia maidenii	34.4	4.7	3639.1	12.0
Acacia melanoxylon	55.7	11.3	1980.1	29.4
Ackama paniculata	76.9	7.8	1866.7	28.0
Acmena smithii	49.8	18.7	2343.7	11.6
Acronychia oblongifolia	121.5	10.8	1310.7	34.2
Alphitonia excelsa	65.2	14.0	2211.7	43.3
Callistemon salignus	118.9	16.3	4136.5	37.2
Casuarina cunninghamiana	81.3	13.2	3504.5	14.6
Ceratopetalum apetalum	85.6	13.5	1158.4	34.4
Croton verreauxii	87.1	14.4	3642.4	15.1
Cryptocarya glaucescens	119.8	5.3	1401.0	20.7
Diospyros pentamera	57.7	3.7	3351.7	9.2
Dysoxylum fraserianum	157.4	8.8	1725.4	17.9
Elaeodendron australe	82.4	11.5	3029.8	10.5
Eucalyptus campanulata	121.6	3.2	1610.3	5.8
Eucalyptus fibrosa	126.6	59.5	2236.4	13.4
Eucalyptus quadrangulata	92.7	5.2	3279.1	31.2
Eucalyptus saligna	136.4	11.5	1554.0	16.1
Eucalyptus siderophloia	46.9	10.0	1865.6	22.4
Eucalyptus paniculata	36.8	10.5	1759.7	11.7
Eucalyptus resinifera	70.5	25.3	1034.0	30.9
Ficus obliqua	72.6	6.0	1648.0	15.6
Ficus coronata	20.4	42.0	2112.3	28.6
Grevillea robusta	49.2	4.5	1817.1	27.7
Lophostemon confertus	50.7	4.8	3289.8	33.7
Melicope micrococca	53.4	4.3	2338.6	27.0
Mischocarpus australis	82.2	3.8	1344.1	28.8
Myrsine variabilis	65.6	8.5	5110.2	37.6
Neolitsea dealbata	36.7	7.2	1234.4	33.6
Olearia argophylla	52.5	3.2	1735.8	14.6
Pittosporum undulatum	56.0	4.2	5564.3	14.2
Planchonella australis	85.7	5.3	2827.2	11.9
Psychotria loniceroides	125.9	3.3	1921.3	28.7
Syzygium australe	65.3	17.8	2569.9	29.1
Tristaniopsis laurina	28.4	8.7	1658.6	12.2

Table A2.5 Leaf traits for all plant species used in this study (mean values across all replicates for each species).

Species	**Leaf area (mm^2)**	**Leaf mass per area (mg/mm^2)**	**Leaf number**	**Leaf energy content (J/g)**
Acacia barringtonensis	1248.2	0.40	44.7	14509.0
Acacia irrorata	2.3	0.00	6650.0	17669.8
Acacia implexa	285.3	1.43	129.5	18573.8
Acacia maidenii	1513.6	0.84	47.8	20172.3
Acacia melanoxylon	1508.1	0.18	69.8	18652.7
Ackama paniculata	678.0	0.25	274.3	18452.3
Acmena smithii	1912.8	0.44	170.3	16868.5
Acronychia oblongifolia	1407.4	0.47	67.5	17371.2
Alphitonia excelsa	1217.5	0.60	126.6	18348.5
Callistemon salignus	1862.2	0.53	67.5	19368.3
Casuarina cunninghamiana	1431.0	0.41	129.3	18176.9
Ceratopetalum apetalum	1418.1	0.45	139.3	18097.6
Croton verreauxii	1541.5	0.48	116.7	18038.5
Cryptocarya glaucescens	1752.7	0.42	25.5	15480.8
Diospyros pentamera	1399.3	0.45	47.0	16485.8
Dysoxylum fraserianum	1252.7	0.50	69.8	17369.7
Elaeodendron australe	1402.6	0.46	63.0	18959.7
Eucalyptus campanulata	1857.4	0.68	91.3	20969.3
Eucalyptus fibrosa	1797.9	0.29	122.3	20462.2
Eucalyptus quadrangulata	1481.4	0.68	88.8	21020.5
Eucalyptus saligna	1352.7	0.65	84.5	21017.0
Eucalyptus siderophloia	3175.0	0.94	52.0	19169.2
Eucalyptus paniculata	2662.5	1.03	50.5	20325.8
Eucalyptus resinifera	3239.4	0.96	73.0	19813.7
Ficus obliqua	1754.1	0.55	72.3	17076.0
Ficus coronata	1721.6	0.40	124.0	13763.8
Grevillea robusta	869.6	0.50	376.5	18785.7
Lophostemon confertus	1909.7	0.49	48.7	18349.0
Melicope micrococca	1845.2	0.55	38.2	16978.2
Mischocarpus australis	1762.9	0.47	82.2	17971.8
Myrsine variabilis	980.9	0.66	78.0	18637.7
Neolitsea dealbata	1872.1	0.57	61.5	18480.7
Olearia argophylla	1766.6	0.41	39.0	15864.8
Pittosporum undulatum	1244.2	0.47	37.5	18981.3
Planchonella australis	1663.8	0.53	89.3	19559.7
Psychotria loniceroides	1987.0	0.49	43.8	14899.7
Syzygium australe	2555.6	0.49	101.3	19643.5
Tristaniopsis laurina	2700.0	0.76	41.5	18276.7

Table A2.6 Table showing PGLS models for simplified models of flammability attributes explained by shoot and leaf traits.

Response	**Trait**	**Estimate**	**SE**	**t value**	**Res. DF**	**P**
TTF	leaf number	-30.803	9.567	-3.220	35	0.003
FD	leaf number	49.015	21.046	2.330	33	0.026
	leaf energy content	0.001	0.000	3.570		0.001
	shoot mass	0.020	0.006	3.500		0.001
FT	leaf energy content	0.004	0.000	7.730	33	< 0.001
	shoot bulk density	1.280	0.499	2.570		0.015
	shoot water content	-0.978	0.346	-2.830		0.008
FH	leaf energy content	0.002	0.000	3.660	35	< 0.001
BB	leaf energy content	0.002	0.000	4.990	35	< 0.001

Table A2.7 Table showing PGLS models comparing Myrtaceous and non-Myrtaceous species in flammability attributes and shoot and leaf traits which emerged as significantly related to flammability attributes.

Response	Explanatory	DF	SS	F	P
TTF	Myrtaceae or other	1	0.001	0.377	0.54
	Residuals	35	0.074		
FD	Myrtaceae or other	1	0.120	9.688	0.004
	Residuals	35	0.435		
FT	Myrtaceae or other	1	0.302	9.720	0.004
	Residuals	35	1.087		
FH	Myrtaceae or other	1	0.082	6.424	0.016
	Residuals	35	0.449		
BB	Myrtaceae or other	1	0.044	4.203	0.048
	Residuals	35	0.364		
Leaf energy content	Myrtaceae or other	1	19032.024	18.441	< 0.001
	Residuals	35	36121.809		
Leafing intensity	Myrtaceae or other	1	< 0.001	0.356	0.55
	Residuals	35	< 0.001		
Shoot mass	Myrtaceae or other	1	30.037	5.801	0.021
	Residuals	35	181.224		
Bulk density	Myrtaceae or other	1	< 0.001	0.194	0.66
	Residuals	35	0.049		
Water content	Myrtaceae or other	1	< 0.001	0.036	0.85
	Residuals	35	0.099		

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