Chapter 1
The Ecological and Applied Potential of *Baccharis*

G. Wilson Fernandes, Yumi Oki, and Milton Barbosa

Abstract The genus *Baccharis* is composed of ca. 440 species, distributed primarily in South and Central America, many of which are of great ecological, economic, and cultural importance. *Baccharis* species are mostly dioecious and highly diverse in chemistry, ecology, architecture, and phenology, occupying many different niches and habitats across several gradients of light, temperature, humidity, altitude, and succession. Its species are found in natural, urban, and highly polluted environments. Many species host a large number of associated organisms, including the largest fauna of gall-inducing insects in the Neotropics, and play crucial roles in biodiversity maintenance as foundation species or ecosystem engineers, while others are invasive species with economic implications around the world. Many species are geographically restricted or endemic. *Baccharis* is also well known for being the source of innumerable chemical compounds widely used in folk medicine and in the cosmetics and pharmaceutical industries. It is one of the most studied genera in the world, owing to these multiple factors that have captured the attention of the scientific community.

Keywords Asteraceae · Bioeconomy · Ecosystem engineer · Foundation species · Nurse species · Plant-animal interactions

1 The Universe of *Baccharis*

The genus *Baccharis* is relatively large with ca. of 440 species so far described in the New World. Its distribution is broad, ranging from 55 degrees South (*Baccharis magellanica*: Isla Hornos, Chile: Lat −55.9416629, Lon −67.26916559) to 43 degrees North (*Baccharis halimifolia*: Nova Scotia, Canada: Lat 43.99676, Lon −65.869709); therefore, with an estimated 11,187 km distance between the most extreme species populations. *Baccharis pilularis* has the northwestern-most

G. W. Fernandes (✉) · Y. Oki · M. Barbosa
Ecologia Evolutiva & Biodiversidade/DGEE, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil

G. W. Fernandes et al. (eds.), *Baccharis*,
https://doi.org/10.1007/978-3-030-83511-8_1

distribution (Seattle, EUA: Lat 47.660917, Lon −122.42093). The species of *Baccharis* are found from sea level at both the Pacific and Atlantic oceans up to 5050 meters above sea level in the Andes. They inhabit forests, savanna, grassland, peat bogs, rocky outcrops, and desert ecosystems. They survive in mesic and xeric habitats, under saline conditions, in the shade and the sun, in extremely nutrient-impoverished environments, and even in polluted or contaminated areas. Many are early succession species (Westman et al. 1975), thriving in habitat conditions where nutrients and light are abundant. Some are rare and endemic to very specific habitats. *Baccharis* range from small herbaceous to treelet species and lianas, while some species are aphyllous. They are mostly dioecious and evergreen and provide the basis for the assembly of many animal communities and, in some cases, function as nurse species. The genus likely underwent true adaptive radiation in the New World, an aspect yet to be explored.

Several species of *Baccharis* are important whether for their beneficial or harmful effects (Palmer 1986; Boldt and Robbins 1987, 1990; Boldt 1989; Palmer and Haseler 1992a, b; Palmer and Tomley 1993; Palmer et al. 1993; Torres et al. 2000; Park et al. 2004; Oliveira et al. 2005; Abad and Bermejo 2007; Morales et al. 2008; Resende et al. 2012; Rabelo and Costa 2018; Cock and Hierro 2020; Schild et al. 2020). Beneficial effects include their use in controlling erosion, as ornamental plants or as a hedge (Thompson et al. 1995), and their medicinal properties (e.g., Budel et al. 2005; Verdi et al. 2005; Rabelo and Costa 2018). *Baccharis* species are important producers of hundreds of bioactive compounds used in several industries (e.g., fiber sensors coupled with an anti-theft alarm, food, chemical, cosmetics) or popularly used to treat many and different illnesses. The diversity of compounds produced by the species is probably a result of their wide range distribution in the most stressful conditions of the globe, which demands biochemical and physiological adaptations to survive. Furthermore, many species of this genus show a high cultural relevance. On the other hand, several species of *Baccharis* are considered invasive species of difficult management that occupy ruderal areas, pasturelands, and crops in Australia, the United States, and Europe (Sims-Chilton et al. 2010; Caño et al. 2016; Calleja et al. 2019). Other *Baccharis* species (e.g., *B. megapotamica* and *B. coridifolia*) produce toxic compounds that can kill livestock (Habermehl et al. 1985; Jarvis et al. 1987, 1988, 1996; Rizzo et al. 1997; Rissi et al. 2005).

Although this book brings to light the most recent update on the scientific studies on the use and relevance of *Baccharis* in the wild, as sources of compounds with potential industrial or commercial application, or as a model system in science, the gaps in the knowledge of the genus are still enormous. For most species, basic knowledge is still lacking, such as information on life span, interactions with other organisms including pollinators and herbivores, population genetics, and propagation, among others. Only a few species (e.g., *B. halimifolia*, *B. trimera*, and *B. dracunculifolia*) have been studied in more detail (Gene et al. 1996; Caño et al. 2016; Fernandes et al. 2018; Rabelo and Costa 2018; Barbosa et al. 2017, 2019; Calleja et al. 2019; Monteiro et al. 2020; Rodrigues et al. 2020). There are few works on niche modeling developed for *Baccharis* (Gonzáles et al. 2019).

While we have often argued that *Baccharis* is highly successful in habitat colonization due to its large seed production and long-distance dispersion, this has only been studied for very few species (e.g., *B. pilularis*, *B. halimifolia*, *B. dracunculifolia*). Most species are not that abundant in nature and inhabit harsh habitats in deserts and mountaintops. The ability to germinate under dark conditions, seed tolerance to shade, wide adaptability to soil nutrient conditions and salinity, survival under high soil humidity, and resprouting capabilities after fire (Westman et al. 1975; Gomes and Fernandes 2002) have also been listed as important causes of *Baccharis* success and widespread distribution. Boldt (1989) argue that these characteristics associated with high root growth capacity, intense sprouting after damage, high carbohydrate storage in the root system, and efficient water uptake and water use suggest several mechanisms responsible for the widespread occurrence and diversity of the genus. But these studies were mostly done for common species in North America, while most species are unknown beyond their taxonomy (e.g., Fernandes et al. 2007).

Baccharis represents a relatively large genus with wide distribution in the New World and presents high scientific and cultural relevance and huge economic potential, such as in producing important goods and services for human well-being. Among the countries that have published scientific literature about *Baccharis* species in the last 40 years are Brazil, United States, Argentina, Chile, Canada, and Mexico. More recently, even countries where the genus does not naturally occur, such as Spain, Japan, Lithuania, Denmark, and France, have produced articles on *Baccharis*.

2 The Ecological Path of *Baccharis*

Baccharis species are widely distributed from their origin, likely the mountaintop areas in eastern Brazil (Barroso 1976; Heiden et al. 2019). In the process of expansion and adaptation of *Baccharis* species, colonization by many species of insects and pathogens occurred, originating several types of associations. Some *Baccharis* species offer excellent resources for herbivorous and pollinating insects since they remain green and in bloom throughout the year (Boldt 1989; Espírito-Santo and Fernandes 1998; Espírito-Santo et al. 2004, 2007, 2012; Marques and Fernandes 2016; Watts et al. 2016; Fernandes et al. 2018; Moreira et al. 2018; Matilde-Silva et al. 2019; Monteiro et al. 2020). Some species bloom in autumn, which makes them very attractive to honey bees in a period when other flowers are absent. For example, *B. salicifolia, B. pilularis* and *B. sarothroides* are late summer and autumn honey plants (Boldt 1989). *Baccharis dracunculifolia* is a very important honey plant in Brazil and the main source of substances for the production of green propolis (Bastos and Oliveira 1999; Santos et al. 2011; Fernandes et al. 2018), while *B. concinna* produces flowers throughout the year (Madeira and Fernandes 1999; Espírito Santo and Fernandes 1998; Espírito Santo et al. 2012; Marques et al. 2002). These characteristics provide a unique scenario where problems of central relevance in ecology and biodiversity can be studied in detail (see Fagundes et al. 2005; Silva et al. 2007) and across large biogeographical regions.

Baccharis species are, to a large extent, primary colonizers of disturbed habitats (eg, *B. dracunculifolia, B. concinna*, *B. pseudomyriocephala, B. halimifolia, B. pilularis*) and, thus, are very important for the recovery, functioning and maintenance of biodiversity in various ecosystems, including those under natural succession (Boldt 1989; Araújo et al. 2003). Due to their biological features, diverse associated fauna, and wide distribution – usually in high frequency and across gradients (altitudinal, hygrothermal, and of habitat disturbance) – the species of *Baccharis* have been extensively used as study models in ecological research; such as in monitoring the impacts of climate change. *Baccharis pilularis,* for instance, a major facilitating species in the chaparral of California (Pelaez et al. 2019), has been used as a model for studies of climate change due to its biological characteristics and ease of experimental manipulation (see Zavaleta 2006; Zavaleta and Kettley 2006). In Brazil, several aspects of the species *B. dracunculifolia* have also been studied, including its invasiveness, environmental recovery capacity (see Julião et al. 2005; Fernandes et al. 2016; Adenesky-Filho et al. 2017), function as a nurse species (Perea et al. 2019) and experimental species for testing the effects of climate change (e.g., Sá et al. 2014; Oki et al. 2020).

Several species of *Baccharis* are, on the other hand, considered pests that are difficult to manage in pastures, growing in recreational areas. These invasions usually occur after changes in the environment and, due to their rapid growth, dense stands are formed (Boldt 1989). In central Chile, the formation of degraded vegetation resulted in optimal conditions for the establishment of hybrids and backcross progenies for some species of *Baccharis* (Faini et al. 1991). Some species interfere with the use of soil water and the maintenance of irrigation and drainage channels (Timmons 1959; Parker 1972; Ellis 2001; Caño et al. 2016; Fried et al. 2016). At least one species is invasive, *Baccharis halimifolia*, which was introduced in Australia (Bailey 1900), France, Spain (Dupont 1966) and Italy (Boldt 1989), being the only species occurring outside the Americas. On the other hand, recent studies point to other *Baccharis* invasions in Europe, such as that of *B. spicata*, and may represent a worrying threat (Verloove et al. 2018). In Brazil, pastures are completely unviable when the invasion by *B. dracunculifolia* is intense (Lorenzi 1992; Kissmann and Groth 1992; Altesor et al. 2005). However, it is a plant that colonizes degraded or abandoned areas and an abandoned pasture can be considered a degraded area compared to the natural environment.

Many studies have been carried out in the United States, Mexico, Brazil, and Australia to verify the richness and importance of insects on some native and introduced *Baccharis* species. In Australia, these studies focus on potential agents for the biological control of *B. halimifolia*, which has reached high population densities, replacing native vegetation (Palmer 1986; Boldt and Robbins 1987, 1990; Boldt 1989; Palmer and Haseler 1992a, b; Palmer et al. 1993; Palmer and Tomley 1993; Donders et al. 2005, Sims-Chilton et al. 2010; Green et al. 2012). This same species is becoming one of the most troublesome invaders in the European continent (Caño et al. 2013; Calleja et al. 2019). Among the organisms that cause damage to the host plant, the most significant are Chrysomelidae, Curculionidae, Tephritidae, and Cecidomyiidae (Tilden 1953; Palmer 1986; Boldt 1989; Cordo et al. 1999; Oki et al. 2009; Fagundes and Fernandes 2011; Espirito-Santo et al. 2012; Fernandes et al. 2014; Monteiro et al. 2020). Chrysomelidae species consume large amounts of *Baccharis* spp. in South America (Blackwelder 1946), and the Brazilian species *Lioplacis elliptica* was introduced into Australia for biological control of *B. halimifolia* (Buzzi 1977; McFadyen 1978). Although only distributed in the North American Southwest, *B. pilularis* is another species that has been widely studied due to its importance as an invader of urban areas and water sources in the United States (Ellis 2001; Laris et al. 2017).

Gall-inducing insects can reach large population densities on some hosts and hence could be of importance in the biological control of *Baccharis* species (see reviews in Fernandes and Santos 2014). The potential for using the gall inducer *Baccharopelma dracunculifoliae* (Homoptera: Psyllidae) to control *B. dracunculifolia* where it represents potential problems due to its invasibility (e.g., Cochabamba, Bolivia) can be high due to its high frequency, impact, and wide distribution (Lara and Fernandes 1996; Espírito Santo and Fernandes 1998; Burkhadt et al. 2004; Araujo et al. 2006). Seed predator and borer insects are also of great relevance in studies of *Baccharis* biological control (Brailovsky 1982; Palmer 1986; McFadyen 1978) but have not been studied with the detail it deserves in recent years.

Thirty-three species of insects cause parasitic diseases on *Baccharis* in the United States (Cummings 1978). However, very little is known about the herbivorous insect fauna that attacks the hundreds of other native *Baccharis* species in the Americas, despite some timid advances made in recent years (e.g., Collevatti and Sperber 1997; Hudson and Stiling 1997; Espírito Santo and Fernandes 1998; Burkhardt et al. 2004; Carneiro et al. 2005, 2006, 2009a, b; Fagundes et al. 2005; Fagundes and Fernandes 2011; Neves et al. 2011; Oki et al. 2009; Espirito-Santo et al. 2012; Monteiro et al. 2020). Less well known are the most attacked species and circumstances or factors that influence the resistance and/or susceptibility to attack by natural enemies, although some initial progress has also been made (e.g., Espírito Santo et al. 2007, 2012).

3 *Baccharis* Interactions and Community Structuring

In the wilderness, *Baccharis* plays a key role in creating opportunities for community assembly and maintenance. A few other genera or species have been reported to be superhosts of gall-inducing insects in the Nearctic and Palearctic regions: *Quercus* (Felt 1940; Abrahamson et al. 1998; Manos et al. 1999; Maldonado-Lopez et al. 2016; Pérez-Lopez et al. 2016), *Larrea tridentata* (Waring and Price 1990), *Salix* (Price et al. 1995), *Populus* (Floate and Whitham 1995), *Rosa* (Shorthouse and Rohfritsch 1992; Stone et al. 2002), *Chrysothamnus* in southwestern North America (Fernandes et al. 2000), and *Solidago* (Abrahamson and Weis 1997). These widely colonized host species have served as laboratories to test for generalities of ecological interactions (see Fernandes and Barbosa 2014). In the Neotropics and southern temperate region, some host plant genera have the same role, such as *Copaifera* (Leguminosae) (Costa et al. 2010, 2011), *Nothofagus* (Quintero et al. 2014), *Protium* (Maia 2011; Julião et al. 2014), and *Baccharis* (Fernandes et al. 1996; Fernandes and Barbosa 2014; Formiga et al. 2015; Barbosa et al. 2017, 2019). In the reviews by Fernandes et al. (1996) and Fernandes and Barbosa (2014), the *Baccharis* hosts that supported the highest numbers of galling insects were *B. dracunculifolia* (17 spp.), *B. concinna* (15 spp.), *B. salicifolia* (13 spp.), and *Baccharis* sp. 1 (11 spp.). In the southeastern mountains of Brazil, the Mantiqueira and Espinhaço Mountains, Coelho et al. (2018) reported 106 galling species on 17 *Baccharis* species. The highest richness of galling insects (13 galling species) was recorded on *B. dracunculifolia*, confirming the previous literature surveys for the species. The study also recorded a high richness of galling insects on *B. minutiflora* (12 spp.), *B. cognata* (10 spp.), *B. reticularia* (9 spp.), *B. intermixta* (8 spp.), and *B. concinna* (7 spp.). The hosts *B. ramosissima*, *B. helychrysoides*, and *B. truncata* supported six galling species each, while *B. serrulata*, *B. ligustrina*, and *B. glutinosa* each had three galling species recorded. A remarkable feature of *Baccharis* is that its galling organisms are from many different orders; e.g., Diptera, Lepidoptera, and Hemiptera. Based on a Web of Science search with the words "insect galls, galls, cecidia, galling insects, galhas, gallmucken, and agallas," we were able to record at least 47 studies on galling insects on 8 species of *Baccharis* in the last 75 years (1945–2020).

While no one has yet listed the number of insects attracted to the flowers of *Baccharis* (but see Ferracini et al. 1995), our own experience indicates it is large. In a short observation on the number of insects attracted to the flowers of *Baccharis dracunculifolia* during a very limited number of days (2–3 days), we have been able to list more than 30 different species (in review). These data confirm that some *Baccharis* species are extremely important in providing resources to pollinators. They also confirm that this species' effects on ecosystem functioning must be even higher where these plants are abundant or are key strategic resources for the community, such in mountaintop regions and deserts (e.g., Boldt 1989; Griffin 1997). Hence, *Baccharis* species could be used in programs to attract pollinators.

On the other hand, the understanding of some ecological and evolutionary paths in *Baccharis* is incipient. For instance, genetic studies are in their infancy, and more applied aspects such as propagation for several uses are not well developed. Genetic studies could be of great relevance in promoting other sorts of ecological and evolutionary studies in the future.

4 The Chemistry of *Baccharis*

Baccharis species are known in traditional culture for the treatment of diseases such as gastrointestinal and liver disorders, anemia, diabetes, diarrhea, infections, cancer, gout, rheumatism, ulcers, and skin problems, among others (Vidari et al. 2003; Abad and Bermejo 2007; Hocayen et al. 2016; Rabelo and Costa 2018;

Romero-Benavides et al. 2018; Ascari et al. 2019; Basso et al. 2019; Costa et al. 2019; Bonin et al. 2020; Paniagua-Zambrana et al. 2020; Souza et al. 2020). Several studies present the most updated information on the production of phytochemicals for pharmaceutical, cosmetic, and other applications, and therefore we will not review these here (Verdi et al. 2005; Grecco et al. 2010; Galvão et al. 2012; Vannini et al. 2012; González et al. 2018; Jaramillo-García et al. 2018; Ueno et al. 2018).

This high usage in folk medicine and interest by the pharmaceutical industry has its origin in the rich chemical properties of the genus. Several species of *Baccharis* produce chemical compounds that are under investigation by many institutes and laboratories around the world (e.g., Jarvis et al. 1988; Brown 1994; Fournet et al. 1994; Verdi et al. 2005; Pereira et al. 2017; Romero-Benavides et al. 2018; Bonin et al. 2020). In folk medicine, tea made from *B. douglasii* is used to treat ulcerations and wounds. Other teas are used to treat headaches and as emetics (Boldt 1989). *B. trimera* ethyl acetate extracts have been used against *Schistosoma* infections in Brazil (Herz et al. 1977). In Argentina, about 50 species of *Baccharis* are used in folk medicine (Boldt 1989). Bandoni et al. (1978) found that two flavonoids extracted from *B. crispa* and *B. notosergila* have antimicrobial activity, but since then this number of studies has continued to grow, showing the relevance of this genus.

Various chemical compounds in *Baccharis* are potentially effective in fighting cancer. Baccharin trichothecene extracted from the leaves, buds, and dried flowers of *B. megapotamica* acts against leukemia and tumors of the colon of mice (Kupchan et al. 1976, 1977; Arcamone et al. 1980; Carvalho et al. 2016; Rodrigues et al. 2020). Two additional groups of trichothecenes, roridins, and verrucarins, found in *B. coridifolia*, are active against nasopharyngeal tumor cells (Jarvis et al. 1988, see also Budel et al. 2005; Verdi et al. 2005). About 180 species have already been analyzed chemically, leaving about 260 species to be prospected for their chemical constituents and efficacy. On the other hand, the potential for discovering new chemicals is greatly expanded when long-term studies are carried out. Collections of botanical material for phytochemical studies are generally gathered in a single opportunity, thus losing the enormous variability and seasonality of the production of compounds (Gershenzon 1984). Hence, the genus has an enormous potential to contribute a large number of chemical substances, some of which might be new to science.

According to Abad and Bermejo (2007), over 150 compounds have been isolated and identified from the *Baccharis* genus. Many substances isolated from this genus have been used as medicine (e.g., *B. trinervis*, used as anti-HIV), perfumes (essential oils of *B. dracunculifolia*, *B. uncinella*, *B. genistelloides*, *B. trimera*), and repellents (terpenoids and flavonoids found in many species), among other products (Jarvis et al. 1988; Argandoña and Faini 1993; Ferracini et al. 1995; Palomino et al. 2002; Agostini et al. 2005; Verdi et al. 2005; Wollenweber et al. 2006). The *Baccharis* species more deeply studied chemically are *B. megapotamica*, *B. incarum*, *B. trimera*, *B. trinervis*, *B. salicifolia*, *B. crispa*, *B. coridifolia*, *B. dracunculifolia*, *B. uncinella*, *B. retusa*, *B. linearis*, *B. grisebachii*, *B. obtusifolia*, and *B. tricuneata* (Bohlmann et al. 1982; Verdi et al. 2005; Budel et al. 2005; Besten et al. 2012;

Campos et al. 2016; Moraes Neto et al. 2019). This arsenal of applicability has led to the filing of 226 *Baccharis* patents. Half of these patents are aimed at the pharmacological area (53.5% of patents), mainly in the treatment of cancer (40 patents). Among the patents, another highlight is the application of *B. gaudichaudiana* in the treatment of coronavirus (Junxing et al. 2003). This information emphasizes the pharmacological potentialities around this genus. In southeastern Brazil, oils extracted from leaves and stems of *B. dracunculifolia* and *B. genistelloides* are used as fragrances (Chialva and Doglia 1990; Suttisri et al. 1994; Fabiane et al. 2008; Frizzo et al. 2001, 2008; Queiroga et al. 1990, 2014), but the potential for new findings is enormous as most of the species were not yet screened for the production of them.

5 Other Applications

Despite their low nutritional content and known unpalatability (Pelaez et al. 2019; Cock and Hierro 2020), some species of *Baccharis*, considered to be nontoxic, have been used as fodder for cattle (Benson and Darrow 1981). *B. sarothroides* has been used as vegetation cover and to correct soils degraded by copper mining in Arizona, USA (Day and Ludeke 1980; Norem et al. 1982; Haque et al. 2008; Haque et al. 2009). In Brazil, mainly in Minas Gerais, where mineral exploration is carried out in the open, studies on the use of plants of this genus for the recovery of degraded areas were initiated, and the species *B. dracunculifolia* and *B. concinna* are suggested as viable alternatives to the introduction of exotic species to habitat and region (e.g., Fernandes et al. 2007; Negreiros et al. 2014; Gomes et al. 2015; Fernandes et al. 2016).

A serious problem is cattle poisoning by *Baccharis*. Animal death cases have been recorded in Brazil (Occhioni 1944; Tokarnia and Dobereiner 1976), Uruguay, and Argentina (Schang 1929). The vegetative parts are toxic throughout the year, while the flowers are 4–8 times more toxic (Tokarnia and Dobereiner 1976). The most common toxic compounds found in some *Baccharis* species studied were macrocyclic trichothecenes (Kupchan et al. 1976, 1977; Habermehl et al. 1985; Jarvis et al. 1988, 1996; Rizzo et al. 1997; Driemeier et al. 2000; Varaschin and Alessi 2003). The symptoms exhibited by the poisoned cattle are anorexia, lack of coordination and direction in walking, tremors, and convulsions. Postmortem analyses reveal lesions in the rumen, necrosis, and detachment of the intestinal mucosa (Tokarnia and Dobereiner 1976; see also Jarvis et al. 1996; Driemeier et al. 2000; Budel et al. 2005; Verdi et al. 2005; Oliveira-Filho et al. 2011; Panziera et al. 2015).

An important applied aspect is that of *B. dracunculifolia* and Africanized honey bee *Apis mellifera* (Kumazawa et al. 2003). This bee collects resins from apical buds of *B. dracunculifolia* and uses it to produce a resinous layer inside the hive, known as green propolis (Teixeira et al. 2005; Fernandes et al. 2018). This resinous mass has antiseptic, anti-inflammatory, anticancer, and healing properties and thus has been widely studied, commercialized, and used, primarily by the pharmaceutical and cosmetics industry (Banskota et al. 2001; Chan et al. 2012; Veiga et al. 2017; Endo et al. 2018). Among the chemicals isolated from propolis, it is worth mentioning the presence of flavonoids, phenylpropanoids, phenolic acids, and essential oils (Kumazawa et al. 2003; Teixeira et al. 2005; Takashima et al. 2019).

Another application of *Baccharis* is associated with its high diversity of symbiotic organisms (bacteria, endophytic fungi, and mycorrhizae), which not only helps in plant survival and development but generates a potential for use in the field of bioprospecting (Oki et al. 2009, 2016; Cuzzi et al. 2012; Vieira et al. 2014; Coutinho et al. 2019). *Baccharis* endophytic fungi have been shown to be effective in antimicrobial and antifungal (Oki et al. 2016; Vieira et al. 2014), as well as anti-herbivory, activities (Oki et al. 2016, 2021).

6 The Content of the Book

This book is arranged into four main parts. Chapter 1 focuses on the main ecological and evolutionary aspects of the genus. Chapter 2 presents the most current understanding of the taxonomy and distribution of the 442 species of *Baccharis*, discussing the genus origins and diversification. Chapter 3 offers a historical overview of genetic studies on *Baccharis* species, including recent method developments. Chapter 4 addresses the relationship between intersexual differences in resource allocation and herbivory in dioecious *Baccharis* species. Chapter 5 provides a detailed description of the network of direct and indirect interactions among arthropods in the well-studied *B. dracunculifolia* system. Chapter 6 brings to light the world of endophytic fungi associated with *Baccharis* and their importance in helping plants cope with environmental stresses and natural enemies and as a source of bioactive compounds. Chapter 7 reveals the crucial role of *Baccharis* species as nurse plants and in community assembly, particularly in stressful and herbivore-dominated environments in the Americas. Then, Chap. 8 closes the section discussing the causes and consequences of biological invasion by *Baccharis* in the world.

The second part concentrates on the structural and chemical particularities of the *Baccharis* species. Chapter 9 provides a comprehensive review of the morphology and anatomy of *Baccharis*, including morphological and anatomical features of particular taxonomic relevance. Chapter 10 reviews the chemical composition of essential oils of *Baccharis* species and their wide range of biological activities. Chapter 11 shows a comprehensive overview of the wide variety of flavonoids present in *Baccharis* species. Chapter 12 presents ethnopharmacological uses of phenolic compounds, focusing on folk medicine, and it also discusses the toxicity of some *Baccharis* species. The main volatile terpenes, which play key roles in the biological activities of *Baccharis* species, are presented in Chap. 13. Trichothecenes are covered in detail in Chap. 14, while in Chap. 15 livestock poisoning by some species of *Baccharis* is reviewed.

Part three explores the social and economic importance of *Baccharis*. Chapter 16 reviews the wide variety of popular uses of several species of *Baccharis* in South

America. Chapter 17 describes the development of the cultivar of *B. trimera*, the first Brazilian medicinal plant to be registered and patent-protected. Chapter 18 exposes the potential of *Baccharis* secondary metabolites in the development of new drugs to fight cancer. The last chapter in this part, Chap. 19, portrays the current status of scientific and technological innovations involving species of *Baccharis*.

This book's final part is devoted to green propolis, whose chief plant source is *B. dracunculifolia*. Chapter 20 reviews the chemical constituents and antioxidant properties of Brazilian green propolis. Chapter 21 examines the potential of green propolis components in the prevention and treatment of obesity and diabetes. Chapter 22 discusses the effects of the green propolis on the immune response. Finally, Chap. 23 presents the current status of innovation and markets of propolis, emphasizing green propolis.

Acknowledgments We thank the funding agencies CAPES, CNPq, Planta Ltda, and FAPEMIG for the field and laboratory supports granted to the authors involved.

References

Abad MJ, Bermejo P (2007) *Baccharis* (Compositae): a review update. ARKIVOC 7:76–96

Abrahamson WG, Weis AE (1997) Evolutionary ecology across three trophic levels: goldenrods, gallmakers and natural enemies. Princeton University, Princeton

Abrahamson WG, Melika G, ScraVord R, Csóka G (1998) Gall-inducing insects provide insights into plant systematic relationships. Am J Bot 85:1159–1165

Adenesky-Filho E, Maçaneiro JP, Vitorino MD (2017) How to select potential species for ecological restoration of rain forest–Southern Brazil. Appl Ecol Environ Sci 15:1671–1684

Agostini F, Santos ACA, Rossato M, Pansera MR, Zattera F, Wasum R, Serafini LA (2005) Studies on the essential oils from several *Baccharis* (Asteraceae) from Southern Brazil. Rev Bras Farmacogn 15:215–219

Altesor A, Oesterheld M, Leoni E, Lezama F, Rodríguez C (2005) Effect of grazing on community structure and productivity of a Uruguayan grassland. Plant Ecol 179:83–91

Araújo APA, Carneiro MAA, Fernandes GW (2003) Efeitos do sexo, do vigor e do tamanho da planta hospedeira sobre a distribuição de insetos indutores de galhas em *Baccharis pseudomyriocephala* Teodoro (Asteraceae). Rev Bras Entomol 47:483–490

Araújo APA, Paula JD, Carneiro MAA, Schoereder JH (2006) Effects of host plant architecture on colonization by galling insects. Austral Ecol 31:343–348

Arcamone R, Cassinelli G, Casazza AM (1980) New antitumor drugs from plants. J Ethnopharmacol 2:41–46

Argandoña VH, Faini F (1993) Oleanolic acid content in *Baccharis linearis* and its effects on *Heliothis zea* larvae. Phytochemistry 33:1377–1379

Ascari J, Oliveira MS, Nunes DS, Granato D, Scharf DR, Simionatto E, Otuki M, Soley B, Heiden G (2019) Chemical composition, antioxidant and anti-inflammatory activities of the essential oils from male and female specimens of *Baccharis punctulata* (Asteraceae). J Ethnopharmacol 234:1–7. https://doi.org/10.1016/j.jep.2019.01.005

Bailey L (1900) The Queensland flora, vol 3. A. Diddams, Brisbane

Bandoni A, Medina J, Rondina R, Coussio J (1978) Genus *Baccharis* L. 1. Phytochemical analysis of a non polar fraction from *B. crispa* Sprengel. Planta Med 34:328–331

Banskota AH, Tezuka Y, Kadota S (2001) Recent progress in pharmacological research of propolis. Phytother Res 15:561–571

Barbosa M, Fernandes GW, Lewis OT, Morris RJ (2017) Experimentally reducing species abundance indirectly affects food web structure and robustness. J Anim Ecol 86:327–336

Barbosa M, Fernandes GW, Morris RJ (2019) Interaction engineering: non-trophic effects modify interactions in an insect galler community. J Anim Ecol 88:1168–1177

Barroso GM (1976) Compositae-subtribo Baccharidinae-Hoffman: estudo das espécies ocorrentes no Brasil. Rodriguesia 40:3–273

Basso BS, Mesquita FC, Dias HB, Krause GC, Scherer M, Santarém ER, Oliveira JR (2019) Therapeutic effect of *Baccharis anomala* DC. extracts on activated hepatic stellate cells. EXCLI J 18:91–105

Bastos EM, Oliveira VC (1999) Aspectos morfo-anatômicos da folha de *Baccharis dracunculifolia* DC. (Asteraceae) visando à identificação da origem botânica da própolis. Acta Bot Bras 12:431–439

Benson L, Darrow R (1981) Trees and shrubs of the southwestern desert. University of Arizona Press, Tucson

Besten MA, Jasinski VC, Costa ÂDG, Nunes DS, Sens SL, Wisniewski A Jr, Simionatto EL, Riva D, Dalmarco JB, Granato D (2012) Chemical composition similarity between the essential oils isolated from male and female specimens of each five *Baccharis* species. J Braz Chem Soc 23:1041–1047

Blackwelder R (1946) Checklist of the coleopterous insects of Mexico, Central America, the West Indies and South America. Bull Am Mus Nat Hist 185:733–757

Bohlmann F, Kramp W, Jakupovic J, Robinson H, King RM (1982) Diterpenes from *Baccharis* species. Phytochemistry 21:399–403

Boldt PE (1989) *Baccharis* (Asteraceae), a review of its taxonomy, phytochemistry, ecology, economic status, natural enemies and the potential for its biological control in the United States. USDA, Agricultural Research Service. Grassland, soil and water research laboratory. Temple, Texas

Boldt PE, Robbins TO (1987) Phytophagous and pollinating insect fauna of *Baccharis neglecta* (Compositae) in Texas. Environ Entomol 16:887–895

Boldt PE, Robbins TO (1990) Phytophagous and flower-visiting insect fauna of *Baccharis salicifolia* (Asteraceae) in the southwestern United States and northern Mexico. Environ Entomol 19:515–523

Bonin E, Carvalho VM, Avila VD, Santos NCA, Benassi-Zanqueta É, Lancheros CAC, Previdelli ITS, Ueda-Nakamura T, Abreu Filho BA, Prado IN (2020) *Baccharis dracunculifolia*: chemical constituents, cytotoxicity and antimicrobial activity. LWT 120:1–10. https://doi.org/10.1016/j.lwt.2019.108920

Brailovsky H (1982) Revision del complejo *Ochrimnus* con descripcion de nuevas especies y nuevos generos (Hemiptera-Heteroptera-Lygaeidae-Lygaeinae). Folia Entomol Mex 51:1–163

Brown GD (1994) Phenylpropanoids and other secondary metabolites from *Baccharis linearis*. Phytochemistry 35:1037–1042

Budel JM, Duarte MR, Santos CAM, Farago PV, Matzenbacher N (2005) O progresso da pesquisa sobre o gênero *Baccharis*, Asteraceae: I-Estudos botânicos. Rev Bras Farmacogn 15:268–271

Burckhardt D, Espírito-Santo MM, Fernandes GW, Malenovský I (2004) Gall-inducing jumping plant-lice of the Neotropical genus *Baccharopelma* (Hemiptera, Psylloidea) associated with *Baccharis* (Asteraceae). J Nat Hist 38:2051–2071

Buzzi Z (1977) Uma nova espécie de *Lioplacis* (Coleoptera: Chrysomelidae) do sul do Brasil. Dusenia 10:229–232

Calleja F, Ondiviela B, Juanes JA (2019) Invasive potential of *Baccharis halimifolia*: experimental characterization of its establishment capacity. Environ Exp Bot 162:444–454

Campos FR, Bressan J, Jasinski VCG, Zuccolotto T, Silva LE, Cerqueira, LB (2016) *Baccharis* (Asteraceae): chemical constituents and biological activities. Chem Biodivers 13:1–17

Caño L, Campos JA, García-Magro D, Herrera M (2013) Replacement of estuarine communities by an exotic shrub: distribution and invasion history of *Baccharis halimifolia* in Europe. Biol Invasions 15:1183–1188. https://doi.org/10.1007/s10530-012-0360-4

Caño L, Fuertes-Mendizabal T, García-Baquero HM, González-Moro MB (2016) Plasticity to salinity and transgenerational effects in the nonnative shrub *Baccharis halimifolia*: insights into an estuarine invasion. Am J Bot 103:808–820

Carneiro MAA, Fernandes GW, De Souza OFF (2005) Convergence in the variation of local and regional galling species richness. Neotrop Entomol 34:547–553

Carneiro MAA, Fernandes GW, De Souza OFF, Souza WVM (2006) Sex-mediated herbivory by galling insects on *Baccharis concinna* (Asteraceae). Rev Bras Entomol 50:394–398

Carneiro MAA, Branco CSA, Braga CED, Almada ED, Costa MBM, Maia VC, Fernandes GW (2009a) Are gall midge species (Diptera, Cecidomyiidae) host-plant specialists? Rev Bras Entomol 53:365–378

Carneiro MAA, Borges RAX, Araújo APA, Fernandes GW (2009b) Insetos indutores de galhas da porção sul da Cadeia do Espinhaço, MG. Rev Bras Entomol 53:570–592

Carvalho MP, Weich H, Abraham WR (2016) Macrocyclic trichothecenes as antifungal and anticancer compounds. Curr Med Chem 23:23–35

Chan GC, Cheung K, Sze DM (2012) The immuno modulatory and anticancer properties of propolis. Clin Rev Allergy Immunol. https://doi.org/10.1007/s12016-012-8322-2

Chialva F, Doglia G (1990) Essential oil from Carqueja (Baccharis genistelloides Pers.). J Essent Oil Res 2:173–177

Cock MC, Hierro JL (2020) Native weed protects species that sustain cattle raising in semi-arid natural grasslands. J Arid Environ 175:1–8. https://doi.org/10.1016/j.jaridenv.2019.104088

Coelho MS, Carneiro MAA, Branco CA, Borges RAX, Fernandes GW (2018) Species turnover drives β-diversity patterns across multiple spatial scales of plant-galling interactions in mountaintop grasslands. PLoS One 13:e0195565

Collevatti RG, Sperber CF (1997) The gall maker *Neopelma baccharidis* Burck. (Homoptera: Psyllidae) on *Baccharis dracunculifolia* DC. (Asteraceae): individual, local, and regional patterns. Ann Soc Entomol Brasil 26:45–53

Cordo HA, DeLoach CJ, Habeck DH (1999) Biology of *Heilipodus ventralis* (Coleoptera: Curculionidae), an Argentine weevil for biological control of snakeweeds (*Gutierrezia* spp.) in the United States. Biol Control 15:210–227

Costa FV, Fagundes MF, Neves FS (2010) Arquitetura da planta e diversidade de galhas associadas à *Copaifera langsdorffii* (Fabaceae). Ecol Aust 20:9–17

Costa FV, Neves FS, Silva JO, Fagundes M (2011) Relationship between plant development, tannin concentration and insects associated with *Copaifera langsdorffii* (Fabaceae). Arthropod Plant Interact 5:9–18

Costa P, Boeing T, Somensi LB, Cury BJ, Espíndola VL, França TCS, Almeida MO, Arruda C, Bastos JK, Silva LM, Andrade SF (2019) Hydroalcoholic extract from *Baccharis dracunculifolia* recovers the gastric ulcerated tissue, and p-coumaric acid is a pivotal bioactive compound to this action. Biofactors 45:479–489

Coutinho ES, Beiroz W, Barbosa M, Xavier JHA, Fernandes GW (2019) Arbuscular mycorrhizal fungi in the rhizosphere of saplings used in the restoration of the rupestrian grassland. Ecol Restor 37:152–162

Cummings G (1978) Rust fungi on legumes and composites in North America. Arizona University Press, Tucson

Cuzzi C, Link S, Vilani A, Sartori C, Onofre SB (2012) Endophytic fungi of the "vassourinha" (*Baccharis dracunculifolia* D. *C.* – Asteraceae*)*. Rev Bras Bioci 10:135–139

Day A, Ludeke K (1980) Reclamation of copper mine wastes with shrubs in the southwestern U.S.A. J Arid Environ 3:107–112

Donders TH, Wagner F, Visscher H (2005) Quantification strategies for human-induced and natural hydrological changes in wetland vegetation, southern Florida, USA. Quat Res 64:333–342

Driemeier D, Cruz C, Loretti AP (2000) *Baccharis megapotamica* var *Weirii* poisoning in Brazilian cattle. Vet Hum Toxicol 42:220–221

Dupont P (1966) L' extension de *Baccharis halimifolia* entre Loire et Gironde. Bull Soc Sci Bretagne 41:141–144

Ellis LM (2001) Short-term response of woody plants to fire in a Rio Grande riparian forest, Central New Mexico, USA. Biol Conserv 97:159–170

Endo S, Hoshi M, Matsunaga T, Inoue T, Ichihara K, Ikari A (2018) Autophagy inhibition enhances anticancer efficacy of artepillin C, a cinnamic acid derivative in Brazilian green propolis. Biochem Biophys Res Commun 497:437–443

Espírito-Santo MM, Fernandes GW (1998) Abundance of *Neopelma baccharidis* (Homoptera: Psyllidae) galls on the dioecious shrub *Baccharis dracunculifolia* (Asteraceae). Environ Entomol 27:870–876

Espírito-Santo MM, Faria ML, Fernandes GW (2004) Parasitoid attack and its consequences to the development of the galling psyllid *Baccharopelma dracunculifoliae*. Basic Appl Ecol 5:475–484

Espírito-Santo MM, Neves FS, Andrade-Neto FR, Fernandes GW (2007) Plant architecture and meristem dynamics as the mechanism determining the diversity of gall-inducing insects. Oecologia 153:353–364

Espírito-Santo MM, Neves FS, Fernandes GW, Silva JO, Andrade-Neto FR (2012) Plant phenology and absence of sex-biased gall attack on three species of *Baccharis*. PLoS One 7:e46896

Fabiane KC, Ferronatto R, Santos ACD, Onofre SB (2008) Physicochemical characteristics of the essential oils of *Baccharis dracunculifolia* and *Baccharis uncinella* DC (Asteraceae). Rev Bras Farmacogn 18:197–203

Fagundes M, Fernandes GW (2011) Insect herbivores associated with *Baccharis dracunculifolia* (Asteraceae): responses of gall-forming and free-feeding insects to latitudinal variation. Rev Biol Trop 59:1419–1432

Fagundes M, Neves FS, Fernandes GW (2005) Direct and indirect interactions involving ants, insect herbivores, parasitoids, and the host plant *Baccharis dracunculifolia* (Asteraceae). Ecol Entomol 30:28–35

Faini F, Hellwig F, Labbe C, Castillo M (1991) Hybridization in the genus *Baccharis*: *Baccharis linearis* X *B. macraei*. Biochem Syst Ecol 1:53–57

Felt EP (1940) Plant galls and gall makers. Comstock, Ithaca

Fernandes GW, Barbosa M (2014) Bottom-up effects on gall distribution. In: Fernandes G, Santos J (eds) Neotropical insect galls. Springer, Dordrecht, pp 99–113

Fernandes GW, Carneiro MAA, Lara ACF, Allain LA, Andrade GI, Julião G, Reis TC, Silva IM (1996) Galling insects on neotropical species of *Baccharis* (Asteraceae). Trop Zool 9:315–332

Fernandes GW, Santos JC (eds) (2014) Neotropical insect galls. Springer, Dordrecht

Fernandes GW, Saraiva C, Cornelissen TG, Price PW (2000) Diversity and morphology of insect galls on *Chrysothamnus nauseous* (Asteraceae) in North Arizona. Bios 8:39–48

Fernandes GW, Rodarte LH, Negreiros D, Franco AC (2007) Aspectos nutricionais em *Baccharis concinna* (Asteraceae), espécie endêmica e ameaçada da Serra do Espinhaço, Brasil. Lundiana 8:83–88

Fernandes GW, Silva JO, Espírito-Santo MM, Fagundes M, Oki Y, Carneiro MAA (2014) *Baccharis*: a neotropical model system to study insect plant interactions. In: Fernandes GW, Santos JC (eds) Neotropical insect galls. Springer, Dordrecht, pp 193–219

Fernandes GW, Toma TSP, Angrisano P, Overbeck G (2016) Challenges in the restoration of quartzitic and ironstone rupestrian grasslands. In: Fernandes GW (ed) Ecology and conservation of mountaintop grasslands in Brazil. Springer, Switzerland, pp 449–477

Fernandes GW, Oki Y, Belmiro MS, Resende FM, Correa Junior AC, Azevedo JL (2018) Multitrophic interactions among fungal endophytes, bees, and *Baccharis dracunculifolia*: resin tapering for propolis production leads to endophyte infection. Arthropod Plant Interact 12:329–337

Ferracini VL, Paraiba LC, Leitão-Filho HF, Silva AGD, Nascimento LR, Marsaioli AJ (1995) Essential oils of seven Brazilian *Baccharis* species. J Essent Oil Res 7:355–367

Floate KD, Whitham TG (1995) Insects as traits in plant systematics: their use in discriminating between hybrid cottonwoods. Can J Bot 73:1–13

Formiga AT, Silveira FAO, Fernandes GW, Isaias RMS (2015) Phenotypic plasticity and similarity among gall morphotypes on a superhost, *Baccharis reticularia* (Asteraceae). Plant Biol J 17:512–521. https://doi.org/10.1111/plb.12232

Fournet A, Barrios A, Muñoz V (1994) Leishmanicidal and trypanocidal activities of Bolivian medicinal plants. J Ethnopharmacol 41:19–37

Fried G, Caño L, Brunel S, Beteta E, Charpentier A, Herrera M, Starfinger U, Panetta FD (2016) Monographs on Invasive Plants in Europe: *Baccharis halimifolia* L. Bot Letters 163:127–153. https://doi.org/10.1080/23818107.2016.1168315

Frizzo CD, Serafini LA, Dellacassa E, Lorenzo D, Moyna P (2001) Essential oil of *Baccharis uncinella* DC. from Southern Brazil. Flavour Fragr J 16:286–288

Frizzo CD, Atti-Serafini L, Laguna SE, Cassel E, Lorenzo D, Dellacassa E (2008) Essential oil variability in Baccharis uncinella DC and *Baccharis dracunculifolia* DC growing wild in southern Brazil, Bolivia and Uruguay. Flavour Fragr J 23:99–106

Galvão LCC, Furletti VF, Bersan SMF, Cunha MG, Ruiz ALTC, Carvalho JE, Santoratto A, Rehder VLG, Figueira GM, Duarte MCT, Ikegaki M, Alencar SM, Rosalen PL (2012) Antimicrobial activity of essential oils against *Streptococcus mutans* and their antiproliferative effects. Evid Based Complement Alternat Med 2012:1–15

Gene RM, Cartañá C, Adzet T, Marin E, Parella T, Canigueral S (1996) Anti-inflammatory and analgesic activity of *Baccharis trimera*: identification of its active constituents. Planta Med 62:232–235

Gershenzon J (1984) Changes in the levels of plant secondary metabolites under water and nutrient stress. Recent Adv Phytochem 18:273–320

Gomes V, Fernandes GW (2002) Germinação de aquênios de *Baccharis dracunculifolia* D. C. (Asteraceae). Acta Bot Bras 16:421–427

Gomes VM, Negreiros D, Carvalho V, Fernandes GW (2015) Growth and performance of rupestrian grasslands native species in quartzitic degraded areas. Neotropical Biol Conserv 10:159–168

Gonzáles P, Caño A, Müller J (2019) An unusual new record of *Baccharis* (Asteraceae) from the Peruvian Andes and its relation with the northern limit of the dry puna. Acta Bot Mex 126:e1393

González ML, Joray MB, Laiolo J, Crespo MI, Palacios SM, Ruiz GM, Carpinella MC (2018) Cytotoxic activity of extracts from plants of central Argentina on sensitive and multidrug-resistant leukemia cells: isolation of an active principle from *Gaillardia megapotamica*. Evid Based Complement Alternat Med 2018:1–13. https://doi.org/10.1155/2018/9185935

Grecco SS, Reimão JQ, Tempone AG, Sartorelli P, Romoff P, Ferreira MJ, Fávero OA, Lago JH (2010) Isolation of an antileishmanial and antitrypanosomal flavanone from the leaves of *Baccharis retusa* DC.(Asteraceae). Parasitol Res 106:1245–1248

Green BJ, Simpson RW, Dettmann ME (2012) Assessment of airborne Asteraceae pollen in Brisbane, Australia. Aerobiologia 28:295–301. https://doi.org/10.1007/s10453-011-9224-0

Griffin GP (1997) Pollination in the genus *Baccharis* (Asteraceae): the role of wind and insects. Doctoral dissertation, Texas A&M University

Habermehl GG, Busam L, Heydel P, Mebs D, Tokarnia CH, Döbereiner J, Spraul M (1985) Macrocyclic trichothecenes: cause of livestock poisoning by the Brazilian plant *Baccharis coridifolia*. Toxicon 23:731–745

Haque N, Peralta-Videa JR, Jones GL, Gill TE, Gardea-Torresdey JL (2008) Screening the phytoremediation potential of desert broom (*Baccharis sarothroides* Gray) growing on mine tailings in Arizona, USA. Environ Pollut 153:362–368

Haque N, Peralta-Videa JR, Jones GL, Gill TE, Gardea-Torresdey JL (2009) Differential effect of metals/metalloids on the growth and element uptake of mesquite plants obtained from plants grown at a copper mine tailing and commercial seeds. Bioresour Technol 100:6177–6182

Heiden G, Antonelli A, Pirani JR (2019) A novel phylogenetic infrageneric classification of *Baccharis* (Asteraceae: Astereae), a highly diversified American genus. Taxon 68:1048–1081

Herz W, Pilotti A, Soderholm A, Shuhama I, Vichnewsy W (1977) New ent-clerodane-type diterpenoids from *Baccharis trimera*. J Organomet Chem 42:3913–3917

Hocayen PDA, Grassiolli S, Leite NC, Pochapski MT, Pereira RA, Silva LA, Snack A, Michel RG, Kagimura FY, Cunha MAA, Malfatti CR (2016) *Baccharis dracunculifolia* methanol extract enhances glucose-stimulated insulin secretion in pancreatic islets of monosodium glutamate induced-obesity model rats. Pharm Biol 54: 1263–1271

Hudson EE, Stiling P (1997) Exploitative competition strongly affects the herbivorous insect community on *Baccharis halimifolia*. Oikos 79:521–528

Jaramillo-García V, Trindade C, Lima E, Guecheva TN, Villela I, Martinez-Lopez W, Corrêa DS, Ferraz ABF, Moura S, Sosa MQ, da Silva J, Henriques JAP (2018) Chemical characterization and cytotoxic, genotoxic, and mutagenic properties of *Baccharis trinervis* (Lam, Persoon) from Colombia and Brazil. J Ethnopharmacol 213:210–220

Jarvis BB, Wells KM, Lee YW, Bean GA, Kommedahl T, Barros CS, Barros SS (1987) Macrocyclic trichothecene mycotoxins in Brazil species of *Baccharis*. Phytopathology 77:980–984

Jarvis BB, Midiwo JO, Bean GA, Abdoul-Nasr MB, Barras CS (1988) The mystery of trichothecene antibiotics in *Baccharis* species. J Nat Prod 51:736–744

Jarvis BB, Wang S, Cox C, Rao MM, Philip V, Varaschin MS, Barros CS (1996) Brazilian *Baccharis* toxins: livestock poisoning and the isolation of macrocyclic trichothecene glucosides. Nat Toxins 4:58–71

Julião GR, Fernandes GW, Negreiros D, Bedê L, Araújo RC (2005) Insetos galhadores associados a duas espécies de plantas invasoras de áreas urbanas e peri-urbanas. Rev Bras Entomol 49:97–106

Julião GR, Almada ED, Fernandes GW (2014) Galling insects in the pantanal wetland and Amazonian rainforest. In: Fernandes G, Santos J (eds) Neotropical insect galls. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-8783-3_19

Junxing D, Huijuan Z, Aiping T (2003) Use of dicaffeoylquinic acid derivative and analogs in treating disease related to coronavirus infection. Applicant: Institute of Radiation Medicine, Chinese Academy of Military Medical Sciences. CN1449751A. https://patents.google.com/patent/CN1449751A/en#citedBy

Kissmann KG, Groth D (1992) Plantas infestantes e nocivas. Tomo I, II e III. BASF, São Paulo

Kumazawa S, Yoneda M, Shibata I, Kanaeda J, Hamasaka T, Nakayama T (2003) Direct evidence for the plant origin of Brazilian propolis by the observation of honeybee behavior and phytochemical analysis. Chem Pharm Bull 51:740–742

Kupchan S, Jarvis B, Dailey R Jr, Bright W, Bryan R, Shizuri Y (1976) Baccharin, a novel potent antileukemic tricothecene triepoxide from *Baccharis megapotamica*. J Am Chem Soc 98:7092–7093

Kupchan SM, Streelman DR, Jarvis BB, Dailey RG Jr, Sneden AT (1977) Isolation of potent new antileukemic trichothecenes from *Baccharis megapotamica*. J Organomet Chem 22:4221–4225

Lara ACF, Fernandes GW (1996) The highest diversity of galling insects: Serra do Cipó, Brazil. Biodivers Lett 3:111–114

Laris P, Brennan S, Engelberg K (2017) The coyote brush invasion of southern California grasslands and the legacy of mechanical disturbance. Geogr Rev 107:640–659

Lorenzi H (1992) Plantas daninhas do Brasil, 2nd edn. Plantarum, São Paulo

Madeira JA, Fernandes GW (1999) Reproductive phenology of sympatric taxa of *Chamaecrista* (Leguminosae) in Serra do Cipó. Br J Trop Ecol 15:463–479

Maia VC (2011) Characterization of insect galls, gall makers, and associated fauna of Platô Bacaba (Porto de Trombetas, Pará, Brazil). Biota Neotrop 11:1–18. https://doi.org/10.1590/S1676-06032011000400003

Maldonado-López Y, Cuevas-Reyes P, Oyama K (2016) Diversity of gall wasps (Hymenoptera: Cynipidae) associated with oak trees (Fagaceae: *Quercus*) in a fragmented landscape in Mexico. Arthropod Plant Interact 10:29–39

Manos PS, Doyle JJ, Nixon KC (1999) Phylogeny, biogeography, and processes of molecular differentiation in *Quercus* subgenus *Quercus* (Fagaceae). Mol Phylogenet Evol 12:333–349

Marques ES, Fernandes GW (2016) The gall inducing insect community on *Baccharis concinna* (Asteraceae): the role of shoot growth rates and seasonal variations. Lundiana 12:17–26

Marques AR, Fernandes GW, Reis IA, Assunção RM (2002) Distribution of adult male and female *Baccharis concinna* (Asteraceae) in the rupestrian fields of Serra do Cipó, Brazil. Plant Biol 4:94–103

Matilde-Silva M, Boeger MRT, Melo Júnior JCFD (2019) O vigor da planta altera a densidade de galhas em populações de *Baccharis longiattenuata* (Asteraceae) sob distintas condições de solo? Rodriguésia 70:e02752017. https://doi.org/10.1590/2175-7860201970018

McFadyen P (1978) A review of the biocontrol of groundsel-bush (*Baccharis halimifolia* L.). In: Proceedings of the first conference of the council Australia Weed Science Society of Melbourne, Australia, pp 123–125

Monteiro GF, Macedo-Reis LE, Dáttilo W, Fernandes GW, Siqueira de Castro F, Neves FS (2020) Ecological interactions among insect herbivores, ants and the host plant *Baccharis dracunculifolia* in a Brazilian mountain ecosystem. Austral Ecol 45:158–167

Moraes Neto RN, Setúbal RFB, Higino TMM, Brelaz-de-Castro MCA, Silva LCN, Aliança ASDS (2019) Asteraceae plants as sources of compounds against Leishmaniasis and Chagas disease. Front Pharmacol 10:1–20. https://doi.org/10.3389/fphar.2019.00477

Morales G, Paredes A, Sierra P, Loyola LA (2008) Antimicrobial activity of three *Baccharis* species used in the traditional medicine of Northern Chile. Molecules 13:790–794

Moreira X, Nell CS, Katsanis A, Rasmann S, Mooney KA (2018) Herbivore specificity and the chemical basis of plant–plant communication in *Baccharis salicifolia* (Asteraceae). New Phytol 220:703–713

Negreiros D, Esteves D, Fernandes GW, Berbara RLL, Oki Y, Vichiato M, Chalub C (2014) Growth-survival tradeoff in the widespread tropical shrub *Baccharis dracunculifolia* (Asteraceae) in response to a nutrient gradient. Trop Ecol 55:167–176

Neves FS, Fagundes M, Sperber CF, Fernandes GW (2011) Tri-trophic level interactions affect host plant development and abundance of insect herbivores. Arthropod Plant Interact 5:351–357

Norem MA, Day AD, Ludeke KL (1982) An evaluation of shrub and tree species used for revegetating copper mine wastes in the South-Western United States. J Arid Environ 5:299–304

Occhioni P (1944) Contribuição ao estudo do "mio-mio" *Baccharis coridifolia* DC. Rev Bras Med Vet 13:193–209

Oki Y, Soares NR, Belmiro MS, Correa-Junior A, Fernandes GW (2009) The influence of the endophytic fungi on the herbivores from *Baccharis dracunculifolia* (Asteraceae). Neotrop Biol Conserv 4:83–88. https://doi.org/10.4013/5119

Oki Y, Goto BT, Jobim K, Rosa LH, Ferreira MC, Coutinho ES, Xavier JH de A, Carvalho F, de Souza MFM, Berbara RLL, Fernandes GW (2016) Arbuscular mycorrhiza and endophytic fungi in ruspestrian grasslands. In: Fernandes GW (ed) Ecology and conservation of mountaintop grasslands in Brazil. Springer, Switzerland, pp. 157–179

Oki Y, Arantes-Garcia L, Costa MB, Nunes BC, Silveira BR, Gélvez-Zúñiga I, Franco A, Fernandes GW (2020) CO_2 fertilizer effect on growth, polyphenols, and endophytes in two *Baccharis* species. Braz Arch Biol Technol 63:e20190302. https://doi.org/10.1590/1678-4324-2020190302

Oki Y, Nascimento IM, Costa NB, Maia RA, Takahashi JA, Ferraz V, Fernandes GW (2021) Effectiveness of endophytic fungi from *Baccharis dracunculifolia* against sucking insects and fungal pathogens. In: Rosa LH (ed) Neotropical endophytic fungi. Springer, Cham, pp 337–349

Oliveira ACP, Endringer DC, Amorim LAS, Graças LBM, Coelho MM (2005) Effect of the extracts and fractions of *Baccharis trimera* and *Syzygium cumini* on glycaemia of diabetic and non-diabetic mice. J Ethnopharmacol 102:465–469

Oliveira-Filho JC, Carmo PM, Lucena RB, Pierezan F, Barros CS (2011) *Baccharis megapotamica* var. *weirii* poisoning in water buffalo (*Bubalus bubalis*). Vet Diagn Invest 23:610–614

Palmer WA (1986) The host range of *Trirhabda flavolimbata* (Mannnerheim) (Coleoptera: Chrysomelidae) and its suitability as a biological control agent for *Baccharis* spp. (Asteraceae: Asterae). Coleopt Bull 40:149–153

Palmer WA, Haseler WH (1992a) The host specificity and biology of *Trirhabda bacharidis* (Weber) (Coleoptera: Chrysomelidae), a species introduced into Australia for the biological control of *Baccharis halimifolia* L. Coleopt Bull 46:61–66

Palmer WA, Haseler WH (1992b) Food plant specificity and biology of *Oidaematophorus balanotes* (Pterophoridae): a North American moth introduced into Australia for the biological control of *Baccharis halimifolia*. J Lepid Soc 46:195–202

Palmer WA, Tomley AJ (1993) The host range and biology of *Amniscus perplexus* Haldeman (Coleoptera: Cerambycidae), a candidate evaluated for the biological control of *Baccharis halimifolia* in Australia. Coleopt Bull 47:27–34

Palmer WA, Diatloff G, Melkshan J (1993) The host specificity of *Rhopalomyia californica* Felt (Diptera: Cecidomyiidae) and its importation into Australia as a biological control agent for *Baccharis halimifolia* L. Proc Entomol Soc Wash 95:1–6

Palomino SS, Abad MJ, Bedoya LM, García J, Gonzales E, Chiriboga X, Bermejo P, Alcami J (2002) Screening of South American plants against human immunodeficiency virus: preliminary fractionation of aqueous extract from *Baccharis trinervis*. Biol Pharm Bull 25:1147–1150

Paniagua-Zambrana NY, Bussmann RW, Romero C, Echeverría J (2020) *Baccharis genistelloides* (Lam.) Pers. Asteraceae. In: Paniagua-Zambrana N, Bussmann R (eds) Ethnobotany of the Andes. Ethnobotany of mountain regions. Springer, Cham, pp 291–296. https://doi.org/10.1007/978-3-030-28933-1_304

Panziera W, Gonçalves MA, Lorenzett MP, Damboriarena P, Argenta FF, Laisse CJ, Pavarini SP, Driemeier D (2015) Intoxicação natural por *Baccharis megapotamica* var. weirii em caprinos. Pesqui Vet Bras 35:360–364

Park YK, Paredes-Guzman JF, Aguiar CL, Alencar SM, Fujiwara FY (2004) Chemical constituents in *Baccharis dracunculifolia* as the main botanical origin of southeastern Brazilian propolis. J Agric Food Chem 52:1100–1103

Parker K (1972) An illustrated guide to Arizona weeds. University of Arizona Press, Tucson

Peláez M, Dirzo R, Fernandes GW, Perea R (2019) Nurse plant size and biotic stress determine quantity and quality of plant facilitation in oak savannas. Forest Ecol Manag 437:435–442

Perea R, Cunha JS, Spadeto C, Gomes VM, Moura AL, Silveira BS, Fernandes GW (2019) Nurse shrubs to mitigate plant invasion along roads of montane Neotropics. Ecol Eng 136:193–196

Pereira CB, Kanunfre CC, Farago PV, Borsato DM, Budel JM, Maia BHLNS, Campesatto EA, Sartoratto A, Miguel MD, Miguel OG (2017) Cytotoxic mechanism of *Baccharis milleflora* (Less.) DC. essential oil. Toxicol in Vitro 42:214–221

Pérez-López G, González-Rodríguez A, Oyama K, Cuevas-Reyes P (2016) Effects of plant hybridization on the structure and composition of a highly rich community of cynipid gall wasps: the case of the oak hybrid complex *Quercus magnoliifolia* x *Quercus resinosa* in Mexico. Biodivers Conserv 25:633–651

Price PW, Craig TP, Roininen H (1995) Working toward theory on galling sawfly population dynamics. In: Cappuccino N, Price PW (eds) Population dynamics: new approaches and synthesis. Academic Press, San Diego, pp 321–338

Queiroga CL, Fukai A, Marsaioli A (1990) Composition of the essential oil of vassoura. J Braz Chem Soc 1:105–109

Queiroga CL, Cavalcante MQ, Ferraz PC, Coser RN, Sartoratto A, Magalhães PM (2014) High-speed countercurrent chromatography as a tool to isolate nerolidol from the *Baccharis dracunculifolia* volatile oil. J Essent Oil Res 26:334–337

Quintero C, Garibaldi LA, Grez A, Polidori C, Nieves-Aldrey JL (2014) Galls of the Temperate Forest of Southern South America: Argentina and Chile. In: Fernandes G, Santos J (eds) Neotropical insect galls. Springer, Dordrecht, pp 429–463

Rabelo ACS, Costa DC (2018) A review of biological and pharmacological activities of *Baccharis trimera*. Chem Biol Interact 296:65–75

Resende FA, Munari CC, Monteiro Neto MAB, Tavares DC, Bastos JK, Silva Filho AA, Varanda EA (2012) Comparative studies of the (anti) mutagenicity of *Baccharis dracunculifolia* and artepillin C by the bacterial reverse mutation test. Molecules 17:2335–2350

Rissi DR, Rech RR, Fighera RA, Cagnini DQ, Kommers GD, Barros CS (2005) Intoxicação espontânea por *Baccharis coridifolia* em bovinos. PesqVet Bras 25:111–114

Rizzo I, Varsavky E, Haidukowski M, Frade H (1997) Macrocyclic trichothecenes in *Baccharis coridifolia* plants and endophytes and *Baccharis artemisioides* plants. Toxicon 35:753–757

Rodrigues DM, De Souza MC, Arruda C, Pereira RAS, Bastos JK (2020) The role of *Baccharis dracunculifolia* and its chemical profile on green propolis production by *Apis mellifera*. J Chem Ecol 46:150–162

Romero-Benavides JC, Ortega-Torres GC, Villacis J, Vivanco-Jaramillo SL, Galarza-Urgilés KI, Bailon-Moscoso N (2018) Phytochemical study and evaluation of the cytotoxic properties of methanolic extract from *Baccharis obtusifolia*. Int J Med Chem 2018:1–5. https://doi.org/10.1155/2018/8908435

Sá CEM, Negreiros D, Fernandes GW, Dias MC, Franco AC (2014) Carbon dioxide-enriched atmosphere enhances biomass accumulation and meristem production in the pioneer shrub *Baccharis dracunculifolia* (Asteraceae). Acta Bot Bras 28:646–650. https://doi.org/10.1590/0102-33062014abb3329

Santos JC, Almeida-Cortez JS, Fernandes GW (2011) Richness of gall-inducing insects in the tropical dry forest (Caatinga) of Pernambuco. Rev Bras Entomol 55:45–54

Schang R (1929) Acción tóxica del romerillo o mio-mio (*Baccharis coridifolia*) algunos conceptos nuevos. Rev Bras Med Vet 11:151–181

Schild CO, Oliveira LGS, Miraballes C, Giannitti F, Casaux ML, Aráoz V, Silveira CS, Boabaid FM, Riet-Correa F (2020) *Baccharis coridifolia* poisoning in livestock in Uruguay. Toxicon 188:5–10

Shorthouse JD, Rohfritsch O (1992) Biology of insect-induced galls. Oxford University, New York

Silva RMD, Fernandes GW, Lovato MB (2007) Genetic variation in two *Chamaecrista* species (Leguminosae), one endangered and narrowly distributed and another widespread in the Serra do Espinhaço, Brazil. Can J Bot 85:629–636

Sims-Chilton NM, Zalucki MP, Buckley YM (2010) Long term climate effects are confounded with the biological control programme against the invasive weed *Baccharis halimifolia* in Australia. Biol Invasions 12:3145–3155

Souza MMQ, Silva GRD, Cola IM, Silva AO, Schaedler MI, Guarnier LP, Palozi RAC, Barboza LN, Menetrier JV, Froelich DL, Auth PA, Veiga AA, Souza LM, Lovato ECW, Ribeiro-Paes JT, Gasparotto Junior A, Lívero FADR (2020) *Baccharis trimera* (Less.) DC: an innovative cardioprotective herbal medicine against multiple risk factors for cardiovascular disease. J Med Food 23:676–684

Stone GN, Schönrogge K, Atkinson RJ, Bellido D, Pujade-Villar J (2002) The population biology of oak gall wasps (Hymenoptera: Cynipidae). Annu Rev Entomol 47:633–668

Suttisri R, Kinghorn AD, Wright AD, Stichert O (1994) Neo-clerodane diterpenoids and other constituents from *Baccharis genistelloides*. Phytochemistry 35:443–446

Takashima M, Ichihara K, Hirata Y (2019) Neuroprotective effects of Brazilian green propolis on oxytosis/ferroptosis in mouse hippocampal HT22 cells. Food Chem Toxicol 132:1–10. https://doi.org/10.1016/j.fct.2019.110669

Teixeira EW, Negri G, Meira RM, Message D, Salatino A (2005) Plant origin of green propolis: bee behavior, plant anatomy and chemistry. Evid Based Complement Alternat Med 2:85–92

Thompson AE, Lee CW, Gass RE (1995) Development of hybrid *Baccharis* plants for desert landscaping. HortScience 30:1357–1362

Tilden J (1953) Biological notes on *Trirhabda flavolimbata*. Coleopt Bull 7:43–53

Timmons F (1959) Phreatophytes – water wasters – a menace in the arid west. Reclam Era 45:85–88

Tokarnia C, Dobereiner J (1976) Intoxicação experimental em ovinos por “mio-mio”, *Baccharis coridifolia*. Pesqui Agropecu Bras 11:19–26

Torres LMB, Gamberini MT, Roque NF, Lima-Landman MT, Souccar C, Lapa AJ (2000) Diterpene from *Baccharis trimera* with a relaxant effect on rat vascular smooth muscle. Phytochemistry 55:617–619

Ueno AK, Barcellos AF, Costa-Silva TA, Mesquita JT, Ferreira DD, Tempone AG, Romoff P, Antar GM, Lago JHG (2018) Antitrypanosomal activity and evaluation of the mechanism of action of diterpenes from aerial parts of *Baccharis retusa* (Asteraceae). Fitoterapia 125:55–58

Vannini AB, Santos TG, Fleming AC, Purnhagen LRP, Lourenço LA, Butzke ETB, Kempt M, Begnini IM, Rebelo RA, Dalmarco EM, Cruz AB, Schmit AP, Cruz RCB, Yamanaka CN, Steindel M (2012) Chemical characterization and antimicrobial evaluation of the essential oils from *Baccharis uncinella* DC and *Baccharis semiserrata* DC (Asteraceae). J Essent Oil Res 24:547–554

Varaschin MS, Alessi AC (2003) Poisoning of mice by *Baccharis coridifolia*: an experimental model. Vet Hum Toxicol 45:42–44

Veiga RS, Mendonça S, Mendes PB, Paulino N, Mimica MJ, Lagareiro Netto AA, Lira IS, López BGC, Negrão V, Marcucci MC (2017) Artepillin C and phenolic compounds responsible for antimicrobial and antioxidant activity of green propolis and *Baccharis dracunculifolia* DC. J Appl Microbiol 122:911–920

Verdi LG, Brighente MC, Pizzolatti MG (2005) Gênero *Baccharis* (Asteraceae): Aspectos químicos, econômicos biológicos. Quim Nova 28:85–94

Verloove F, Dana ED, Alves P (2018) *Baccharis spicata* (Asteraceae), a new potentially invasive species to Europe. Plant Biosyst 152:416–426. https://doi.org/10.1080/11263504.2017.1303001

Vidari G, Finzi PV, Zarzuelo A, Gálvez, Zafra C, Chiriboga X, Berenguer B, La Casa C, Lastra CA, Motilva V, Martin MJ (2003) Antiulcer and antidiarrhoeic effect of *Baccharis teindalensis*. Pharm Biol 41:405–411

Vieira ML, Johann S, Hughes FM, Rosa CA, Rosa LH (2014) The diversity and antimicrobial activity of endophytic fungi associated with medicinal plant *Baccharis trimera* (Asteraceae) from the Brazilian savannah. Can J Microbiol 60:847–856. https://doi.org/10.1139/cjm-2014-0449

Waring GL, Price PW (1990) Plant water stress and gall formation (Cecidomyiidae: *Asphondylia* spp.) on creosote bush. Ecol Entomol 15:87–95

Watts S, Dormann CF, González AMM, Ollerton J (2016) The influence of floral traits on specialization and modularity of plant–pollinator networks in a biodiversity hotspot in the Peruvian Andes. Ann Bot 118:415–429

Westman WE, Panetta FD, Stanely TD (1975) Ecological studies on reproduction and establishment of the woody weed, groundsel bush (*Baccharis halimifolia* L.: Asteraceae). Aust J Agric Res 26:855–870

Wollenweber E, Valantvetschera KM, Fernandes GW (2006) Chemodiversity of exudate flavonoids in *Baccharis concinna* and three further South-American *Baccharis* species. Nat Prod Commun 1:627–632

Zavaleta ES (2006) Shrub establishment under experimental global changes in a California grassland. Plant Ecol 184:53–63

Zavaleta ES, Kettley LS (2006) Ecosystem change along a woody invasion chronosequence in a California grassland. J Arid Environ 66:290–306. https://doi.org/10.1016/j.jaridenv.2005.11.008