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Review

Purely Australian Essential Oils Past and Present: Chemical Diversity, Authenticity, Bioactivity, and Commercial Value

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Abstract: In this comprehensive commentary, Australian essential oils and their components are listed and discussed in the context of their value to industry and aesthetics. The historic and cultural significance of endemic essential oils is explained. Several promising candidates are identified that have commercial potential and will enter the marketplace in the not-too-distant future. This text elaborates on the current progress in research, and explains the up-to-date view of 'bioactive,' with reference to insect repellence, antimicrobial activity, anti-inflammatory activity, and potential toxicity. The concept of chemotypes and chemophenetics is explained in detail to justify why chemically variable species in Australia require standardisation practices to ensure reproducibility of their derived natural products: standardisation practice includes cultivar development and authentication protocols. Thereafter, some of the more significant essential oils are defined and some background information provided. This review concludes with a comprehensive table of aromatic species that were studied by Joseph Brophy over the last 30 years, thereby providing the most comprehensive overview available, on the chemistry of Australian essential oil yielding species.

Keywords: industry; commerce; business; farming; chemistry; health; medicine

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1. Introduction

The two most famous Australian essential oils are tea tree oil (TTO) from *Melaleuca alternaifolia* (Maiden et Betche) Cheel., and eucalyptus oil from various species of *Eucalyptus*, particularly *E. radiata* Sieber ex DC (syn. *E. australiana*), and formerly *E. globulis* Labill. Both TTO and eucalyptus oil are sold in nearly every country of the world, making them two of the most successful natural products to enter the market since the start of the industrial revolution.

TTO and eucalyptus oil are defined in the British Pharmacopoeia and the International Standards Organisation (ISO) according to a specific chemical profile. Eucalyptus oil must contain >70% of a monoterpene oxide called 1,8-cineole [1], and TTO must include 14 ingredients, such as terpinen-4-ol, within a specific concentration range according to gas chromatography [2].

Standardisation across industry is a necessary measure to ensure that consumers pay for the same item as advertised [3]. While, today, most of the commercial crops give a product that adheres to the standards, they were established 50–100 years ago, so the farmers, wholesalers, and retailers are no longer interacting with wild plants. The wild Australian flora is highly chemically diverse, and chemical diversity occurs even within species. When aromatic species produce different types of essential oils, they are divided into varieties called chemotypes [2]. Thus, if farmers started new crops of TTO or Eucalyptus that were propagated from wild species, there is a strong chance that their product will differ dramatically from the defined standard.

All commercial crops were originally established from wild plants, and extensive bioprospecting, following by propagation from a single genotype, was a necessary undertaking to create today's industrial scale plantations that conform to the pharmacopoeia standards. Commercial crops must, therefore, start from a single genotype, called a cultivar, so that there is chemical uniformity across the natural products in industry.

When studying essential oils, natural product chemists first look at the chemical phenotype (chemophenetics) of a species, then divide the species according to chemotypes [2]. Occasionally, the opposite happens; rather than finding chemotypes within species, the chemistry of one species is identical to another closely related species, meaning that one chemotype is assigned for several species. For this reason, even if it is from the wrong species, the chemistry of an essential oil can meet the requirements of the standard defined by the ISO.

For example, both the Australian standard (AS 2782-2009) and the ISO (ISO 4730:2004) define TTO as an oil produced from any one of multiple species, such as *M. alternifolia*, *M. linariifolia* Smith, and *M. dissitiflora* F.Muell. They also specify that any other species in *Melaleuca* that can produce an essential oil that matches the standard chemical profile is classified as TTO [2].

Paradoxically, the eucalyptus oil that is defined according to 1,8-cineole content (ISO 770:2002), usually has little to no globulol, which is an antimicrobial sesquiterpene [4] that is etymologically related to the name of the species *E. globulus*. So much value has been attributed to 1,8-cineole in meeting the pharmacopoeia standard that perceptions have conflated the value of 1,8-cineole and globulol is largely forgotten about. However, a well-rounded oil that is rich in 1,8-cineole with moderate amounts of globulol and aromadendrene is theoretically better for antimicrobial applications [5], particularly because of the synergistic antimicrobial combination between aromadendrene and 1,8-cineole [6]. Such a well-rounded essential oil can be produced by ensuring that the fruits (gum nuts or capsules) of *Eucalyptus* are included in the distillation with the leaves. However, today, this cannot be done, as the essential oil will not meet the pharmacopoeia standard.

There are several other Australian essential oils that are achieving national and international commercial success. For example, Australian sandalwood oil, from *Santalum spicatum* A.DC has been feeding the international market for over 185 years [7] as a variant of the East Indian and Indonesian sandalwood oil, from the species *S. album* L [8].

Another Australian oil that was called 'bastard sandalwood,' from *Eremophila mitchellii* Benth. [9,10], was also marketed as an alternative to Indian sandalwood, but it was a failure. It should have been branded separately because it was considered inferior to sandalwood. However, it would have been successful under another name, such as 'buddha wood oil,' which is adapted from its vernacular name 'buddha wood.' Fortunately, today, there is a market for buddha wood oil, and the branding has incorporated yogic stereotypes as a hook for practitioners of new age crafts.

There are several other Australian essential oils that have had a long history of moderate success in international trade. There are also many more that were never developed or have only recently been discovered. The current review article summarises the potential value of Australia as a source of unique essential oils, their roles in aesthetics or therapy, and how they are facing up to the marketplace.

2. Progress in Research

Research in the last 30 years on Australian essential oils has created a comprehensive overview of nearly all the aromatic species (Table 1 and Section 3) [11]. However, with repeated sampling of species that were previously studied, new information has emerged about the chemical diversity within each taxon. Some of this chemical information has supported taxonomic revision of species, but in most cases, taxa are split into chemotypes [12].

In going beyond chemical reports, studies of Australian essential oils and natural volatiles also focus on antimicrobial activity and their possible involvement in Aboriginal traditional medicine (ethnopharmacology) [12,13]. Antimicrobial effects from essential oils generally place them as antiseptic ingredients, such as topical anti-infectives and surface sprays. Essential oil components are also known to exert immunological effects, but these are not explained by the outcomes of antimicrobial assays [14].

Antimicrobial outcomes are also influenced by synergistic effects between volatile organic compounds and fixed components in extracts [15,16], the concentrations are still many orders of magnitude above antibiotics [17]. Furthermore, antimicrobial outcomes are augmented when essential oils are delivered as vapours in warm air [18,19], but again, the inhibitory concentrations are only significant in the context of household usage, topical antiseptic use or in ethnopharmacology. Thus, the industrial development of essential oils should continue to focus on development of fragrances, aesthetics, and products for dermatological end uses.

During the last 50 years or so, studies of the Australian flora have described countless new molecules to science [2]. For this reason, there is minimal information related to the biological effects, or toxicity of exclusively Australian volatile organic compounds. Information is usually restricted to toxicity data from effects observed over the span of hundreds of years against grazing stock. Information of antimicrobial data is also readily available because it is generated quite easily in standard university labs [14,17].

2.1. Bioactivity of Australian Essential Oils

There is a significant number of volatile molecules that are only found in Australian aromatic plants. Many Australian essential oils contain these exclusive components, but they also include components that are familiar to other parts of the world. For this reason, an educated guess of the biological effects of Australian essential oils can be made by extrapolating from pharmacological information produced in other parts of the world.

2.1.1. Insect Repellent or Insecticidal Essential Oils

Cedrol and 8,14-cedranoxide are sesquiterpenes familiar to Mediterranean and Asian species in the family Cupressaceae [20–24]. Because both of these components were identified in *Eremophila sturtii* R.Br. [9], it is expected that biological effects converge between products from *E. sturtii* and Mediterranean Cupressaceae. To evidence this, 8,14-cedranoxide is the major insecticidal component of *Juniperus recurva* Buch.-Ham. ex D.Don [25]. As it is also present in leaves of *E. sturtii*, this explains the fly repellent effects achieved in traditional use of this species [9,26].

Australia is home to many insecticidal plants, but those that entered industry are limited to the termite resistance timbers. The observation of termite resistance in native timbers occurred in several waves. It is possible that Aboriginal people and early colonialists observed this phenomenon in wild trees, but no detailed records were found to confirm this. However, when the timbers were arbitrarily used in construction, their resistant properties were realized, and commercial initiatives quickly followed. The first to promote the use of these timbers was Joseph Henry Maiden [27,28], who made the knowledge public in the late 1800s to early 1900s.

Use of the timbers from *Eremophila mitchellii* was based on the observation that fence posts coincidentally made from the timber were still standing a century later [29], whereas other posts littered along the same fence line had disintegrated. A research group in Lismore (NSW) later demonstrated that the essential oils from the timber of *E. mitchellii* are a repellent against termites [30]. The active components are in the eudesmane and eremophilone class, including eremophilone, santalcamphor, and 9-hydroxy-7(11), 9-eremophiladien-8-one [10].

Maiden's observations were based on the timbers used to make houses. Timbers made from Australian species of cypress, from the genus *Callitris* (Cupressaceae), were resistant to termite infestation. He encouraged the establishment of a plantation of *Callitris endlicheri* (Parl.) F.M.Bailey as an export timber [28], but the costs of transporting the timber from NSW to the shipping ports in the Northern Territory proved economically unfeasible. However, several years after Maiden died (1859–1925), a plantation of *Callitris intratropica* R.T.Baker & H.G.Sm (accepted name is *C. columellaris* F.Muell. [31]) was initiated in the region near Darwin (Northern Territory).

During the years 1950–1974, the timber from *C. intratropica* entered the market and was being used in the construction of houses. However, in the year of 1974, a category 4 cyclone arrived on Darwin's shores, Cyclone Tracey. Most of the houses constructed from timber of *Callitris* were destroyed [2]. Thereafter, the plantation of *C. intratropica* was abandoned as a source of timber. In later years the plantation was accessed for the blue essential oil, which is used today in aesthetics. A possible dermatological application may involve inhibition of *Demodex* [32], which is a human ectoparasite that causes skin complaints in some individuals [33].

Lastly, there is an Australian essential oil that is rich in pregeijerene, which is a known insecticidal molecule, with activity against the tobacco cutworm, *Spodoptera litura* (F.) [34]. It is also an attractant to subterranean nematodes that feed on herbivorous insect larvae. A study of entomopathogenic nematodes demonstrated that the roots of species of the genus *Citrus* express pregeijerene. This sesquiterpene increases when herbivorous larvae, such as *Diaprepes abbreviatus*, graze on the roots, indicating that it is possibly a phytoalexin. The presence of pregeijerene then attracts nematodes that eat the herbivorous larvae and reduce their population density. These effects were also replicated in blueberry fields by attracting nematodes that eat the respective blueberry larvae, *Galleria mellonella* and *Anomala orientalis* [35].

2.1.2. Antimicrobial Effects of Essential Oils

There is a wide selection of possible applications for essential oils in aesthetics where antimicrobial activity is needed. Although essential oils are not considered a primary treatment for dermatological infections, they are preventative and can be used like a disinfectant [17]. Essential oils are better for antibacterial and antifungal applications than pure alcohol, because alcohol is quickly evaporated, whereas the essential oil components absorb into the dermis and confer protection for longer.

For example, medical practitioners will discourage self-treatment for potentially dangerous infections, such as staph or septic wounds, but they will accept use of essential oils to prevent spreading the infection, or to support antibiotic treatment. Some dermatological problems that will benefit from the antimicrobial effects of essential oils include acne [36], hair loss pathologies where overgrowth of *Propionibacterium* and *Malassezia* promote microinflammation [37,38], foot odours [39], athletes foot [40], and protection of skin grazes, cuts, or non-infected wounds.

Australian essential oils that have strong antimicrobial effects include TTO [41,42], some chemotypes of *Eremophila longifolia* [18,19,40], essential oil from some species of *Eucalyptus* [43], or from some species of *Prostanthera* [44–46]. Although there are many antimicrobial essential oils, the antimicrobial effects can be traced to active ingredients that are either common or are common in Australian species. For example, the antifungal oil from the Australian species *Zieria smithii* Jacks. is rich in elemicin [47], a known antifungal component [48].

In another example, several chemotypes of *Geijera parviflora* L. were identified and some demonstrated antimicrobial and antifungal activity. The most active essential oils were the green oils rich in geijerene and pregeijerene (35–50%), which are the components that taint the oil to the colour green. The antimicrobial effects of these components, in combination with linalool, were demonstrated against Gram-positive bacteria, and some fungal species in the genus *Trichophyton* [49]. This green essential oil is currently being developed for the market under the brand name 'green lavender.'

Geijerene and pregeijerene were also identified in the chemical profile of another Australian species, *Flindersia maculosa* (Lindl.) Benth [50]. Although these components, geijerene and pregeijerene, were first described in Australia, they have also been detected in essential oils distilled from African species [51]. They were also characterised at high abundance in a south Indian species, *Chloroxylon swietenia* DC. [34], which was used traditionally in anti-fungal applications by the south Indian people, giving a parallel to in vitro data obtained on the Australian essential oil [49]. Lastly, pregeijerene is expressed in the roots of citrus, as previously mentioned [35].

Another exclusively Australian antimicrobial sesquiterpene comes from the genus *Prostanthera*. Essential oils from some species demonstrated relatively interesting inhibitory activity against Gram-positive organisms. The active component of the oils is named 'prostantherol,' which is evidently etymologically related to the genus from where it was first isolated [52]. The antimicrobial values were in the range of 125–250 ug.mL^{-1} [45], which is regarded as good in the context of an essential oil. As a comparison, a similar inhibitory concentration is achieved from TTO [53]. Furthermore, when the essential oils from *Prostanthera* were encapsulated using α-cyclodextrin, the antimicrobial effects were augmented by 2–5 folds, and Gram-negative organisms were also inhibited [46]. It is possible that the hydrophilic cyclodextrin exterior of the complex acts as a vehicle for the transport of lipophilic compounds across the periplasmic space, enabling essential oils to have inhibitory activity against Gram-negative microbes.

These types of synergistic antimicrobial effects also occur in nature, between two or more essential oil components [6], or in mixtures of essential oils and non-volatile components in the source plant material [15,16]. Synergistic antimicrobial effects are evident in TTO [54], and in the fruit essential oil from *Eucalyptus globulus* [6].

A very common essential oil component is globulol, which is one of the main ingredients from fruits of *Eucalytpus* and is responsible for the antimicrobial effects of many essential oils against Gram-positive organisms [4]. Another common component is aromadendrene, which was demonstrated to have an optimal synergistic combination with 1,8-cineole in antimicrobial outcomes [6].

Although the synergistic antimicrobial effects between 1,8-cineole and non-volatile components has not been investigated, it is encouraged to examine combinations between 1,8-cineole and the known antimicrobial meroterpenes. These unique meroterpenes represent condensation products between phloroglucinols and terpenes [55]. In a similar way to the effects of prenylation of flavonoids in augmenting antimicrobial outcomes [56], it is possible that the lipophilic terpene moiety of the antimicrobial meroterpene euglobal series [57] enhances the penetration ability into Gram-positive bacterial cells, conferring significant antimicrobial outcomes. The effects of terpenes to bacterial cell walls should, therefore, be explored in research of synergy between essential oil components and phloroglucinols.

2.1.3. Toxic Australian Essential Oils

Although essential oils cannot be compared to poisonous substances, such as the taxines from the genus *Taxus*, or the toxic pesticide strychnine from *Strychnos nux-blanda* A.W.Hill, some can be toxic at high doses. An example of such a compound known to be lethal with a high dose is ngaione [58], which is responsible for the deaths of grazing stock animals.

Sheep and cattle graze harmlessly on the species *Eremophila deserti* (A.Cunn. ex Benth.) Chinnock, which normally expresses a high yield of the iridoid methoxymyodesert-3-ene. However, the species is made up of several chemotypes, and one is the ngaione type [59], or types that include related furanosesquiterpenes. Because stock animals graze heavily on the species, *E. deserti* has been associated with animal fatalities, but the inconsistency in poisonings was a mystery until it was realized that toxicity was caused by a ngaione chemotype. The Australian desert genus *Eremophila* has several species that express furanosesquiterpenes like ngaione [59], and they should all be regarded as inedible.

Controversy over claims of toxicity also prevails in the context of essential oils. For example, a chemotype of *Eremophila longifolia* F. Muell. produced high yields of an essential oil with only two components, safrole and methyl eugenol [60]. Safrole was previously used as a flavour ingredient in soft drinks, but it was banned after a study in the 1960s demonstrated hepatotoxicity in mice, leading to the formation of liver cancers [61]. The mice were administered extremely high doses of safrole, and hepatotoxicity was related to some phase 1 metabolites [62], which have not been detected in humans. Safrole is present in several herbs and spices that form part of a standard oriental diet. However, it is not natural for humans to be exposed to the levels like those mice in the assays that demonstrated hepatotoxicity.

Essential oils may also be considered toxic if they cross the blood-brain barrier and enact psychotropic effects that are either recreational, or at higher concentrations, dangerous. An example of a psychotropic essential oil component is elemicin. Elemicin is the major component of essential oil from *Myristica fragrans* Houtt., a herb that has been used and abused for its psychotropic effects [63,64]. While nutmeg is not an Australian species, several species in Australia express elemicin in their essential oil profiles. The best example is one of the chemotypes of *Zieria smithii* Jacks., which expressed 50% of elemicin, and an essential oil yield of 2% [47].

As a final example, animal studies were conducted to determine the toxic dose of 1,8-cineole. The 50% oral lethal dose of 1,8-cineole in mice is approximately 3.8 $g.kg^{-1}$ [65]. This is the equivalent of a human drinking approximately 200–500 mL of 1,8-cinoele liquid. It was later determined that reversable signs of toxicity occur over the course of 2–3 months with an oral dose of 0.19 $g.kg^{-1}$ (10–20 mL equivalent in humans). In the same study, no adverse effect was noticed at one third of that dose [65]. This illustrates that toxicity is relative to dose, and that even a household product, eucalyptus oil, that is widely considered safe, can be branded as a toxic item if it were not for the long history of safe use.

Although the above study reiterates that toxicity is dose and context specific, some consumers of essential oil products experience sensitisation due to allergy [66], which is not easy to predict using data from animal studies. However, it is more common that natural products are therapeutic within a reasonable concentration range, then become toxic above that concentration [3], as in the above example. Toxic effects can also either be persistent (chronic) or they reverse when the toxin has been metabolised and removed from the system.

In 1994, a case of poisoning from TTO was reported to the Journal of Toxicology: Clinical Toxicology [67]. It described the experience of a 23-month-old boy who ingested an entire 10 mL bottle of the liquid. According to the child's parents, he became confused and incapacitated (unable to walk) 30 min after ingestion, before being taken to a nearby hospital. Allegedly his condition steadily improved, he became completely asymptomatic after five hours and endured no long-term effects.

Unfortunately, knowledge of long-term effects of natural products from the Australian flora is unavailable, because Australia's recorded history is still young. Detailed records of long-term safe use are not available for most natural products and medicines. Although there is a rich ethnobotanical history with the Aboriginal people, so much of the information has been lost because of the cultural fragmentation that occurred with colonization. However, as previously mentioned, tentative knowledge of Australian botanicals will largely come from examples of chemically similar species in other nations that have more comprehensive written records and pharmacopoeias.

2.2. Chemophenetics of Natural Volatiles and Essential Oils

The chemical signature of natural volatiles and essential oils has found place in taxonomy, but not as a tool to delimitate taxa, but rather, as a tool for exploration. Chemophenetics may be defined as an exploration of chemical relationships, which can be either intraspecific (within species) or interspecific (across species). Chemophenetics focuses on small molecules, often natural volatiles, and essential oils, but it is not restricted to volatiles, because fixed components, such as flavonoids, saponins, coumarins and others, are also of interest in exploration of taxa.

The term chemophenetics was introduced as a replacement for the previous outdated terms, chemosystematics, or chemotaxonomy [68]. The new term was necessary because the older terms have become obsolete. When chemotaxonomy was initially finding place as a tool in taxonomic delimitation, the sudden development of complex phylogenetic and macro-molecular systematic techniques overshadowed chemotaxonomy. It is explained that most importantly, chemophenetics contributes to the phenetic description of taxa, i.e., just like shape, colour and other physical characters, the chemical profile is a description of the specimen's phenotype, however, chemical profiles are not as easily determined as observable morphology.

In chemophenetic studies of taxa, if multiple specimens within or across taxa are chemically characterised, the data can be analysed by multivariate analysis, such as principal component analysis, or cluster hierarchical analysis. Thereafter, chemical patterns are determined within and between taxa. The type of data used for such studies can come from any chemical group, such as flavonoids, coumarins, saponins and volatile organic compounds. When volatiles are studied, they can either be in the form of an essential oil or as a solvent extract. Furthermore, chemophenetic studies can be enriched by acknowledging biosynthetic relatedness between components, or by using oxidation indices to add another layer of complexity to the analysis and tease out more relationships, particularly in the context of circadian rhythms [69].

2.2.1. Examples of Essential Oils in Australian Chemophenetic Studies

From hundreds of hydrodistillations of *Eremophila longifolia*, 12 or 13 potential chemotypes were discovered [59,60]. Samples were taken from across the continent, from a transect that spans 3300 km from east to west, and 1500 km north to south. It was revealed that chemical diversity within a radius of several hundred kilometres is similar to right across the country, from Sydney to Perth. For example, the borneol/fenchol type of *E. longifolia* in NSW is like the fenchol/borneol type in the Murchison district of WA. The only difference between the two is the relative expression of the two compounds, fenchol and borneol. Furthermore, the random populations or individuals that express karahanaenone are found purely by chance, right across the country [60].

In NSW, there is also a diploid population of *E. longifolia* that expresses high yields of a terpenoid essential oil with menthone and isomenthone as major components [40]. Another diploid population is in WA, also giving high yields of essential oil, but the major components are the phenylpropanoids, safrole and methyl eugenol [70]. A latter study demonstrated that diploid specimens of *E. longifolia* express high yields of essential oils from their leaves, in contrast to the tetraploids that express low yields [60]. Furthermore, within the distribution of the eastern Australian diploids that span from NSW into central Qld, there are several chemotypes, such as the karahanaenone type (White Cliff, Wilcannia, Cobar), the isomenthone/menthone type (White Cliff), and the piperitol type (Grey Ranges, Qld) [59].

According to biogeographic theory, the flora of the Murchison district of Australia is remnants of an 'eremaeon' stock of diploid species. It is postulated that in ancient history a post glaciation drought caused a continent-wide die-back of indigenous flora and the surviving species in the far west of WA recolonised the continent by developing polyploidy, increasing drought tolerance. Hence, the observation that tetraploid species of *E. longifolia* express lower yields of specialised metabolites is a validation of that hypothesis because the tetraploids are more resource efficient.

The chemophenetic study of *E. longifolia* cast doubt over the taxonomic rank of the diploid chemotype in WA. This is because it is the only chemotype among the 13 that has phenylpropanoid essential oils, whereas all others follow terpenoid biosynthesis. In this regard, the location in NSW known as Mutawintji NP should be explored as another potential 'eremaeon' stock, and it should be considered whether the Australia-wide tetraploids are descendants of the eastern diploids from that region, because they follow terpenoid biosynthesis, rather than the western diploids [60].

Furthermore, the leaves of the western diploid are a greyish green colour, and the growth habit is distinctly different. However, Robert Chinnock mentions that no floral or leaf characters are available to justify the splitting of the diploids [71]. Hence, it is necessary to investigate this further, perhaps by following a macro-molecular approach.

A chemophenetic approach was followed in exploration of the *Phebalium squamulosum* Vent heterogeneous species aggregate [72], using hydrodistilled essential oils. Patterns were identified that agreed with the newest taxonomic placements. The first finding came from a study of *P. squamulosum* subsp. *verrucosum* Paul G.Wilson, which has a stronger morphological relationship to the *Phebalium glandulosum* Hook., heterogeneous species aggregate. Hydrodistillation produced an essential oil at a yield of 2%, and the major component identified as dihydrotagetone [73]. This chemical observation validated the morphological relationship to *P. glandulosum* [74]. However, rather than correct subspecies placement, *P. squamulosum* subsp. *verrucosum* was elevated to species rank as *P. verrucosum* (Paul G.Wilson) I.Telford & J.J.Bruhl [75].

Hydrodistilled essential oils were also used in a chemophenetic study of the *Prostanthera lasianthos* Labill., heterogeneous species aggregate, which identified chemotypes within single taxa that resulted from phenotypic plasticity of volatiles, in response to soils, moisture and shading [76]. In this latter case, the chemophenetic data was not taxonomically informative [77]. Conn et al., [77] stated that:

> "no dataset has primacy in defining segregate taxa, and … a combination of morphological and molecular data was required to determine the taxa within."

This reiterates the objective of chemophenetics, which is not to use a chemical profile as a taxonomic tool, but rather, to describe the phenotype and look for patterns, which could be related to taxa or to other variables, such as abiotic factors. Whether or not it supports taxonomic delimitation is a matter of context and if it represents the converging effect of multiple lines of evidence, as was explained by De Queiroz [78].

2.2.2. Examples of Solvent Extracted Volatiles in Australian Chemophenetic Studies

Chemophenetic studies have recently started to use single leaf extracts as an alternative to essential oils that require laborious, time consuming and energy-taxing hydrodistillation. In this approach, a small leaf, or fragment of big leaf, is extracted into approximately 2 mL of solvent, which is usually dichloromethane, hexane, or ethyl acetate, and less commonly ethanol or methanol.

Organic solvents extract the volatile components and non-volatile or semi-volatile components that have vapour pressures too high to be afforded by hydrodistillation. Some of these compounds still have a vapour pressure, but it is not high enough for the component to be driven into the essential oil during hydrodistillation. However, their vapour pressures are still high enough for them to be detected by GC-MS. This means that the chemical profiles of solvent extracts often include more than just the essential oil components. If the GC-MS operating conditions are manipulated so that the column is heated to its highest temperature and held for 20–30 min, components with lower vapour pressures will also be detected, even if they are absent from the essential oils.

An example of where a solvent extract was used as part of a chemophenetic study, includes the work of Collins et al. [79,80], who created a taxonomic revision of *Eucalyptus magnificata* L.A.S.Johnson & K.D.Hill. This species normally produces a high yield of an essential oil in hydrodistillation, made up of the three eudesmol isomers, i.e., α-, β-, and γ-eudesmol. However, when using solvent extracts in the place of essential oils the dominant component was cryptomeridiol [79,80], which is a biosynthetic precursor to the eudesmol isomers. In hydrodistillation, cryptomeridiol undergoes a heat-driven elimination of the hydroxyl moiety (loss of water) at position four, which instils a double bond that randomly occurs in one of three directions, i.e., α- = 3(4), β- = 4(14), and γ- = 4(5), creating the three isomers. Hence, a solvent extract is significantly different by comparison with the essential oil.

In another example, the heat labile precursor to spathulenol, bicyclogermacrene [81], was of high relative abundance in solvent extracts of taxa in the *Phebalium nottii* (F.Muell.) Maiden & Betche heterogeneous species aggregate [82], whereas hydrodistillation afforded spathulenol-rich essential oils. Furthermore, the use of solvent extracts revealed several semi-volatile coumarins that are too 'heavy' to be driven into the essential oils. From this study the semi-volatile coumarin myrsellin stood out as a taxonomic marker for the putative new taxa, *P.* sp. Goobang and *P.* sp. Texas, which have subsequently been joined as a single taxon awaiting a taxonomic rank. In this context, the use of solvent extracts in the place of essential oils was more informative in the chemophenetic study, because more chemical information was obtained.

2.2.3. Chemophenetics as an Authentication Tool

In the current paradigm of natural products in health, the opportunism in industry has become polarised between honest and dishonest marketing. The consumer is understandably concerned that their turn to health is contradicted by products that are not authentic, that harm health rather than confer the effects described in scientific studies. The rise in counterfeited items in the marketplace has been met with authentication initiatives that aim to help the consumer to have faith in the product, and to help the company be rewarded for their honesty [3].

Chemophenetic studies may be regarded as a powerful tool to be used in the authentication of essential oils and aromatic extracts. This is because chemophenetics is the best procedure for the determination of natural variation in essential oil profiles, before standards are stipulated. The authenticator might observe chemical variation of an essential oil and determine that it is natural and not a sign of tampering or adulteration, because a chemophenetic study demonstrated the same variation.

Furthermore, chemophenetic studies identify chemotypes. Knowledge of chemotypes informs authenticators about expected differences within a single species. Armed with this knowledge the authenticator will recognise that an apparent substitution is the unintended outcome of harvesting plant material from a different chemotype, but not the wrong species, causing a non-match to the known standard defined in the pharmacopoeia or by ISO. Chemotypes can be recognised according to a unique chemical profile but claims in the marketplace need to be consistent with the standard described for that chemotype.

3. Natural Volatiles in Ethnopharmacology

In Australia there is a high proportion of endemic aromatic species, by comparison with the other continents. There are also a significant number of aromatic species utilised by the Aboriginal people, past and present. Thus, volatile organic compounds feature prominently in the *materia medica* of Australia's first people.

3.1. The Eucalyptus Paradox

Paradoxically, there is limited information on how species of *Eucalyptus* were used in traditional medicine. Although there are numerous articles on the web, and in the published literature [83], that present *Eucalyptus* as an ethnobotanically significant genus, the truth is that records of traditional use are scarce. Lassak and McCarthy [84] also observed this paradox and stated that the northern species of *Eucalyptus* contain irritants and were unlikely to have been used in fumigation type medicine, however, the southern and eastern species were an obvious good choice for therapeutic use. They went on to present the theory that because the south-eastern part of the country was the first place to be colonized, the culture of the Aboriginal people was fragmented before ethnobotanical records were made of their use of *Eucalyptus*.

While it seems odd that there are no records, it is also possible that species in *Eucalyptus* were used as warm vapours. Although this was not observed, it has been extrapolated from archaeological findings of 'hot oven rock' that are associated with procedures designed to drive vapours out of the leaves of aromatic species [85]. The procedure involved the lining of a hole in the earth with hot rocks that were heated over a fire. The hot rocks were then overlaid with aromatic foliage, followed by the patient, then sealed. The ground oven was closed with enough soil to cover the body, but not the face or head of the living patient. The reason archaeologists believed that species from *Eucalyptus* were chosen for this procedure is that the vegetation in the respective region was limited to that genus.

3.2. How Volatile Organic Compounds Were Used in Ancient Australian History

In the Australian flora there are several antimicrobial and anti-inflammatory compounds that are present in the essential oils [2]. The traditional Australian people did not use essential oils per se, because distillation apparatus was not available. Instead, they utilised volatile organic compounds in the form of poultices, fat extracts and vapours [86].

Volatile organic compounds are often directly responsible for the therapeutic outcome of a medicinal application, but they are also involved in synergy with fixed medicinal compounds. While there is limited empirical work to support this latter observation in the Australian context, studies on African aromatic species have confirmed that synergistic effects occur between fixed and volatile components [15,16,87].

One way that the volatiles of aromatic plants were used by traditional Australian people was by direct inhalation of the vapours emitted by crushed aromatic plant material. The aromatic poultice was held to the nose, or near the nose, and the vapours inhaled. Species with written records confirming this include *Eremophila bignoniiflora* (Benth.) F.Muell. [88], and *Pittosporum angustifolium* G.Lodd. [89]. However, it is likely that vastly more species were used in this way, but records were not made by the colonialists or early ethnobotanists who observed this.

Aromatic species were also pulverised and applied to the surface of the skin. Because volatile organic compounds are lipophilic, they partition into and across the dermis. Thus, aromatic species that were applied to the skin as a poultice targeted both superficial and deeper ailments, possibly related to infection or inflammation [86].

Volatile organic compounds were also extracted into animal fat (and maybe fixed plant oils). The aromatic species were pulverised and mixed with fat, and the fat used for topical applications [84,90]. This method was possibly chosen to improve the longevity of aromatic species (for travel) and to encapsulate volatiles to improve flux into the dermis.

Evidently in all the above scenarios, the volatile organic compounds are delivered to the dermis in combination with fixed compounds. In such cases, synergistic effects are possible between volatiles and fixed components. However, in the final example, vapours were also utilised by placing aromatic foliage over the smouldering embers of an extinguished fire. Although records of how many species were utilised this way are limited, there is strong evidence that species in *Eremophila* were used, such as *E. sturtii*, *E. longifolia*, *E. bignoniiflora*, and *E. freelingii* F.Muell. [85]. Furthermore, a desert species named *Prostanthera striatiflora* F.Muell., and two temperate species, *P. angustifolium* and *G. parviflora* were also observed in such modalities and recorded before the information was lost [85].

One variation of body fumigation with aromatic vapours involved the use of a bark hut to contain vapours (and artefact aerosols). This was evidently practiced with species from *Eremophila* and may have been practiced using other species. Communications from surviving traditional elders of the Gamilaraay nation describe using *E. bignoniiflora* and *E. longifolia* this way [86].

When the fumigation ritual of *E. longifolia* was replicated in a university laboratory, a heart-derived artefact was produced that had antimicrobial activity that was stronger than the volatile organic compounds naturally present in the leaves. The product was a furan aldehyde; thus it was named 'genifuranal' because it is believed to be a derivative from geniposidic acid [18]. Genifuranal may be a contributor to other biological effects that have been described for this species.

The use of *E. longifolia* in fumigation rituals, either over open embers or in a closed hut, was practiced widely across the Australian continent, but there are some places where this practice was not active. In the same study that identified genifuranal, it was observed that some specimens of *E. longifolia* did not yield genifuranal, despite having the same essential oil profile as the ones that did. Furthermore, the diploid specimens did not yield genifuranal on any occasion [18]. This explains why there was variation in traditional use of this species in fumigation rituals.

4. Significant Genera and Industrial Progress

Several species and genera have potential but have not yet found a niche in the essential oils industry. In this section, some of the most promising candidates are discussed, with consideration to feasible yield and novelty.

4.1. *Prostanthera (Lamiaceae)*

This genus is currently undergoing extensive taxonomic revision, particularly the *Prostanthera ovalifolia* R.Br. [44,45,52,91–93], and *P. lasianthos* Labill. [76,77], heterogeneous species aggregates. In the *P. ovalifolia* group, several sesquiterpenes are expressed singularly or in combinations, commonly diluted by 1,8-cineole [44]. The sesquiterpenes, such as maaliol, prostantherol, cis-dihydroagarofuran and kessane, have minimal dedicated pharmacological research (Figure 1). However, in the *P. lasianthos* group, the essential oils are predominantly monoterpenoid in character, including 1,8-cineole, linalool, linalyl acetate, butanoic esters, and occasionally, pinene isomers [76].

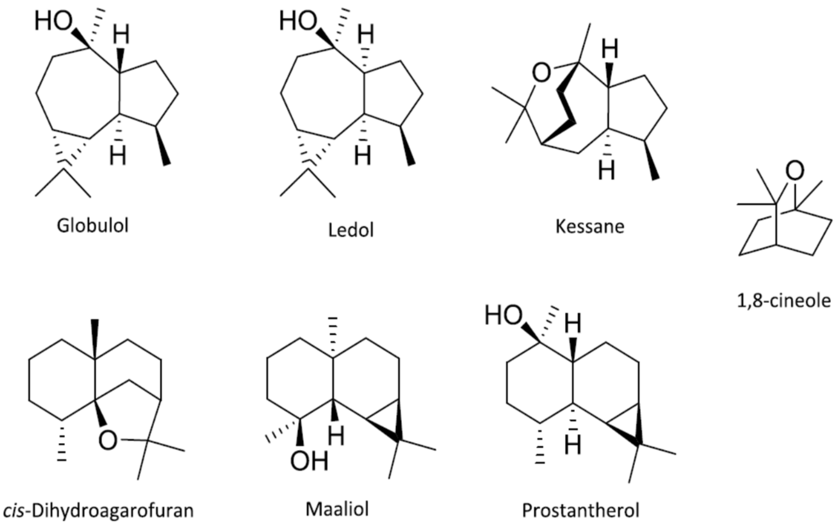

Figure 1. Major sesquiterpenes and 1,8-cineole in the *Prostanthera ovalifolia* heterogeneous species aggregate.

4.2. *Eremophila and Myoporum (Scrophylariaceae)*

These two genera are regarded as clade sisters. Chemophenetic discoveries of *E. longifolia* were elaborated upon in Section 2.2.1. *Eremophila* is a genus of over 200 species [71], but the number is rising as new species are discovered or segregated. Similarly, *Myoporum* is also comprised of a phenotypic and chemical diversity that is nearly comparable to that of *Eucalyptus*.

Species in Myoporum are occasionally revised and placed into *Eremophila*. This is what happened to *Eremophila deserti* (A.Cunn. ex Benth.) Chinnock, which was chemically characterised under its previous name, *Myoporum deserti,* during the late 20th century. This species is morphologically consistent across its distribution, yet its chemophenetic pattern is varied significantly. The combination of past and present data confirms that *E. deserti* includes over five chemotypes [59]. It is noteworthy that there is no geographical pattern to these chemotypes. Furthermore, multiple chemotypes of *E. deserti* are often found growing together in the same population.

Due to the high yield of the essential oil from leaves of *E. deserti*, that is sometimes dominated by a single component, there is an opportunity to use the components as precursors for industrial scale synthesis to produce known or therapeutic compounds. A similar observation is made for *Eremophila dalyana* F.Muell., which produces a high yield of an essential oil dominated by myodesert-1-ene [94].

4.3. Correa (Rutaceae)

It is strange that the chemical character of the essential oils has not been published for members of this genus. However, this may be due to the chemical diversity within the essential oil profile, which is an apparent insurmountable obstacle to quality data reporting. This was experienced by the author who produced essential oils from the three known variants within *Correa glabra* Lindl., which are *C. glabra* var *glabra*, *C. glabra* var *leucoclada* (Lindl.) Paul G.Wilson and *C. glabra* var *turnbullii* (Ashby) Paul G.Wilson. The essential oils from all three variants were populated by hundreds of components in some cases. However, by focusing on only the major components, comments on the chemical character can be made.

The essential oil from the taxon known only as *C. glabra* is rich in the phenylpropanoid elemicin and two other phenylpropanoids that were not successfully identified. This taxon also had several sesquiterpenes in its profile, including cubebene and bisabolene. The taxon *C. glabra* var *glabra* has two morphological variants, one with long leaves and the other with shorter leaves. The two had strikingly different chemical profiles, with the long leaf variant dominated by sesquiterpenes, mostly azulene derivatives, and the short leaved variant had a monoterpenoid composition, thujene and terpinolene. The taxon named *C. glabra* var *turnbullii* produced an essential oil that was part terpenoid and part pheylpropanoid, comprising elemicin, β-phellandrene and thujene. A similar essential oil profile was determined for *C. glabra* var *leucoclada*, but the phenylpropanoids were more diverse, also including anethole and estragole, in addition to elemicin, phellandrene and thujene. The essential oils that were mixtures between phenylpropanoids and monoterpenes demonstrated the strongest antimicrobial effects, which were evident against both Gram-positive and Gram-negative bacteria.

4.4. Geiera (Rutaceae)

Nearly 90 years ago today, Arthur Penfold encouraged the commercialization of essential oils from *Geijera parviflora* [95]. The species includes several chemotypes, and strong overlap with *G. salicifolia* Schott [49]. Among the several chemotypes is the xanthoxylin type (phloroacetophenone dimethyl ether). During hydrodistillation the compound crystallises onto the condenser, creating the appearance of a paraffin-type wax, but it is evidently a volatile compound. Xanthoxylin is also known under the vernacular name brevifolin, which is the name used with reference to pomegranate (*Punica granatum* L). This chemotype is currently being explored as a supply for Australian natural product industries and a topical cream is under development that includes xanthoxylin at a concentration of 0.1%.

Another chemotype from *G. parviflora* is the geijerene/pregeijerene chemotype described earlier. The green essential oil will be marketed under the vernacular name 'green lavender' and it will also be used in dermatological applications. The reason for using the name 'lavender' in the branding is due to an old vernacular, lavender bush, used to describe this chemotype. The note that influences likeness to lavender is the co-major component linalool [49].

4.5. Melaleuca (Myrtaceae)

The TTO industry was starting to gain momentum in the 1920s [95]. In 1929, Penfold wrote under the image of *M. linariifolia*:

> "The essential oil derived from this tree, which is one of a number of trees and shrubs known collectively as Tea Trees, is about to be placed upon the markets of the world." [96]

Only three years after Penfold's prescient observation, he reported back on the progress that had been made in the commercial development of TTO. He reported that the oil had achieved an exalted status in medicine and dentistry, and that those who had entered the market with the oil disguised the ingredient to protect their commercial interest. Thus, TTO was marketed as 'ti-trol' as a pure oil, and in a 40% soap solution, it was branded as ‘melasol’ or ‘intol’ [95]. These brands were still in the market by 1954 (22 years later) according to a much older Penfold [97].

Penfold was also insistent that the 1,8-cineole content must be kept below 10% to avoid dilution of the medicinal benefit, particularly when used in surgery for sterilisation. His earlier comments influenced the formation of the modern ISO standard for the terpinen-4-ol type. He also described the use of TTO in munitions factories during WW2, by incorporation of 1% into machine cutting oil to reduce infection of skin injuries. TTO was also used by the soldiers in the WW2, as it was a compulsory item in the first aid kit, also for sterilization and prevention of infections.

After WW2 demand for TTO declined and the success of antibiotics overshadowed TTO for another 20 years, until a renaissance of nature occurred in the 1970s [41]. At this time plantations were established and TTO entered the market as a lifestyle product, rather than a medical liquid. One of the major suppliers of TTO today is the Thursday Plantation.

4.6. Backhousia (Myrtaceae)

A species that captured the attention of Penfold was *Backhousia angustifolia* F.Muell., which contained a very unusual triketone called angustione [95]. Although the species has since been demonstrated to contain five chemotypes, three of which include unusual monoterpenes [98], they never had the same success as *B. citriodora* F.Muell. Today the species is used to flavour soaps that have a market across the globe. The essential oil of the popular chemotype is dominated by citral [98], which is a mixture of two aldehydes, namely geranial and neral [99].

In the 1950s, Penfold described the *l*-citronellal chemotype of *B. citriodora*, which was a serendipitous discovery made by a farmer who noticed the difference of aroma between leaves he was foraging for distillation [97]. Brophy et al. [100] commented that this chemotype was ‘lost’ for nearly 40 years before it was rediscovered in 1996. The concern was that it became of interest, because of yields of approx. 3%, making it feasible as a feedstock for the perfume industry. The citral chemotype of *B. citriodora* is already a well establish commercial essential oil, however, it is likely that Brophy’s work has led to the establishment of plantations that use the citronellal chemotype.

4.7. Leptospermum and Kunzea (Myrtaceae)

Leptospermum and *Kunzea* are regarded as clade sisters. The two produce chemically diverse essential oils across the genus. One that is worth mentioning is *Leptospermum micromyrtus* Miq., which grows as thick impenetrable scrub at the top of mountains in Australia’s capital territory, south of Canberra. The leaves yield an essential oil on hydrodistillation at 1–2%, dominated by the eudesmol isomers (α-, β-, and γ-) [101]. This sesquiterpenoid oil solidifies shortly after its production, taking on the appearance of a camphor block.

It was demonstrated that the chemistry of essential oil from species of *Leptospermum* can be influenced by availability of soil nitrogen [102]. This was evident in two out of the three species examined, *L. petersonii* F.M.Bailey., and *L. flavescens* Sm. Higher nitrogen content resulted in reduced expression of α- and β-pinene.

Penfold was fond of *L. liversidgei* R.T.Baker & H.G.Sm., as a source of essential oil [96], which is rich in citral, and another chemotype is rich in citronellal. However, both chemical profiles can be produced by two chemotypes of *Backhousia* that have higher yields, thus interest in these species waned.

Despite the efforts of Penfold, only two species of *Leptospermum* are commercialised today, which are unfortunately not those that captured his interest. One is produced from *L. petersonii* by the company “Essentially Australia.” They branded it as ‘Australian rose’ or ‘rose myrtle’ and the chemistry demonstrates why this name was chosen. The chosen chemotype, chemotype b, is rich in geranyl acetate, γ-terpinene, geraniol, terpinolene, α-pinene, p-cymene, and linalool [103]. This is like the chemistry in the headspace of some roses [104].

The other species that is marketed by "Essentially Australia" is *L. scoparium* J.R.Forst. & G.Forst., which is being called manuka essential oil. It is the same species that produces the flowers that bees use to make manuka honey. The essential oil is dominated by a β-triketone named grandiflorone [105]. Although this species is from New Zealand, a similar essential oil is produced from *L. morrisonii* Joy Thomps [106]. Furthermore, the triketone grandiflorone was first described by Penfold's successor, Hellyer, who isolated it from the Australian species *Leptospermum grandiflorum* G.Lodd., and *Leptospermum lanigerum* (Aiton) Sm [107].

The sister genus of *Leptospermum*, namely *Kunzea*, includes several putative new species. Several of the new or known species have been chemical studied. *Kunzea ambigua* (Sm.) Druce is a Tasmanian species that has the vernacular name 'tick bush,' due to the tick repellent effect. This property was realized when farmers observed that wild animals preferred to shelter under this bush. It was eventually discovered that the foliage protected them from tick infestation. The essential oil from this species is available from 'Essentially Australia.' The chemistry includes α-pinene, 1,8 cineole, globulol, viridifloral, and bicyclogermacrene [108].

4.8. Philotheca and Eriostemon (Rutaceae)

Many species that were once in the genus *Eriostemon* have been placed into *Philotheca*. One of the species know previously as *Eriostemon myoporoides* is now known under the accepted name of *Philotheca myoporoides* (DC.) Bayly. The species is also divided into five subspecies.

In 1925, Penfold published a chemical characterization of the essential oil of *E. myoporoides*, that is known today as *P. myoporoides* subsp. *myoporoides*, which grows in the mountains of the Hunter Valley in NSW. Penfold reported that the essential oil is dominated by α-pinene, camphor and ocimene [109].

The author has been to the place where Penfold made his collection (Mt Dangar, Sandy Hollow), and it was found growing alongside *Prostanthera prunelloides* R.Br. It is likely that Penfold also collected *P. prunelloides* because nearly 40 years later his successor, Hellyer, found an essential oil in Penfold's retired laboratory that was dominated by maaliol [110]. In a recent study, the essential oil from the leaves of *P. prunelloides* was characterized and demonstrated to be dominated by maaliol [44]. However, the sample was mislabelled as *E. myoporoides*, thus Hellyer incorrectly described the essential oil from *E. myoporoides* as maaliol. This was in error, because Penfold had previously published the composition, as mentioned above.

Thus, it is likely that Penfold had incorrectly labelled the sample of *P. prunelloides* that he collected the same day of collection of *E. myoporoides*. He probably declined to publish the composition when he saw an inconsistency. This error is likely to have occurred because the leaves of *P. prunelloides* radically change shape in mountainous cliffs, becoming morphologically like *Eriostemon*. Thus, on the day of collection the samples were incorrectly labelled.

4.9. Syzygium (Myrtaceae)

The essential oil from *Syzygium oleosum* (F.Muell.) B.Hyland. is being called 'mango myrtle' in the Australian essential oils market (Essentially Australia). This species is commonly known as 'lily pily' and produces a little pink-red fruit that is edible. The essential oil was previously available commercially, but the plantation has been very recently established and it may take time to reach sustainable levels. Greg Trevena is currently growing a plantation outside of Byron Bay, NSW.

Another species is *Syzygium anisatum* (Vickery) Craven & Biffin, previously known as *Backhousia anisata*, and *Anetholea anisata*. The essential oil is very similar to that of anise, with phenylpropanoids that confer the liquorice aroma. This essential oil has had more success in the industry than other species in the same genus.

4.10. Calytrix (Myrtaceae)

Another essential oil from 'Essentially Australia' is made from a species endemic to Western Australia, named *Calytrix exstipulata* DC., or by the vernacular 'Kimberley Heather.' The essential oil is dominated by the pinene isomers, pulegol, isopulegol, aromadendrene, and ledene [111].

4.11. Cassinia (Asteraceae)

The genus *Cassinia* is known widely as 'native rosemary,' but the resemblance is poor. The species has foliage that can be mistaken for that of *Rosmarinus*, or *Melaleuca*, but *Cassinia* belongs to Asteraceae, and this is evident when in flower. The best essential oil from *Cassinia quinquefaria* R.Br. was produced by the author from the flower calyx, which gave a high yield of a predominantly monoterpenoid oil. This is consistent with a chemical report of an oil dominated by the pinene isomers from the same species [112].

The other common species is *C. laevis* R.Br., which has a subspecies by the name of *Cassinia laevis* subsp. *rosmarinifolia* (A.Cunn. ex DC.) Orchard. This is probably due to the apparent resemblance to rosemary. The essential oil is also dominated by α-pinene, but also includes some spathulenol and viridiflorol [113].

4.12. Eucalyptus and Corymbia (Myrtaceae)

The vernacular name used for the smooth barked Australian eucalyptus tree is the 'gum tree.' Most people are unaware that the name derives from the ironbark species and not the smooth bark. The name was also given in error, because the intention was to define a tree that exudes a water-soluble sap called a 'gum.' But the actual product is correctly known as a 'kino,' which is an astringent tannin that was used as a 'bitter' for general health in the 1800s. The kino was produced from the bark of the ironbark [84,96].

In 1929, Penfold explained that the first medicinal oil used from a species of *Eucalyptus* was far removed from the current standard prescribed by the ISO (ISO 3065:2021). It was distilled from *E. piperita* J.White., in 1788, by a surgeon on the first fleet, Dr John White, who was initially attracted by its resemblance to the mint familiar to Europe. The major component is piperitone, which is used today to manufacture menthol by reduction, or thymol by oxidation. Today the main species used to feed the piperitone industry is *E. dives* S.Schauer. Nevertheless, Penfold commented that the standard for eucalyptus oil, with a requirement of >70% 1,8-cineole, is at odds with the oils that are used in therapy, or for that matter, the oil that was first used in commerce [96].

Although the first cineole oil was produced from *E. globulus*, this species is no longer the major biota that feeds the eucalyptus oil industry. This is because the yield of 0.75% is lower than that from a chemically similar alternative, *E. radiata*, which gives a yield of 2–3%.

More recent work by Boland et al. [114] demonstrates that the essential oils across the 300 or so species in the genus *Eucalyptus* are extraordinarily chemically diverse. Some of the more common species in industry include *E. phellandra* R.T.Baker & H.G.Sm., which is etymologically related to its major component phellandrene, *E. macarthurii* H.Deane & Maiden, which is a source of geranyl acetate, and *E. citriodora*, which has recently been taxonomically revised to *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson. This latter species has the vernacular name 'lemon scented gum' and is a popular fragrance in remote communities. The dominant component in the essential oil is citronellal [96], which can be used as an insect repellent [115].

4.13. Phebalium and Leionema (Rutaceae)

Phebalium and *Leionema* are regarded as clade sisters. Aside from taxa in the *P. glandulosum* complex [73], the two genera do not produce high yields of essential oils. Thus, research on volatiles has centered on chemophenetics in heterogeneous species aggregates. As mentioned in Section 2, much work needs to be done on *P. squamulosum* to get it taxonomically correct. An initial study was completed by Brophy et al. [116], which gave single specimens from each species. Then when more samples were analysed, it was realized that intraspecific variability is common. Furthermore, during that chemophenetic study it was realized that the etymologically related sesquiterpene 'squamulosone' is detected in only a limited number of taxa. The remaining taxa yields predominantly hedycaryol, which is converted to elemol in hydrodistillation [72].

One of the best known species from the genus *Leionema* is the 'fruit salad plant' known botanically as *Leionema ambiens* (F.Muell.) Paul G.Wilson. The species grows in the granite mountainous terrain of regional NSW and when in flower it puts a fruity scent into the air that can be perceived from hundreds of metres away. The aroma was studied by Brophy et al. [117] and revealed to be dominated by the *cis*/*trans* isomers of β-ocimene.

4.14. Boronia (Rutaceae)

For well over 100 years, an essential oil has been marketed from Tasmania that is extracted, not distilled, from the flowers of *Boronia megastigma* Nees ex Bartlett. In earlier practice, the flower was hydrodistilled, but Penfold explained that the aroma changes considerably in hydrodistillation and a significant loss of volatile organic compounds occurs. To retain the compounds and to maintain a pleasing aroma, the plant is extracted into petroleum ether (pentane/hexane) and a 'concrete' is produced, which is an aromatic resin that contains the volatile component β-ionone and the flower's waxes [95].

This is consistent with the author's observations in distillation of other species in *Boronia*. Although the leaves and flowers are strongly aromatic and the odour is pleasant, on distillation the odour becomes unpleasant and scarcely any of the volatiles are captured. This is because of the high solubility of components in the hydrosol, which prevents phase separation of the volatile organic compounds.

In 1929, Penfold listed four species of *Boronia* that he considered of potential commercial value. These are *B. pinnata* Sm, *B. muelleri* (Benth.) Cheel., *B. thujona* Penfold & M.B.Welch., and *B. safrolifera* Cheel. It is noteworthy that the latter two species are named according to the dominant component in their essential oil, i.e., *B. thujona* expresses thujone in its essential oil and *B. safrolifera* expresses safrole. Unsurprisingly, Penfold is an authority on the species named *B. thujona* [96].

4.15. Callitris (Cupressaceae)

Although there are 20 or so accepted species of *Callitris*, there are four that are known widely in Australia [32,118]. Two of these major species are *C. endlicheri* (Parl.) F.M.Bailey., and *C. columellaris* F.Muell. As of today, the World Checklist of Vascular Plants does not recognise the two other major species. Both *C. glaucophylla* J.Thomps. & L.A.S.Johnson and *C. intratropica* R.T.Baker & H.G.Sm. are currently regarded as synonyms of *C. columnellaris*, yet they stand out as distinct chemical entities in chemophenetic analysis [32]. Today they are tentatively regarded as chemotypes before an international audience but are regarded as distinct species within Australia.

Whether *C. columellaris* occupies a large or small geographic area is a matter of debate. If *C. glaucophylla* is recognised internationally, as it is in Australia, then it occupies the greatest land area of all *Callitris* and the range of *C. columellaris* is reduced to coastal areas in the Brisbane area.

The chemical differences between species are evident in the essential oil from timber and leaves, and in the non-volatile components too. The leaves of *C. glaucophylla* express the abietanes pisiferic acid, pisiferal and pisiferol. These were not detected in the leaves of *C. columellaris* or *C. intratropica*. The timber of *C. intratropica* is rich in guaiazulene, which is responsible for the blue colour of the oil. This component is not present in the timber essential oil of the other two species. However, despite their chemical differences, all four of the species yield a wood oil that is dominated by guaiol, which has an earthy aroma that can also be detected when burning the timber [32]. Today, there are still some Australians from remote regions who understand the following quote from Sir Joseph Henry Maiden more than 100 years ago in reference to *C. glaucophylla* (White Cypress Pine):

> "there is nothing more delightful in the approach, on a winter evening, to a township where Cypress pine is used as a fuel. Its delicious perfume is borne on the air for miles, and is often the first intimation that the weary traveller experiences that he is approaching a human habitation, and that his long journey is drawing to a close." [119]

4.16. *Santalum (Santalaceae)*

For over 185 years, the essential oil from *Santalum spicatum* was used to produce one of the most popular forms of sandalwood essential oil [95]. However, the species is facing sustainability issues, which is a consequence of over harvesting from wild populations. Because the tree is a hemiparasite, it is difficult for the seedlings to become established, making it difficult for the population to recover naturally. Today it is illegal to harvest the species from the wild in South Australia, but it is not recognised as a threatened species in Western Australia, even though the same population decline is evident in that state [7].

Due to population decline of wild specimens, most of the timber to make sandalwood essential oil is harvested from commercial plantations. This is good from a sustainability perspective, but it may also be the reason that sandalwood essential oil no longer adheres to the standard chemical profile defined by the ISO (2002). According to a study from RBG Kew, most commercial sandalwood essential oils that are derived from *S. spicatum* contain a significantly lower santalol content than specified, at approximately 25%, compared to ISO's recommended 90% [8]. These results contrast with those put forth by Penfold in 1932, who described Australian sandalwood as being comprised of 60% santalols [95].

Most of the commercial essential oils from the original sandalwood, Indian sandalwood (*S. album*), also fail to meet the standard specified by ISO, with a santalol content of 60% [8]. However, Penfold again reported in 1932 that the santalol content of the Indian sandalwood is 90% [95].

There are three possible reasons for the change to modern day essential oils, which are: (1) Hydrodistillation technology has improved so that condensation and technique is optimised. This improves the capture of compounds with higher vapour pressures, which dilutes the lower vapour pressure ingredients, such as the santalols; (2) By using cultivated trees in the place of wild specimens, younger trees are harvested. In the wild, *S. spicatum* takes 90–115 years to reach ecological maturity, but in traditional wild harvesting older trees were chosen for essential oil production, because they contained a greater mass of timber (thicker trunk). These older trees take 250–300 years to build that quantity of biomass, which is a much longer timespan than the life of the sandalwood essential oil industry [7]. It is possible that older trees retain santalols while the higher vapour pressure terpenes, such as the monoterpenes, diffuse through the timber layers and evaporate over time; (3) Distillation time will influence the successful exhaustion of lower vapour pressure ingredients from the source plant material. In the modern age, distillation times have been minimised because of the higher costs of fossil fuel energy. Shorter distillation times produce essential oils with higher monoterpene content [2].

Two other species from the genus *Santalum* are also common in Australia, which are *S. acuminatum* (R.Br.) A.DC., and *S. lanceolatum* R.Br. In the former, *S. acuminatum* is known by its vernacular name 'quandong.' It produces a sweet red edible fruit that is used in home cooking in Australia's remote areas. The kernel from quandong is also edible and when roasted has a pleasant taste [120,121].

In the mid to late 1800s, RBG Kew supplied the University of Strasburg with wood samples labelled as sandalwood that allegedly came from *S. acuminatum*, under the previous older synonyms *Fusanus acuminatus* and *Eucarya acuminata*. These specimens were later revealed to be misidentified and the actual identity remains a mystery [122]; however, an 'oil' sample that was made from this old specimen, and retained in an old collection at RBG Kew, was used in the more recent study of sandalwood essential oils [8]. No santalols were detected. Since the identification was wrong, it is not known if the timber of the quandong produces an essential oil. There is currently no confirmation that the timber is even aromatic. However, a fixed oil is produced from the quandong kernel, and this may cause confusion among scientists or the lay community.

In the same study, an essential oil that was allegedly from Australia under the name of *S. latifolium* Meurisse, was also rich in the santalol isomers [8]. However, this is not an Australian species, it is Hawaiian and is currently known under the accepted name *S. paniculatum* var. *paniculatum* [123]. The chemical profile of this specimen is consistent with the Hawaiian species [124], but it is also consistent with the Australian species *S. lanceolatum* [125]. It is therefore unclear whether the mistake was in the provenance or the species identification.

Nevertheless, *S. lanceolatum*, is known commonly as east Australian sandalwood. The essential oil from the timber was previously used as an adulterant to *S. spicatum* to make it more like the Indian sandalwood oil, by changing the optical rotation of the oil (in the days before GC-MS) [95,122]. However, the use of east Australian sandalwood was very short lived because the yield was below an economically feasible threshold [95].

4.17. *Lagarostrobos franklinii (Hook.F.) Quinn (Podocarpaceae)*

Lagarostrobos franklinii is a conifer that is endemic to Tasmania, known by the vernacular Huon Pine. Penfold referred to it by its older synonym *Dacrydium franklinii* and lamented that it was one of Australia's few wood-based essential oils to be used in industry, before the wild population was decimated [97]. The timber essential oil was chemically characterised by Penfold and Morrison [126], and it was revealed to be rich in the phenylpropanoids elemicin and methyl eugenol.

In 1995, just over 40 years since Penfold published his comment on the species, a hectare-wide stand of trees containing specimens that had remained genetically unchanged for over 10,500 years was found in western Tasmania on Mount Read [127]. Within this stand are wild specimens just over 2000 years old [128]. Because these trees are slow growers and are among the oldest living beings, their conservation status is critical. Hence, they are no longer used to produce essential oils.

4.18. *Pittosporum (Pittosporaceae)*

Essential oils from species in *Pittosporum* are sometimes difficult to produce in hydrodistillation, due to the saponins in the leaves. This was a challenge faced when studying *P. angustifolium* G.Lodd., to produce essential oils from both leaves and fruits. The problem was overcome by adding a thick layer of pearlite obsidian to the still, which floats over the aqueous phase and crushes the bubbles as they are formed [129].

The essential oil of fruits and leaves of *P. angustifolium* were dominated by saturated alkanes, cycloalkanes, alkanols, and alkane esters. Furthermore, some chemotypes expressed caryophyllene in their profiles. This contrasts with *Pittosporum undulatum* Vent. which produced essential oil from leaves and fruits dominated by limonene and bicyclogermacrene, with no issues related to saponins [129]. However, the latter species, *P. undulatum*, is introduced. It is expected that all native Australian *Pittosporum* will express saponins in their organs.

4.19. *Zieria (Rutaceae)*

Species in the tri-folate genus *Zieria* yield high quantities of essential oil, generally 1.5–2.5% wet leaf weight. The chemistry between species is considerably varied, with components that are either terpenoid, phenolic, or phenylpropanoid. The major terpenoids are car-3-en-2-one and chrysanthenone, the major phenol is benzaldehyde (same as almond flavour) and the major phenylpropanoids are safrole, methoxystyrene, methyl eugenol, and elemicin [47].

During the years of chemotaxonomy, the efforts to recognise chemical fingerprints across species within the genus *Zieria* were thwarted by intraspecific chemotypes. For example, *Zieria smithii* Jacks., is made up of at least five chemotypes that are predominantly phenylpropanoid, except for the chrysanthenyl acetate type [130–132]. However, there are examples of chemical convergence for morphologically similar species, such as *Z. floydii* J.A.Armstr., which is morphologically like *Z. furfuracea* R.Br. ex Benth., and *Z. granulata* C.Moore ex Benth., all of which express car-3-en-2-one as dominant in their gas chromatography spectrums [47].

4.20. Citrus (Rutaceae)

The Australian finger lime, *Citrus australasica* F.Muell., yields an essential oil from its leaves that is dominated by limonene, γ-terpinene, β-citronellol, and citronellal [133]. This edible lime is distributed in the rainforest regions of coastal eastern and east-northern Australia. The arid version is the desert lime, *Citrus glauca* (Lindl.) Burkill, which is distinguished by two furanoid forms of linalool oxide in the essential oil profile [134]. The limes are a favourite bush fruit among the Australian Aboriginal people, particularly those in arid communities.

4.21. Tasmannia (Winteraceae)

There are several species of *Tasmannia* that grow in Australia and Tasmania. Each of the species is described as having a peppery flavour, thus their fruits have become an alternative pepper. However, the work by Southwell and Brophy demonstrated that the chemical profile of volatiles from the seven Australian species did not include components known to confer a peppery flavour. Rather, they were dominated by monoterpenes (pinene isomers, limonene, sabinene phellandrene, 1,8-cineole and linalool), sesquiterpene components (caryophyllene, copaene, elemol, eudesmol isomers and viridiflorol) and phenylpropanoids [135].

This contrasts with the chemistry of the commercial pepper, the Tasmanian species *Tasmannia lanceolata* (Poir.) A.C.Sm., which is dominated by the drimane sesquiterpene polygodial [136]. The drimane sesquiterpenes are also known for the peppery aroma they confer to the African pepper bark tree, *Warburgia salutaris* (G.Bertol.) Chiov [137]. The drimane sesquiterpenes were originally identified as the peppery aroma constituents of the water pepper plant *Persicaria hydropiper* (L.) Delarbre, published under the old name *Polygonum hydropiper* L [138].

4.22. Agonis fragrans (syn. Taxandria) (Myrtaceae)

Australian fragonia is a commercial essential oil from *Taxandria fragrans* (J.R.Wheeler & N.G.Marchant) J.R.Wheeler & N.G.Marchant, which was previously known under the name *Agonis fragrans*. This species is from coastal Western Australia, south of Perth, and the essential oil that is now commercialised represents one of several chemotypes that was selected by husband-and-wife John and Peta Day, respectively. The chemistry of the essential oil they had chosen includes 1,8-cineole, linalool, geraniol, and terpinen-4-ol. Another chemotype that was later identified by John Day had no 1,8-cineole, but included α-pinene, linalool, and myrtenol as dominant components [139].

A selection of mostly unrecognised species from the genus *Agonis* (*A. pariceps*, *A. juniperina*, *A. flexuosa* (Willd.) Sweet, A. sp. nov. 'Swamp' and S. sp. nov. 'Rose') were studied and the chemistry of their essential oils was reportedly dominated by the monoterpenes sabinene, β-pinene, limonene, linalool, terpinene-4-ol and α-terpineol [140].

5. Miscellaneous GC-MS Characterisations by Joseph Brophy (UNSW)

Table 1 summarises the Australian essential oils that were characterised over the last 30 years by Joseph Brophy (from his google scholar page). The species are provided in order of most recently published. The species are listed according to their arrangement in the publications. The essential oil components are listed in order of relative abundance.

Table 1 only includes Australian native species but does not include species mentioned in the earlier text. Because *Melaleuca* and *Eucalyptus* were comprehensively covered in Brophy's published books, that information is not included here. For more information, see Brophy's book on *Melaleuca* [141] and his book on *Eucalyptus* [114].

Table 1. Australian essential oils that were chemically studied by Joseph Brophy from the School of Chemistry, The University of New South Wales, Sydney, NSW 2052, Australia; (J.Brophy@unsw.edu.au).

Species	Chemistry Info from Abstract	Family	Year and Ref.
Acmenosperma claviflorum (Roxb.) E. Kausel	Bicyclogermacrene (36%), α-copaene (7%), δ-cadinene (4.9%), globulol (5.2%)	Myrtaceae	1999, [142]
Acradenia euodiiformis (F.Muell.), *A. frankliniae* Kippist	*A. euodiiformis*: type 1, α-pinene (16%), limonene (8%), p-cymene (13%), type 2, aromadendrene (11–22%), caryophyllene oxide (4–13%), globulol (11–13%), spathulenol (12–18%). *A. frankliniae*: 1.2–3.0% yield, type 1, xanthoxylin (90%), type 2, α-pinene (19–21%), camphene (13–14%), β-pinene (24–25%), (E)-β-ocimene (8–10%)	Rutaceae	2001, [143]
Acronychia aberrans, A. acuminata, A. acidula, A. acronychioides, A. baeuerlenii, A. chooreechillum, A. crassipetala, A. eungellensis, A. imperforata, A. laevis, A. wilcoxiana, A. littoralis, A. octandra, A. oblongifolia, A. parviflora, A. pubescens, A. sp. (Batavia Downs, J.R.Clarkson + 8511), *A. suberosa, A. vestita*	*A. aberrans*: (Z)-ocimenone (40–55%), (E)-ocimenone (23–28%). *A. acuminata*: α-pinene (33–64%). *A. acidula*: δ-3-carene (32–40%), terpinolene (13–46%) α-santalene (2–15%), aromadendrene (2–8%), germacrene B (0.6–18%). *A. acronychioides*: spathulenol (37–52%). *A. baeuerlenii*: α-pinene (65%). *A. chooreechillum*: α-pinene (45–66%). *A. crassipetala*: 40% monoterpenes. *A. eungellensis*: α-pinene (21–26%). *A. imperforata*: β-caryophyllene (13–20%), bicyclogermacrene (21–26%). *A. laevis*: elemol, α-pinene, bicyclogermacrene. *A. wilcoxiana* and *A. littoralis:* β-caryophyllene, pregeijerene, geijerene. *A. octandra*: (Z)-β-ocimene (15–23%), (E)-β-ocimene (15–23%), limonene (4–21%). *A. oblongifolia*: α-pinene (34–87%), limonene (0.1–26%), terpinolene (0.1–29%). *A. parviflora*: β-caryophyllene (2–34%), allo-aromadendrene (0.3–20%). *A. pauciflora*: α-pinene (14–45%), β-caryophyllene (10–24%). *A. pubescens*: β-caryophyllene (15–39%). *A.* sp. (Batavia Downs): (3–21%). *A. suberosa*: (Z)-ocimenone (20–23%), (E)-ocimenone (9–13%), β-caryophyllene (4–10%). *A. vestita*: α-pinene (40%), β-caryophyllene (23.5%), limonene (67–80%)	Rutaceae	2004, [144]
Actinodium cunninghamii	90% α-Pinene	Myrtaceae	1994, [145]
Actinostrobus pyramidalis, A. arenarius, A. acuminatus	*A. pyramidalis*: α-pinene (60–78%), limonene (1–17%), citronellal, citronellyl acetate, citronellol. *A. arenarius*: α-pinene (40–76%), limonene (1–28%), citronellal, citronellyl acetate, citronellol. *A. acuminatus*: α-pinene (17–79%), limonene (1–39%), spathulenol (6–17%)	Cupressaceae	2004, [146]
Agathis atropurpurea, A. microstachya, A. robusta, A. australis, A. macrophylla, A. moorei, A. ovata	*A. atropurpurea*: phyllocladene (13%), 16-kaurene (19%), α-pinene (8%), δ-cadinene (9%). *A. microstachya*: α-pinene (18%) myrcene (7%), bicyclogermacrene (6%), δ-cadinene (6%). *A. robusta*: spathulenol (37%), rimuene (6%). *A. australis*: 16-kaurene (37%), sclarene (5%) germacrene-D (9%). *A. macrophylla*: 5,15-rosadiene (60%), 16-kaurene (7%). *A. moorei*: allo-aromadendrene (6%), germacrene-D, δ-cadinene (10%), 16-kaurene (6%). *A. ovata*: caryophyllene oxide (15%), phyllocladene (39%)	Araucariaceae	2000, [147]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Agonis obtusissima F.Muell., (syn. Agonis baxteri (Benth.) J.R.Wheeler & N.G.Marchant)	α-Pinene (12%), trans-β-ocimene (16%), globulol (39%)	Myrtaceae	2004, [148]
Allosyncarpia ternata S.T.Blake	β- and α-Pinene, limonene, β-caryophyllene, globulol, spathulenol	Myrtaceae	1992, [149]
Angasomyrtus salina	α-Pinene (77–83%), campholenic aldehyde (1%), 1,8-cineole (0.1–1.0%), β-pinene (1–2%), bicyclogermacrene (1–3%)	Myrtaceae	1994, [150]
Angophora spp.	Essential oils overlap with *Eucalyptus*	Myrtaceae	1999, [151]
Araucaria angustifolia, A. bidwillii, A. columnaris, A. cunninghamii, A. heterophylla, A. hunsteinii, A. luxurians, A. montana, A. muelleri, A. scopulorum,	*A. angustifolia*: germacrene-D (9%), hibaene (30%), phyllocladene (20). *A. bidwillii*: hibaene (76%). *A. columnaris*: hibaene (9%), sclarene (6%), luxuriadiene (13-epi-dolabradiene) (23%). *A. cunninghamii*: 16-kaurene (53%), hibaene (29%). *A. heterophylla*: α-pinene (52%), phyllocladene (32%). *A. hunsteinii*: α-Pinene (18%), sclarene (11%), germacrene-D (5%).*A. luxurians*: 5,15-rosadiene (20%), luxuriadiene (13-epi-dolabradiene) (66%). *A. montana*: phyllocladene (61%), 16-kaurene (23%). *A. muelleri*: sclarene (20%), luxuriadiene (19%). *A. scopulorum*: 16-α-phyllocladanol (41%), luxuridiene (10%), δ-cadinene, α-copaene	Araucariaceae	2000, [147]
Archirhodomyrtus beckleri (F. Muell.) A.J. Scott	Type 1, (E)-β-ocimene (69–87%), type 2, α-pinene, β-caryophyllene, α-terpineol, (E)-nerolidol and α-, β, and γ-eudesmol	Myrtaceae	1996, [152]
Arillastrum gummiferum (Brongriart & Gris) Pancher ex Baillon	80% (−)-limonene, α- and β-pinene, caryophyllene (3–7%)	Myrtaceae	1994, [153]
Artabotrys sp. (Claudie River B.Gray 3240)	Oxygenated sesquiterpenes	Annonaceae	2004, [154]
Asteromyrtus angustifolia, A. arnhemica, A. brassii, A. lysicephala, A. symphyocarpa	*A. angustifolia*: α-pinene (10%), 1,8-cineole (31%), β-caryophyllene (23%). *A. arnhemica*: α-pinene (92%). *A. brassii*: α-pinene (6%), 1,8-cineole (24%), γ-terpinene (21%). *A. lysicephala*: α-pinene (11.2%), 1,8-cineole (49%), α-terpinyl acetate (4%). A. magnifica: α-pinene (14%), β-pinene (20%), 1,8-cineole (36%). *A. symphyocarpa*: α-pinene (16%), 1,8-cineole (40%)	Myrtaceae	1994, [155]
Austrobaileya scandens	β-Pinene (1.3–44.2%), α-pinene (3.1–30.3%), β-caryophyllene (2.3–13.0%), δ-cadinene (2.8–9.0%), spathulenol (0.9–11.9%)	Austrobaileyaceae	1994, [156]
Austromatthea elegans L. S. Smith	Type 1, benzyl benzoate (96.25%), type 2, benzyl salicylate, benzyl benzoate	Austrobaileyaceae	1995, [157]
Austromyrtus sp. nov.	(E)-β-Ocimene (83%), myrcene	Austrobaileyaceae	1995, [158]
Austromyrtus dulcis (C. T. White) L. S. Smith, *A. tenuifolia* (Sm.) Burret.,	*A. dulcis*: type 1, isobaeckeol (80%), type 2, β-pinene (34–45%), 1,8-cineole (24–35%). *A. tenuifolia*: 1.8–3.0% yield of isobaeckeol (97–98%)	Austrobaileyaceae	1995, [159]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Austromyrtus gonoclada, *A. floribunda*, *A. hillii*, *A. inophloia*, *A. minutiflora*, *A. pubiflora*, *A. shepherdii*, *A.* sp. (Bamaga, B. P. Hyland 10235), *A.* sp. (Brookfield, L. W. Jessup 155), *A.* sp. (McIlwraith Range, B. P. Hyland 11148), *A.* sp. (Pinnacle Track, P.I. Forster PIF15535), *A. acmenoides*, *A. bidwillii*, *A. dallachiana*, *A. fragrantissima*, *A. hillii* type 2, *A. racemulosa*, *A.* sp. (Byerstown Range, G. P. Guymer 2037), *A.* sp. (Forty Mile Scrub, G. C. Stocker 1758), *A.* sp. (Mt. Beatrice, P. I. Forster PIF14662), *A.* sp. (Mt. Lewis, P.I. Forster PIF15613), *A.* sp. (Mt. White, P.I. Forster PIF13461), *A.* sp. (Danbulla, L. S. Smith 10123), *A.* sp. (Spencer Creek, P. I. Forster PIF13701)	*A. gonoclada*: 2-hydroxy-4,6-dimethoxy-3,5-dimethylacetophenone. Sesquiterpenoid oils: *A. floribunda*, *A. hillii*, *A. inophloia*, *A. minutiflora*, *A. pubiflora*, *A. shepherdii*, *A.* sp. (Bamaga), *A.* sp. (Brookfield), *A.* sp. (McIlwraith Range), *A.* sp. (Pinnacle Track). Monoterpenoid oils: *A. acmenoides*, *A. bidwillii*, *A. dallachiana*, *A. fragrantissima*, *A. hillii* type 2, *A. racemulosa*, *A.* sp. (Byerstown Range), *A.* sp. (Forty Mile Scrub), *A.* sp. (Mt. Beatrice), *A.* sp. (Mt. Lewis), *A.* sp. (Mt. White), *A.* sp (Danbulla), *A.* sp. (Spencer Creek)	Austrobaileyaceae	1996, [160]
Austromyrtus lasioclada (F. Muell.) L.S. Sm., *A.* sp. (Blackall Range P.R. Sharpe 5387), *A* sp. (Upper Mudgeeraba Creek N.B. Byrnes +4069), *A.* sp. (Main Range P.R. Sharpe 4877)	*A. lasioclada*: δ-cadinene (8–14%), germacrene-D (4–12%). *A.* sp. (Blackall Range P.R. Sharpe 5387): α-copaene (12–16%), β-caryophyllene (4–20%), allo-aromadendrene (3–13%). *A* sp. (Upper Mudgeeraba Creek N.B. Byrnes +4069): α-copaene (8–15%), β-caryophyllene (3–8%) and allo-aromadendrene (8–14%). *A.* sp. (Main Range P.R. Sharpe 4877): spathulenol (8–12%), allo-aromadendrene (7–9%)	Austrobaileyaceae	1995, [161]
Athrotaxis cupressoides, *A. selaginoides*, *A. laxifolia*	*A. cupressoides*: limonene (46–56%), spathulenol (3–10%), α-acorenol (8–13%) and 8-β-hydroxyisopimarene (2–24%). *A. selaginoides*: limonene (40–48%), spathulenol (4–11%), α-bisabolol (6–14%), rimuene (0.8–7%), 8-β-hydroxyisopimarene (11–29%). *A. laxifolia*: limonene (34–58%), spathulenol (4–10%), α-acorenol (7–18%), γ-acorenol (0.1–0.5%), α-bisabolol (0.6–4%), rimuene (1–4%) and 8-β-hydroxyisopimarene (2–18%)	Cupressaceae	2002, [162]
Backhousia angustifolia F. Muell, *B. anisata* Vickery, *B. bancroftii* F. M. Bailey & F. Muell., *B. citriodora* F. Muell, *B. hughesii* C. T. White, *B. kingii* Guymer, *B. myrtifolia* Hooker & Harvey, *B. sciadophora* F. Muell., *Backhousia* sp. (Didcot P.I. Forster PIF12671)	*B. angustifolia*: 1,8-cineole, (E)-β-ocimene, angustifolenone, angustifolionol, dehydroangustione and angustione. *B. anisata*: type 1, (E)-anethole, type 2, methyl chavicol. *B. bancroftii*: octyl acetate (0.3–61.7%), dodecyl acetate (0.2–21.0%), dodecanol (trace—22.9%), decyl acetate (0.5–39.0%), decanol (0.1–17.4%), 2,4,6-trimethoxy-3-methylacetophenone (trace—23.0%), bancroftinone (trace—90.0%). *B. citriodora*: type 1, citral, type 2, citronellal. *B. hughesii*: β-bisabolene (1.0–44.0%) unidentified (8.0–54.0%). *B. kingii*: α-pinene (24.0–49.0%), limonene (7.0–24.0%), 1,8-cineole (10.0–17.0%). *B. myrtifolia*: type 1, methyl eugenol, type 2, (E)-methyl isoeugenol, type 3, elemicin, type 4, (E)-isoelemicin. B. sciadophora: α-pinene (44.0–55.0%), β-pinene (2.4–8.0%), limonene (6.5?12.7%), linalool (2.8–6.7%). *Backhousia* sp. (Didcot): α-pinene (11.0%), β-pinene (5.3%), β-caryophyllene (12.0%), dodecyl acetate (8.1%), dodecanol (8.2%)	Myrtaceae	1995, [98]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Backhousia anisata Vickery	Type 1: *E*-anethole (90+ %), methyl chavicol (<5%), Z-anethole (<0.1%). Type 2: methyl chavicol (60–75%), E-anethole (<25%), Z-anethole (<0.1%)	Myrtaceae	1991, [163]
Backhousia citriodora F. Muell.	The *l*-citronellal type of *B. citriodora* described by Penfold was lost until 1996: 85–89% citronellal, 6–9% isopulegol isomers, citronellol (approx. 3%)	Myrtaceae	2001, [100]
Barongia lophandra	α-Pinene (58%), β-pinene (19%)	Myrtaceae	2003, [164]
Bosistoa brassii, B. floydii, B. medicinalis, B. pentacocca, B. pentacocca var. connaricarpa, B. pentacocca var. dryanderensis, B. pentacocca var. pentacocca, B. selwynii, and *B. transversa*	*B. brassii*: β–caryophyllene (2–12%), α-humulene (1–18%,), bicyclogermacrene (trace—24%). *B. floydii*: α-pinene (46–67%). *B. medicinalis*: α–pinene (13–57%), β–caryophyllene (1–9%). *B. pentacocca*: δ–cadinene (6–11%), α–copaene (2–7%), germacrene D (4–14%), α–cadinol (2–8%). *B. transversa*: α–pinene (24–83%)	Rutaceae	2007, [165]
Bouchardatia neurococca (F. Muell.) Baillon	β-Caryophyllene (38.5%), α-humulene (16.1%), bicyclogermacrene (10.8%), caryophyllene oxide (13.0%)	Rutaceae	1994, [166]
Brombya platynema, B. sp. (Gap Creek L.S. Smith 11116)	*B. platynema*: germacrene D (11–78%), β-bisabolene (0.8–22%), bicyclogermacrene (14–22%), kessane (1–17%), type 2: β-bisabolene (19–53%), curcumene (26.7%), bicyclogermacrene (7.7%), ar-curcumene (10.6%). *B.* sp. (Gap Creek): β-bisabolene (22.9%), ar-curcumene (14.6%), α-santalene (9.2%)	Rutaceae	2004, [167]
Callistemon viminalis (Sol. ex Gaertner) G.Don ex Loudon	α-Pinene, β-pinene, myrcene, 1,8-cineole, leptospermone, flavesone.	Myrtaceae	1997, [168]
Callistemon spp (high yields), low yield species, *C. brachyandrus, C. montanus, C. polandii, C. teretifolius, C.* sp. (Walsh's Pyramid P.I. Forster 13767), *C.* sp. nov. Oakey, *C. pachyphyllus*,	High yielding species: 1,8-cineole (45–80%), α-pinene (2–40%), limonene (2–9%), α-terpineol (1–13%). Low yielding species: 1,8-cineole (<20%), sesquiterpenoid	Myrtaceae	1998, [169]
Cananga odorata	β-Caryophyllene (34–52%), sabinene (1–20%), α-humulene (6–11%), α-pinene (1–17%)	Annonaceae	2004, [154]
Choricarpia subargentea (C.T. White) L.A.S. Johnson, *C. leptopetala* (F. Muell.) Domin	*C. subargentea*: α-pinene (30–76%), limonene (2–55%), 1,8-cineole (2–20%), jensenone. *C. leptopetala*: α-pinene, limonene, p-cymene, 1,8-cineole	Myrtaceae	1994, [170]
Cinnamomum baileyi, C. oliveri, C. baileyi, C. oliveri, C. propinquum, C. virens	*C. baileyi*: methyl eugenol, bicyclogermacrene. *C. oliveri*: camphor, safrole, methyl eugenol. *C. laubatii*: type 1, safrole, methyl eugenol, elemicin and bicyclogermacrene, type 2, bicyclogermacrene, β-selinene, spathulenol and γ-eudesmol. *C. propinquum*: p-cymene, β-eudesmol. *C. virens*: α-pinene, (E)-nerolidol	Lauraceae	2001, [171]
Clausena brevistyla Oliv. and *C. smyrelliana* P.I.Forst.	*C. brevistyla*: type 1, myrcene (72.4%), type 2, limonene (83.3%), type 3, β-caryophyllene (19.4%), α-humulene (4.3%), bicyclogermacrene (9.5%), caryophyllene oxide (7.6%), spathulenol (10.6%). *C. smyrelliana*: α-pinene (73.3%), β-caryophyllene (8.5%)	Rutaceae	2016, [172]
Coatesia paniculata F.Muell., syn. *Geijera paniculata*.	Leaf oil: α-pinene (27–57%), β-caryophyllene (4–12%)	Rutaceae	2005, [173]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Coleonema pulchellum Williams	α- and β-Pinene, myrcene, β-phellandrene, linalool, terpinen-4-ol, caryophyllene, germacrene-D, bicyclogermacrene	Rutaceae	1986, [174]
Corymbia dallachiana (Benth.) K.D.Hill & L.A.S.Johnson	Papuanone	Myrtaceae	1999, [175]
Crowea exalata, *C. saligna*, *C. angustifolia* var. *angustifolia*	*C. exalata*: Type 1, safrole (81–88%), type 2, (E)-methyl isoeugenol (18–25%), (E)-carpacin (47–51%), type 3, safrole (27–35%), (E)-methyl isoeugenol (29–46%), α-pinene (12–25%), type 4, safrole (6–29%), asaricin (57–74%), type 5, exalatacin, croweacin (10–20%). C. saligna: croweacin (84–94%), safrole. *C. angustifolia* var. *angustifolia*: β-asarone (68%), exalatacin (13%), croweacin (7%)	Rutaceae	1997, [176]
Crowea exalata F.Muell	exalaticin	Rutaceae	2000, [11]
Cryptocarya bellendenkerana, *C. cocosoides*, *C. cunninghamii*, and *C. lividula* (Lauraceae)	*C. cocosoides*: bicyclogermacrene (3–26%), spathulenol (16–47%), massoia lactone (11–15%), (6-heptyl-5,6-dihydro-2H-pyran-2-one (0.3–3%) and benzyl benzoate (0.2–5%). *C. cunninghamii*: benzyl benzoate (80.2%). *C. bellendenkerana*: limonene (8.3%), β-phellandrene (11.8%), viridiflorene (9.1%). *C. lividula*: bicyclogermacrene (26.1%), spathulenol (21.1%), β-eudesmol (6.1%)	Lauraceae	2016, [177]
Cryptocarya cunninghamii Meissner	Type 1, bicyclogermacrene (52.4%), type 2, 6-nonyl-5,6-dihydro-2H-pyran-2-one (78–88%)	Lauraceae	1998, [178]
Cyathostemma micranthum	Caryophyllene oxide (26%), spathulenol (11%), benzyl benzoate (4%)	Annonaceae	2004, [154]
Darwinia citriodora (Endl.) Benth	Yield: 0.5% to 1.1%: methyl myrtenate (56–76%) methyl geranate (49–75%), α-pinene (7.8%), (Z)-β-ocimene (2.0%), linalool (1.7%), bicyclogermacrene (1.3%), viridiflorol (2.3%)	Myrtaceae	2001, [179]
Darwinia procera, *D. fascicularis* subsp. *fascicularis* and *D. peduncularis*	*D. procera*: myrtenyl acetate (6.1–29.6%), α-pinene (6.9–25.1%), γ-terpinene (6.2–13.6%), bicyclogermacrene (5.5–10.8%), (E)-nerolidol (3.4–9.7%). *D. fascicularis* ssp. *fascicularis:* (E)-nerolidol (33.0%), α-pinene (15.1%), γ-terpinene (10.2%). *D. peduncularis*: α-pinene (33.5%), γ-terpinene (23.1%), bicyclogermacrene (6.7%)	Myrtaceae	2010, [180]
Decaspermum humile (Sweet ex G.Don) A.J.Scott, *D. struckoilicum* N.Snow & Guymer	*D. struckoilicum*: α-pinene (37.5%), β-caryophyllene (2.4%), α-humulene (2.2%) and α- and β-eudesmol (8.2% and 8.1%, respectively). *D. humile*: a-thujene (0.1–13%), α-pinene (0.2–21%), limonene (0.2–8%), myrcene (0.3–10%), β-phellandrene (0.1–5%), linalool (0.3–9%) and terpinen-4-ol (0.3–6%), β-caryophyllene (0.7–5%), aromadendrene (1–6%), viridiflorene (1–7%), δ-cadinene (0.4–14%), bicyclogermacrene (0.2–10%), globulol (1–9%)	Myrtaceae	2005, [181]
Desmos goezeanus, *D.* spp. (Mossman River L.W. Jessup 550), *D. wardianus*,	*D. goezeanus*: benzyl benzoate, benzyl salicylate. *D.* spp. (Mossman River): benzyl benzoate (52%). *D. wardianus*: α-pinene (37%)	Annonaceae	2002, [182]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Dinosperma erythrococca, *D. stipitata*, *D. melanophloia*,	*D. erythrococca*: type 1, geranyl acetate (80%), type 2, (E)-β-ocimene (3–28%), geranyl acetate (2–32%), linalool (2–10%), β-caryophyllene (7–11%), bicyclogermacrene (2–10%), spathulenol (1–10%), type 3, spathulenol (30%), type 4, furanoid linalool oxides (5–8%), (E)-β-ocimene (13%), γ-elemene (36.4%), type 5, myrcene (13.3%), limonene (26.3%), (E)-β-ocimene (18.5%). *D. stipitata*: type 1, bicyclogermacrene (22–32%), germacrene B (11–12%) evodionol methyl ether (11.5%), (E)-methyl isoeugenol (6–11%), type 2, hydrocarbon C15H,4 (9–26%), bicyclogermacrene (7–16%), γ-elemene (7–9%). *D. melanophloia*: methyl chavicol (59%), (E)-methyl isoeugenol (15%)	Rutaceae	2002, [183]
Dinosperma longifolium T.G. Hartley (Rutaceae)	Niranin, S-methylthiocarboxylic acid-N-methyl-N-phenylethylamide, (39–62%), β-caryophyllene (5–12%), (E)-β-farnesene (5–12%), bicyclogermacrene (10–14%)	Rutaceae	2004, [184]
Diselma archeri Hook.f.	Yield 0.6–0.8%: Leaves, α-pinene (45–73%), δ-3-carene (1–15%), limonene	Cupressaceae	2003, [185]
Doryphora sassafras Endl., *D. aromatica* (F. M. Bail.) L. S. Smith	*D. sassafras*: methyl eugenol (27–47%), safrole (15–30%), camphor (15–19%). *D. aromatica*: α-, β- and γ-eudesmol, spathulenol, elemol, guaiol	Atherospermataceae	1993, [186]
Drummondita calida (F.Muell.) Paul G.Wilson	α-pinene (79–86%)	Rutaceae: Boronieae	2006, [187]
Dryadodaphne sp. (Mt. Lewis B.P. Hyland RFK1496)	Leaves: δ-cadinene (10.7%), globulol (4.6%), T-cadinol (3.7%). Bark and wood: guaiol, bulnesol	Atherospermataceae	1998, [188]
Endressia wardellii (F.Muell.) Whiffin	*E. wardellii*: α-humulene (14–17%), bicyclogermacrene (17–24%)	Apiaceae	2009, [189]
Eremaea pauciflora (Endl.) Druce	1,8-Cineole (22%), eudesmols (α-, β-, γ-; 26%)	Myrtaceae	2004, [148]
Eriostemon banksii A. Cunn. ex Endl, *E. australasius*	*E. australasius* and *E. banksia*: cis and trans-methyl-4-isoprenoxycinnamate, β-elemene (7.2–8.1%), β-caryophyllene (7.7–8.4%) sesquiterpene n.d. (12.3–15.1%), α-pinene (2.8–8.3%), β-pinene (0.2–0.8%), limonene (0.4–0.5%)	Rutaceae	1998, [190]
Eryngium expansum F. Muell, *E. pandanifolium* Cham. et Schlecht, *E. rostratum* Cav., *E. vesiculosum* Labill.	*E. expansum*: 7-epi-α-selinene (38.3%), cis-β-guaiene (10.8%), 2,3,6-trimethylbenzaldehyde (8.0%), (E,E)-α-farnesene (7.3%). *E. pandanifolium*: bornyl acetate (20.8%), β-selinene (13.8%), α-selinene (11.3%), α-muurolene (8.0%). *E. rostratum*: spathulenol (20.0%), β-bisabolol (8.6%), fruit oil: β-bisabolol (65.3%). *E. vesiculosum*: β-caryophyllene (20.3%), germacrene D (19.2%), α-humulene (8.8%)	Apiaceae	2003, [191]
Eryngium paludosum (C.Moore) P.W.Michael	γ-terpinene (12.9%), β-bisabolene (12.2%), germacrene D (7.6%), myrcene (7.3%), β-caryophyllene (7.0%), limonene (6.0%), α-humulene (5.1%)	Apiaceae	2008, [192]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Eryngium rosulatum P.W. Michael Ined	β-elemene (16.0%), bicyclogermacrene (12.5%), δ-elemene (7.0%), (E)-caryophyllene (5.9%)	Apiaceae	2006, [193]
Eryngium vesiculosum Labill.	Caryophyllene (20.3%), germacrene D (19.2%), α-humulene (8.8%), bicyclogermacrene	Apiaceae	2003, [194]
Euodia hylandii, E. pubifolia	*E. hylandii*: spathulenol (12–20%). *E. pubifolia*: spathulenol (18.3%)	Rutaceae	2004, [195]
Fitzalania heteropetala F. Muell.	β-Caryophyllene (33–8%), aromadendrene (14.0%)	Annonaceae	1997, [196]
Flindersia acuminata, F. australis, F. bennettiana, F. bourjotiana, F. brassii, F. brayleyana, F. collina, F. dissosperma, F. ifflaiana, F. laevicarpa, F. maculosa, F. oppositifolia, F. pimenteliana, F. schottiana, and *F. xanthoxyla*	*F. maculosa*/*F. dissosperma*: geijerene, pregeijerene, methyl geranate, α-pinene, β-caryophyllene and bicyclogermacrene. *F. acuminata*/*F. australis*: bicyclogermacrene, guaiol, bulnesol. *F. australis* type 2: β-caryophyllene, spathulenol. *F. bennettiana*: bicyclogermacrene. *F. bourjotiana*: β-caryophyllene. *F. brassii*: α-cadinol, δ-cadinene. *F. brayleyana*: spathulenol, caryophyllene oxide. *F. collina*: (E,E)-farnesol. *F. ifflaiana*: β-caryophyllene, α-humulene, bicyclogermacrene. *F. Laevicarpa*: β-caryophyllene, germacrene D, bicyclogermacrene, elemol. *F. oppositifolia*: diverse. *F. pimenteliana*: β-caryophyllene, bicyclogermacrene, chemotype 2: α-pinene. *F. schottiana*: α-pinene, sabinene. *F. xanthoxyla*: bicyclogermacrene, δ-cadinene, β-caryophyllene	Rutaceae	2005, [50]
Galbulimima baccata F.M.Bailey (Himantandraceae)	Elemol/hedycaryol (12–30%), α-, β- and γ-eudesmol (0.6–3%, 0.4–3% and 0.2–3%, respectively), spathulenol (1–3%)	Himantandraceae	2005, [197]
Geijera linearifolia (DC.) J.M.Black	Leaf oil: spathulenol (10–17%), geranyl acetate (4–9%), bicyclogermacrene (3–6%), (E,E)-farnesol (23–30%)	Rutaceae	2005, [173]
Geleznowia verrucosa Turcz	Leaves: α-pinene (80%), flower, α-pinene + eugenyl acetate	Rutaceae	1995, [198]
Goniothalamus australis Jessup	Type 1, pinocarvone (10%), trans-pinocarveol (17%), type 2, α-pinene (10–11%)	Annonaceae	2004, [154]
Gyrocarpus americanus Jacq., subsp. *americanus*	α-pinene, β-pinene, germacrene D (31%)	Hernandiaceae	2000, [199]
Halfordia kendack (Montrouz.) Guillaumin S.L.	methyl eugenol and elemicin	Rutaceae	2004, [200]
Haplostichanthus johnsonii F.Muell., *H.* sp. (Coopers Creek B.Gray 2433), *H.* sp. (Johnstone River L.W Jessup+ 471), *H.* sp. (Mt. Finnigan L.W Jessup 632), *H.* sp. (Rocky River Scrub P.I. Forster+ PIF10617), *H.* sp. (Topaz L.W. Jessup 520)	*H.* sp. (Rocky River Scrub): caryophyllene oxide (26.2%), humulene oxide (10.1%), spathulenol (31.6%). *H.* sp. (Mt. Finnigan): spathulenol (15.4%). *H.* sp. (Coopers Creek): β-caryophyllene (10%), γ-muurolene (12.4%), bicyclogermacrene (9.6%). *H.* sp. (Johnstone River): β-caryophyllene (trace—27%), α-humulene (trace—10%), caryophyllene oxide (3–19%), spathulenol (6–31%). *H.* sp. (Topaz): spathulenol (24–38%). *H. johnsonii*: spathulenol (21–36%)	Annonaceae	2006, [201]
Haplostichanthus johnsonii	Yield 1.5–2%. 2,3,4,5-tetramethoxyallylbenzene (79%), elemicin (5.9%), α-copaene (5%), elemene (2%)	Annonaceae	1992, [202]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Hedycarya angustifolia A.Cunn. and *H. loxocarya* (Benth.) W.D.Francis	Elemol and α-, β- and γ-eudesmol	Monimiaceae	2005, [203]
Hernandia albiflora, H. bivalvis, H. nymphaeifolia	*H. albiflora*: bicydogermacrene (trace -19%), β-caryophyllene (5–9%), caryophyllene oxide (7–18%), globulol (4–6%). *H. bivalvis*: bicyclogermacrene (20–30%), β-caryophyllene (4–13%), α-copaene (11–13%), germacrene D (7–12%). *H. nymphaeifolia*: β-caryophyllene (11–44%), α-humulene (14–17%), caryophyllene oxide (5–20%)	Hernandiaceae	2000, [199]
Homoranthus biflorus, H. binghiensis, H. cernuus, H. flavescens, H. montanus, H. sp. nov. Nandewar Range, *H. bornhardtiensis, H. decumbens, H. homoranthoides, H. prolixus, H. decumbens, H. thomasii, H. tropicus*	*H. biflorus, H. binghiensis, H. cernuus* type 1, *H. flavescens, H. montanus* and *H.* sp. nov. Nandewar Range type 1: β-pinene, (Z)-β-Ocimene (>40%), bicyclogermacrene, globulol. *H. bornhardtiensis, H. decumbens* type 1, *H. homoranthoides, H. prolixus, H.* sp. nov. Nandewar Range type 2: β-pinene, limonene, bicyclogermacrene, globulol. *H. decumbens, H. thomasii, H. tropicus*, H. sp. nov. Nandewar Range type 3: β-pinene, γ-terpinene, bicyclogermacrene, globulol. *H. tropicus*: methyl geranate, bicyclogermacrene, globulol	Myrtaceae	2004, [204]
Homoranthus montanus Craven and S. R. Jones, *H. flavescens* Cunn. ex. Schauer.	*H. montanus*: (Z)-β-ocimene (85%). *H. flavescens*: (Z)-β-ocimene (69–71%)	Myrtaceae	1998, [205]
Idiospermum australiense (Diels) S. T. Blake	Bicyclogermacrene (48%), caryophyllene (8%), globulol, viridiflorol, spathulenol	Calycanthaceae	1992, [206]
Kibara rigidifolia A.C.Sm.	(Z)-β-Ocimene (3–12%), (E)-β-ocimene (1.5%), bicyclogermacrene, germacrene-B, guaiol, spathulenol	Monimiaceae	1998, [188]
Kunzea pulchella (Lindl.) A.S.George	Globulol (83–88%)	Myrtaceae	2004, [148]
Lagarostrobos franklinii (Hook.f.) Quinn	Yield 0.8–0.9%: Leaves, α-pinene (13–36%), δ-3-carene (1–17%), limonene (16–42%), 16-kaurene (3–7%), phyllocladene (4–10%), sclarene (2–23%). Wood, methyl eugenol (74%), (E)-methyl isoeugenol (2%) elemicin (24%)	Podocarpaceae	2003, [185]
Leionema ambiens (F.Muell.) Paul G.Wilson	(E)-β-ocimene (>10%), (Z)-β-ocimene (0.1–4%), viridiflorene (6–7%), bicyclogermacrene (6–13%), globulol (6–7%), viridiflorol (4–6%), (E,E)-farnesol (14–23%)	Rutaceae	2003, [117]
Leptospermum amboinense, L. emarginatum, L. grandiflorum, L. liversidgei, L. petersonii, L. rotundifolium, L. wooroonooran	*L. amboinense*: type 1, geranial (13%), sabinene (13%). *L. emarginatum*: α-eudesmol (7–17%), β-eudesmol (17–26%), γ-eudesmol (9–18%). *L. grandiflorum*: α-, β- and γ-eudesmol. *L. liversidgei*: citronellal (ca. 44%), neral (20%), geranial (35%). *L. petersonii*: type 1, citronellal, low neral/geranial, type 2, low citronellal and high neral/geranial, type 3, Penfold's 'variety A,' monoterpenes, type 4, β-caryophyllene, globulol/viridiflorol/spathulenol, type 4, Penfold's 'variety B,' geranyl acetate (21–38%), geraniol (21–29%). *L. rotundifolium*: α-pinene (16–25%), 1,8-cineole (21–28%). *L. wooroonooran*: α-pinene (4–11%), β-pinene (4–9%), sabinene (9–19%), β-caryophyllene (5–7%), humulene (11–20%)	Myrtaceae	2000, [207]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Leptospermum arachnoides, L. crassifolium, L. deuense, L. epacridoideum, L. glabrescens, L. grandifolium, L. lanigerum, L. macrocarpum, L. nitidum, L. petraeum, L. riparium, L. spectabile, L. sphaerocarpum, L. thompsonii, L. turbinatum	Oils were dominated by α-, β- and γ-eudesmol. *L. glabrescens*: flavesone, leptospermone, eudesmol isomers	Myrtaceae	1999, [208]
Leptospermum blakelyi, L. brevipes, L. neglectum, L. parvifolium, L. sp. (Woodgate, P. I. Forster, PIF 13959), *L. multicaule, L. namadgiensis, L. microcarpum*	*L. brevipes, L. neglectum, L. parvifolium, L.* sp. (Woodgate): α-pinene. *L. blakelyi, L. multicaule, L. namadgiensis* and *L. sericatum*: sequiterpenoid. L. divaricatum and *L. microcarpum*: monoterpenoid	Myrtaceae	1998, [209]
Leptospermum brachyandrum (F. Muell.) Druce, *L. luehmannii* F. M. Bailey, *L. madidum* A. R. Bean subsp. *madidum*, *L. purpurascens* Joy Thomps., *L. speciosum* Schauer, *L. whitei* Cheel and *L. pallidum* A. R. Bean	All species produce α-pinene and lesser amounts of β-pinene, β-caryophyllene, aromadendrene, humulene, spathulenol, 1,8-cineole	Myrtaceae	1998, [210]
Leptospermum coriaceum (F. Muell. Ex Miq.) Cheel, *L. fastigiatum* S. Moore, and *L. nitens* Turcz	*L. coriaceum*: α-pinene (25.4%), 1,8-cineole (11.5%), globulol (15.4%). *L. fastigiatum* and *L. nitens*: α-pinene (82.8% and 64.8–70.6% respectively)	Myrtaceae	1999, [211]
Leptospermum spp. *Eudesmol types:* [*L. micromyrtus* Miq., *L. minutifolium* C.T. White, *L. myrtifolium* Sieber ex DC., *L. rupestre* Hook. f., *L. sejunctum* Joy Thomps.] *L. novae-angliae* Joy Thomps., *L. rupicola* Joy Thomps. Sesquiterpenoid types [*L. continentale* Joy Thomps., *L. gregarium* Joy Thomps., *L. juniperinum* Sm, *L. obovatum* Sweet., *L. scoparium* J. R. Forst & G. Forst. and *L. squarrosum* Gaertn.]	Eudesmol types dominated by α-, β- and γ-eudesmol. *L. myrtifolium* type 2: (E,Z)-farnesal (5.8%), (E,E)-farnesal (12.9%), 2,3-dihydro-(E)-farnesol (10.3%), (E,E)-farnesol (26.5%). *L. novae-angliae*: (E)-nerolidol (50%). *L. rupicola*: α- and β-pinene	Myrtaceae	1999, [101]
Leptospermum morrisonlii, L. oreophilum, L. variabile, Leptospermum sp. (Mt Maroon, A.R. Bean 6665), *L. polygalifolium*, ssp. *polygalifolium, montanum, howense, cismontanum, transmontanum, tropicum* and 'wallum,' *L. madidum* spp. *sativum*	*L. morrisonlii*: grandiflorone. *L. oreophilum*: (E,E)-farnesol. *L. variabile*: type 1, geranyl acetate, β-caryophyllene, humulene, type 2, 1,8-cineole, type 3, α-pinene, β-caryophyllene, α-, β- and γ-eudesmol. *L.* sp. (Mt Maroon): type 1, β-caryophyllene, humulene, type 2, β-caryophyllene, δ-cadinene, calamenene, sesquiterpene n.d. *L. polygalifolium*, ssp. polygalifolium, montanum and howense: α-, β-, and γ-eudesmol. L. ssp. *cismontanum, transmontanum, tropicum* and *'wallum'*: 1,8-cineole. *L. madidum* spp. *sativum*: α-pinene, β-pinene, γ-terpinene α-, β-, and γ-eudesmol	Myrtaceae	2000, [212]
Leptospermum scoparium	Isoleptospermone	Myrtaceae	1999, [175]
Levieria acuminata (F.Muell.) Perkins	n-Dodecanal (28%), δ-cadinene (5.8%), calamenene (5.7%)	Monimiaceae	1998, [188]
Lindera queenslandica B. Hyland	γ-Elemene (21.4%), α-copaene (17.9%), β-caryophyllene (7.4%), α-humulene (9.0%)	Lauraceae	1999, [213]
Lindsayomyrtus racemoides (Greves) Craven	β-Caryophyllene (7.4–13%), humulene (5.2–11.6%), β-trans-ocimene (5.0–7.3%)	Myrtaceae	1996, [214]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Lophostemon Schott spp.	α-Pinene, aromadendrene, allo-aromadendrene, globulol, spathulenol.	Myrtaceae	2000, [215]
Lunasia amara Blanco var. *amara*	γ-Elemene (0.7–19%), germacrene-D (18–51%), bicyclogermacrene (7–26%), bicycloelemene (1–2%), β-bourbonene (0.7–3%), γ-elemene (4–9%), α-farnesene (1–3%), δ-cadinene (3–5%)	Rutaceae	1997, [216]
Lycopus australis R.Br.	β-phellandrene (26–40%), β-caryophyllene (7–16%), α-humulene (18–30%)	Lamiaceae	2005, [217]
Lysicarpus angustifolius (Hook.) Druce	α-Pinene, β-pinene, limonene (8%), α-terpineol (2–5%), viridiflorene (5–8%), aromadendrene (5–8%), globulol (4–5%), spathulenol (2–5%)	Myrtaceae	1994, [218]
Malleostemon tuberculatus (E.Pritz.) J.W.Green	α-Pinene (33%), 1,8-cineole (21%), E,E-farnesol (6%)	Myrtaceae	2004, [148]
Medicosma cunninghamii, M. elliptica, M. fareana, M. glandulosa, M. obovata, M. riparia, M. sessiliflora, M. sp. (East Mulgrave River R.L. Jago + 3696), *M.* sp. (Karnak P.I. Forster+ PIF15541), *M.* sp. (Mt Mellum P.I. Forster + PIF25572)	*M. cunninghamii*: evodionol, evodionol methyl ether, α-pinene, myrcene, ocimene. *M. elliptica*: α-pinene (0.6–29%), sabinene (12–55%), myrcene (8–16%), limonene (0.4–13%). *M. fareana*: bicyclogermacrene (15–44%). *M. glandulosa*: α-pinene (t-35%), β-caryophyllene (t-15%), aromadendrene (t-10%), (E,E)-α-farnesene (1–13%), bicyclogermacrene (1–13%), globulol (1–8%), spathulenol (3–10%). *M. obovate*: α-pinene (1–12%), limonene (10–13%), (E)-β-ocimene (14–23%), β-caryophyllene (17–19%), α-humulene (6–14%). *M. riparia*: α-selinene (7–15%), evodionol (1–3%), evodionol methyl ether (30–56%). *M. sessiliflora*: β-caryophyllene (3–11%), aromadendrene (5–14%), humulene (8–19%), spathulenol (3–12%). *M.* sp. (East Mulgrave) bicyclogermacrene (17–21%). *M.* sp. (Karnak): α-pinene (1–40%), bicyclogermacrene (3–8%), spathulenol (10–22%). *M.* sp. (Mt Mellum): α-pinene (38–54%) (Z)-β-ocimene (10–13%)	Rutaceae	2004, [219]
Melicope affinis, *M. bonwickii, M. broadbentiana, M. elleryana, M. fellii, M. hayesii, M. jonesii, M. micrococca, M. peninsularis, M. rubra, M. vitiflora, M. xanthoxyloides*	*M. affinis*: bicyclogermacrene (7–18%), bisabolene (t-9%). *M. bonwickii*: zierone (0.3–3%). *M. broadbentiana*: α-pinene (21–76%), limonene (0.6–28%). *M. elleryana*: zierone (26–42%), allo-evodione (4–10%), evodione (10–22%). *M. fellii*: β-caryophyllene (9.9%), α-humulene (8.4%), caryophyllene oxide (7.4%). *M. hayesii*: bicyclogermacrene (22.8%), germacrene D (13.9%), (E,E)-α-farnesene (9.2%), globulol (10.6%). *M. jonesii*: sesquiterpenic. *M. micrococca*: α-pinene (1–46%), (E)-(β-ocimene (t-10%), (β-caryophyllene (0.4–15%), bicyclogermacrene (t-11%), caryophyllene oxide (0.3–23%), spathulenol (1–12%). *M. peninsularis*: β-caryophyllene (30–49%), α-humulene (26?35%). *M. rubra* and *M. vitiflora*: sabinene (31.1%), γ-terpinene, germacrene D (22.6%), sabinene (0.1–54%), limonene (1–47%). *M. xanthoxyloides*: β-caryophyllene (13–47%), spathulenol (1–18%), α-pinene (t-15%)	Rutaceae	2004, [195]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Melicope contermina, M. polybotrya	*M. contermina*: limonene (33%), elemol (23%). *M. polybotrya*: geijerene (41%), pregeijerene (38%), limonene (9%)	Rutaceae	2004, [220]
Melicope melanophloia C.T. White	Type 1, methyl chavicol (5–13%), methyl eugenol (51–67%), type 2, α-pinene (34–37%), myrcene, α-phellandrene, limonene, 1,8-cineole (4–12%), type 3, limonene (1–8%), (Z)-β-ocimene (12–18%), (E)-β-ocimene (23–56%), 2-hydroxy-4,6-dimethoxyacetophenone (4–6%)	Rutaceae	1997, [221]
Melodorum sp. (Font Hills G. Sankowsky 380), *M.* sp. (Stone Crossing L.W. Jessup 814), *M.* sp. (Topaz G. Sankowsky + 244), *M.* sp. (Claudie River B.P.Hyland 21171V), *M. uhrii, M. leichhardtii,*	*M.* sp. (Font Hills): α-eudesmol (9–5%), β-eudesmol (7–11%), β-caryophyllene (10–16%), bicyclogermacrene (1–9%) and α-pinene (14–15%). *M.* sp. (Stone Crossing): benzyl benzoate (20%), benzyl salicylate (2.7%). *M.* sp. (Topaz): bicyclogermacrene (34–50%), β-caryophyllene (11–16%), spathulenol (2–10%). *M.* sp. (Claudie River): bicyclogermacrene (29.3%), β-caryophyllene (26.7%). *M. uhrii*: bicyclogermacrene (45%), benzyl benzoate (5%). *M. leichhardtii*: germacrene D (6–10%), bicyclogermacrene (15–19%), (Z)-β-ocimene (6?8%), (E)-β-ocimene (2–5%)	Annonaceae	2004, [222]
Mentha diemenica Sprengel	1% Yield, menthone (32%), neomenthyl acetate (0.0–18.3%), pulegone (25–44%), neomenthol (2.5–9.0%), menthyl acetate (2.7–5.7%), menthol (1.8–2.7%), isomenthone (1–3%)	Lamiaceae	1996, [223]
Mentha grandiflora Benth	trans-piperitone oxide (21%), piperitenone oxide (36%), pulegone (19%), menthone (10%)	Lamiaceae	1997, [224]
Microcachrys tetragona (Hook.) Hook.f.	Yield 0.1–0.5%: α-pinene (44–50%), limonene (10–13%)	Podocarpaceae	2003, [185]
Micromelum minutum (G.Forst.) Wight & Arn.	*M. minutum*: δ-elemene (3.3–18.6%), β-caryophyllene (4.8–30.3%), germacrene-D (2–15.8%), germacrene-B (3.9–34.3%)	Rutaceae	2016, [172]
Micromyrtus striata J. W. Green	Isoamylisovalerate (23.0–48.7%), α-pinene (5.9–27.7%)	Myrtaceae	1991, [225]
Microstrobos fitzgeraldii, M. niphophilus	M. fitzgeraldii: α-pinene (22.7%), myrcene (24.1%), hibaene (27.0%). *M. niphophilus*: α-pinene (26.9%), limonene (30.5%) myrcene (20.8%)	Podocarpaceae	2001, [226]
Miliusa traceyi, M. horsfieldii, M. brahei	*Miliusa traceyi*: α-pinene (18.7%), β-pinene (18.6%), β-caryophyllene (13.5%). *M. horsfieldii*: β-caryophyllene (20.2%), caryophyllene oxide (12.5%). *M brahei*: β-caryophyllene (12.8%), α-humulene (11.3%), bicyclogermacrene (12.9%)	Annonaceae	2004, [227]
Mitrantia bilocularis Peter G.Wilson & B.Hyland	β-Caryophyllene (29%) and globulol (13%).	Myrtaceae	2003, [164]
Mitrephora zippeliana Mig.	Type 1, α-pinene (13%), β-pinene (15%), caryophyllene oxide (10%), spathulenol (10%), β-caryophyllene (8%), type 2, β-caryophyllene (18%), α-humulene (7%), γ-curcumene (4%), bicyclogermacrene (4%), ar-curcumene (5%), caryophyllene oxide (3%), spathulenol (5%)	Annonaceae	2004, [154]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Murraya paniculata (L.) Jack.	Small leaves variant: High yield. Big leaves variant: small yield. Both germacrene-D, E-nerolidol	Rutaceae	1994, [228]
Neolitsea australiensis, *N. brassii*	*N. australiensis*: bicyclogermacrene (12–16%), guaiol (13–17%). *N. brassii*: bicyclogermacrene (11–15%), cubenol (6–10%), guaiol (7–10%). Northern chemotypes: germacrone (50%), bicyclogermacrene (12–35%), spathulenol (4–38%), type 2, furanogermenone (43%). Southern chemotypes: γ-eudesmol (3–30%), spathulenol (5–30%)	Lauraceae	2002, [229]
Neofabricia myrtifolia, *N. mjoebergii*, *N. sericisepala*	*N. mjoebergii*: caryophyllene, humulene, β-pinene. *N. sericisepala*: over 50% α-pinene, caryophyllene. *N. myrtifolia*: type 1 α-pinene (>60%) caryophyllene, type 2, α-pinene, caryophyllene (up to 60%)	Myrtaceae	1992, [230]
Osbornia octodonta F. Muell.	α-Pinene (35%), 1, 8-cineole (24%), α-terpineol (11%)	Myrtaceae	1993, [231]
Palmeria F.Muell., spp.	Elemol, spathulenol, bicyclogermacrene, ishwarane	Monimiaceae	2004, [232]
Pentaceras australe (F. Muell.) Benth.	α-Bisabolol (0.3–18%), γ-elemene (11–25%), germacrene D (13–25%), sesquicineole (4–7%)	Rutaceae	2002, [233]
Phebalium distans, P. glandulosum subsp. glandulosum, P. longifolium, P. nottii, P. squamulosum subsp. squamulosum, P. squamulosum subsp. gracile, P. whitei, and P. woombye	*P. distans*: α-pinene (0.8–42%), bicyclogermacrene (12–22%). *P. glandulosum* subsp. *glandulosum*: dihydrotagetone, 75–95%. *P. longifolium*: β-caryophyllene (9–20%), bicyclogermacrene (7–23%). *P. nottii*: α-pinene (25–42%), guaiol (t-28%), bulnesol (nil to 34%). *P. squamulosum* subsp. *squamulosum*: α-phellandrene (12–25%), β-phellandrene (14–15%), bicyclogermacrene (2–12%), elemol/hedycaryol (12–36%). *P. squamulosum* subsp. *gracile*: geijerene (4–8%), α-pinene (44–50%), guaiol (9–11%). *P. whitei*: α-pinene (22–42%), limonene (1–12%), bicyclogermacrene (11–20%). *P. woombye*: α-pinene (10–21%), β-phellandrene (12–20%), bicyclogermacrene (11–20%), germacrene D (5–10%)	Rutaceae	2006, [116]
Phyllocladus aspleniifolius (Labill.) Hook.f.	Yield 0.5–1%: α-pinene (44–55%), phyllocladene (15–28%), 8-β-hydroxyisopimarene (5–7%)	Podocarpaceae	2003, [185]
Pilidiostigma glabrum Burret, *P. recurvum* (C.T. White) A.J. Scott, *P. rhytisperma* (F. Muell.) Burret, *P. tetramerum* L.S. Sm., *P. tropicum* L.S. Sm. and *Pilidiostigma* sp. (Mt Lewis G.P. Guymer 2024)	All species: aromadendrene, allo-aromadendrene, β-caryophyllene, α-copaene, viridiflorene, bicyclogermacrene, δ- and γ-cadinene and globulol	Myrtaceae	1999, [234]
Pistacia lentiscus L.	α-Pinene, β-pinene, myrcene, limonene, thymol, carvacrol	Anacardiaceae	1990, [235]
Pitaviaster haplophyllus (F. Muell.) T. G. Hartley	Germacrene D (10–28%), germacrene B (1–30%), bicyclogermacrene (2–10%), elemol (5–21%)	Rutaceae	2002, [236]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Podocarpus dispermus, *P. drouynianus*, *P. elatus*, *P. grayae*, *P. smithii*, *P. spinulosus*	*P. dispermus*: isopimara-9(11),15-diene (10.3%). *P. drouynianus*: bicyclogermacrene (57%). *P. elatus*: α-pinene, β-caryophyllene, bicyclogermacrene. *P. grayae*: Bicyclogermacrene (27–44%), germacrene D (4–11%), spathulenol (3–11%). P. lawrencei: α-pinene (14–18%), β-caryophyllene (3–15%), spathulenol (0.8–19%), rimuene (0.2–30%), sandarocopimara-8(14), 15-diene (0.1–20%), beyerene (7–9%). *P. smithii*: α-copaene (4–8%), β-caryophyllene (5%), cadinene (9–11%). *P. spinulosus*: limonene (13–16%), bicyclogermacrene (15–18%) and viridiflorol (16–18%)	Podocarpaceae	2004, [237]
Polyalthia australis, *P. michaelii*, *P. nitidissima*, *P.* sp. (Wyvuri B.P.Hyland RFK2632)	*P. australis*: β-caryophyllene (4–15%), germacrene D (1–13%), bicyclogermacrene (1–10%), caryophyllene oxide (6–10%), spathulenol (7–24%). *P. michaelii*: spathulenol (42.2%). *P. nitidissima*: type 1, α-pinene (10–12%), limonene (4–6%), (E)-β-ocimene (0.7–2%), δ-cadinene (4–8%), spathulenol (15–17%), type 2, spathulenol (22–28%), bicyclogermacrene (4–24%), β-caryophyllene (2–10%). *P.* sp. (Wyvuri): globulol (1–34%), spathulenol (4–6%), ledol (1–10%), germacrene B (22–39%)	Annonaceae	2001, [238]
Polygonum odoratum Lour	Decanal (27.73%), dodecanal (44.05%), decanol (10.88%)	Polygonaceae	1997, [239]
Pseuduvaria mulgraveana var. mulgraveana, *P. mulgraveana var. glabrescens*, *P. hylandii*, *P. villosa*, and *P. froggattii*	*P. mulgraveana* var. *mulgraveana* and *P. mulgraveana* var. *glabrescens*: elemicin (87%) and methyl eugenol (61%). *P. villosa*: β-caryophyllene (3–13%) and α-copaene (4–11%). *P. froggattii*: caryophyllene oxide (2–22%), froggatt ether (0.1–18%), spathulenol (9–18%). *P. hylandii*: β-caryophyllene (22–28%), α-himachalene (2–10%), α-humulene (8–9%)	Annonaceae	2004, [240]
Ristantia gouldii, *R. pachysperma*, *R. waterhousei*	*R. gouldii*: α-pinene (39–48%), β-pinene (19–34%). *R. pachysperma*: (E)-nerolidol (42%). *R. waterhousei*: α-Pinene (53–66%)	Myrtaceae	2003, [164]
Rhodamnia dumicola, *R. pauciovulata*, *R. rubescens* and *R.* sp. (McIlwraith Range, L.J. Webb + 9527), *R. australis*, *R. blairiana*, *R. costata*, *R. dumicola*, *R. argentea*, *R. whiteana*, *R.* sp. (Cape York, L. S. Smith 12538), *R. glabrescens*, *R. sessiliflora*, and *R. spongiosa*, *R. maideniana*, *R.* sp. (Calliope, N. Gibson 1335)	*R. dumicola*, *R. pauciovulata*, *R. rubescens* and *R.* sp. (McIlwraith Range): α-pinene. *R. australis*, *R. blairiana*, *R. costata*, *R. dumicola*, *R. argentea*, *R. whiteana* and R. sp. (Cape York): α-, β-, and γ-eudesmol, α- and β-pinene. *R. glabrescens*, *R. argentea* type 2, *R. sessiliflora*, *R. spongiosa*: β-caryophyllene, globulol, viridiflorol, spathulenol. *R. maideniana*, *R.* sp. (Calliope): unidentified oxygenated sesquiterpenes	Myrtaceae	1997, [241]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Rhodomyrtus canescens C. T. White & W. D. Francis, *R. effussa* Guymer., *R. macrocarpa* Benth., *R. pervagata* Guymer., *R. psidioides* (G. Don.) Benth., *R. sericea* Burret., *R. trineura* (F. Muell.) F. Muell. ex Benth. subsp. *trineura*, *R. trineura* subsp. *capensis* Guymer	*R. canescens*: α-pinene (20–23%), β-pinene (6–10%), aromadendrene (12?17%). *R. effussa*: globulol (11–22%), viridiflorol (8–10%), spathulenol (5–18%). *R. macrocarpa*: β-caryophyllene (9–44%), aromadendrene (6–11%), globulol (8–10%). R. pervagata: α-pinene (27–35%), β-pinene (18–24%). *R. psidioides*: α-pinene (28–66%), limonene (1–24%). *R. sericea*: α-pinene (28%), β-pinene (21%), β-caryophyllene (13%). *R. trineura* subsp. *trineura*: β-caryophyllene (16–29%), caryophyllene oxide (2–12%), globulol (7–10%). *R. trineura* subsp. *capensis*: α-pinene (tr-26%), globulol (9–19%), viridiflorol (5–12%), spathulenol (4–7%)	Myrtaceae	1997, [242]
Sarcomelicope simplicifolia subsp. *simplicifolia* (Endl.) T.G. Hartley	β-Caryophyllene (14–22%), bicyclogermacrene (10–42%), α-copaene (1–8%), γ-elemene (1–3%), α-humulene (1–4%), δ-cadinene (1–7%), δ-elemene (0.2–2%), spathulenol (1–5%)	Rutaceae	1997, [216]
Sphaerantia chartacea Peter G.Wilson & B.Hyland	β-Bisabolene (t-25%), bicyclogermacrene (15–40%), globulol (6–10%)	Myrtaceae	2003, [164]
Sphaerantia discolor Peter G.Wilson & B.Hyland	Bicyclogermacrene (19%), globulol (15%), viridiflorene (14%), viridiflorol (8%), ar-curcumene (9%)	Myrtaceae	2003, [164]
Steganthera australiana, S. cooperorum, S. hirsute, S. laxiflora subsp. laxiflora, S. laxiflora subsp. lewisensis, and *S. macooraia*	*S. australiana*: sesquiterpenoid. *S. cooperorum*: aromadendrene (6–10%), viridiflorene (7–8%), globulol (7–9%), b-eudesmol (8–11%); dodecanal (2–4%), type 2, elemol (30–42%), hedycaryol (approx. 8%), α-, β- and γ-eudesmol (10–14%, 10–14%, 5–9%, respectively). *S. hirsute*: bicyclogermacrene (37–56%), β-caryophyllene (2–17%), germacrene D (2–22%). *S. laxiflora* subsp. *laxiflora*: viridiflorene (13–20%). *S. macooraia*: guaiol (2–23%), bulnesol (0.7–10%), elemol (10–22%). *S. laxiflora* subsp. *lewisensis*: viridiflorene (11.8%), 2-dodecenal (6.3%)	Monimiaceae	2009, [189]
Sundacarpus amarus (Blume) C.N.Page	β-Selinene (67–77%), bicyclogermacrene (9–11%)	Podocarpaceae	2000, [243]
Syncarpia glomulifera (Sm.) Nied. subsp. *glomulifera*, *S. glomulifera* subsp. *glabra* (Benth.) A. R. Bean, *S. verecunda* A. R. Bean, S. hillii F. M. Bailey	*S. glomulifera* (Sm.) Nied. subsp. *glomulifera*, *S. glomulifera* subsp. *glabra* (Benth.) A. R. Bean and S. verecunda A. R. Bean: α-pinene (30–50%), α-thujene (11–27%), aromadendrene (1–13%), globulol (3–8%). S. hillii: hillyl acetate (53–80%), hillone (6–12%), α-pinene (2–22%)	Myrtaceae	1996, [244]
Syncarpia hillii F.M.Bailey	Hillyl acetate, 7-acetoxy-2,2,6,6,8,8-hexamethyl-5-oxo-5,6,7,8-tetrahydro-2H-chromen,	Myrtaceae	1994, [245]
Thaleropia queenslandica (L.S.Sm.) Peter G.Wilson	α-Pinene (61–83%), spathulenol (1–4%), bicyclogermacrene (1–3%)	Myrtaceae	1997, [246]
Thryptomene australis, T. kochii	*T. australis*: geranic acid (52%), α-pinene (22%). *T. kochii*: α-pinene (58–60%)	Myrtaceae	2004, [148]
Thryptomene hexandra, T. parviflora, T. oligandra	*T. hexandra* and *T. parviflora*: 1,8-cineole (up to 70%), α-pinene (up to 16%). *T. oligandra*: γ-terpinene (32–62%), p-cymene (25–50%), α-pinene (1–20%)	Myrtaceae	2000, [247]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Trachymene incisa Rudge	β-selinene, bicyclogermacrene, γ-bisabolene, α-pinene, β-caryophyllene	Araliaceae	2021, [248]
Tristaniopsis collina, T. exiliflora, T. laurina, T. neriifolia	*T. collina*: α-pinene (trace—35–9%), myrcene (5.6–29.3%), cubenol (0–16.6%). *T. exiliflora*: β-caryophyllene (13.4%), δ-cadinene (16.4%). *T. laurina*: type 1, α-pinene (79.4%), type 2, limonene (13.0%), globulol (9.7%). *T. neriifolia*: α-pinene (24.4%), α-eudesmol (17.8%), β-eudesmol (17.2%) and γ-eudesmol (28.0%)	Myrtaceae	1999, [249]
Uromyrtus australis A. J. Scott, *U. metrosideros* (F. M. Bailey), *A.* J. Scott, *U.* sp. (Tinaroo Range G. P. Guymer 2034), *U.* sp. (McPherson Range G. P. Guymer 2000)	*U. australis*: β-caryophyllene (21%), β-, α- and γ-eudesmol (13, 9 and 11% respectively). *U. metrosideros*: α-pinene (13–20%), β-pinene (33–42%), α-terpineol (3–7%), spathulenol (9–15%). *U.* sp. (Tinaroo Range): bicyclogermacrene (14–23%), globulol (9–12%), viridiflorol (5–7%) and spathulenol (3–4%). U. sp. (McPherson Range): terpinen-4-ol (8–13%), α-pinene (3–10%)	Myrtaceae	1996, [250]
Uvaria rufa, U. concave	*U. rufa*: α-humulene (50%), benzyl benzoate *U. concave*: spathulenol (32%)	Annonaceae	2004, [154]
Vitex limonifolia Wall	Caryophyllene (43%), caryophyllene oxide (13%), α-pinene (6%)	Lamiaceae	1990, [251]
Vitex trifolia L., *V. trifolia* L. var. *simplicifolia* Cham	*V. trifolia*: 1,8-cineole, terpinyl acetate, sabinene, α-pinene, caryophyllene. *V. trifolia* var. *simplicifolia*: 1,8-cineole, α-pinene, terpinyl acetate, sabinene	Lamiaceae	1991, [252]
Viticipremna queenslandica Munir (syn. *Vitex queenslandica*)	β-caryophyllene (27–34%), germacrene D (1–16%), bicyclogermacrene (9–15%), spathulenol (2–6%)	Lamiaceae	2008, [253]
Waterhousea floribunda, W. hedraiophylla, W. unipunctata, W. mulgraveana	*W. floribunda*: α- and β-pinene (17–21%). *W. hedraiophylla*: spathulenol, calamenene, δ-cadinene, bicyclogermacrene. *W. unipunctata*: germacrene D (8.2–25.6%), bicyclogermacrene (3.2–12.3%), globulol (0.4–15.8%), viridiflorol (0.2–9.6%). *W. mulgraveana*: 1,3,5-trimethoxybenzene, 2,4,6-trimethoxyethylbenzene, 2,4,6-trimethoxystyrene, 2,4,6-trimethoxy-3,5-dirnethylstyrene	Myrtaceae	2002, [254]
Wollemia nobilis W.G.Jones, K.D.Hill & J.M.Allen	(+)−16-Kaurene (60%), α-pinene (9%), germacrene-D (8%)	Araucariaceae	2000, [147]
Welchiodendron longivalve (F. Muell.) Peter G. Wilson & J. T. Waterh	β-Trans-ocimene (17–28%), caryophyllene (39–57%), humulene (7–22%)	Myrtaceae	1996, [214]

Table 1. *Cont.*

Species	Chemistry Info from Abstract	Family	Year and Ref.
Wilkiea angustifolia, *W. austroqueenslandica*, *W. cordata*, *W. huegeliana*, *W. longipes*, *W. macrophylla*, *W. pubescens*, *W. rigidifolia*, *W. smithii*, *W.* sp. (McDowall Range J.G.Tracey 14552), *W.* sp. (Palmerston B.P.Hyland 80) and *W.* sp. (Russell Gorge S.J.Dansie 1909)	*W. angustifolia*: β-eudesmol (35%). *W. austroqueenslandica*: (E)- β-ocimene (5–9%), germacrene D (7–18%), bicyclogermacrene (23–26%). *W. cordata*: β-eudesmol (22–25%), spathulenol (11.3%). *W. huegeliana*: α-pinene (10–12%), viridiflorene (4–9%). *W. longipes*: (Z)-β-ocimene (11–15%). *W. macrophylla*: dodecanal (2–35%), (2)-dodecenal (0.1–2%), β-caryophyllene (14–24%). *W. pubescens*: sesquiterpenes. *W. rigidifolia*: (Z)-β-ocimene (3.4–11.5%), bicyclogermacrene (3.2–17.4%), germacrene B (0.3–14.5%). *W. smithii*: β-caryophyllene (10.4%), bicyclogermacrene (9.6%), caryophyllene oxide (8.9%), spathulenol (16.7%). *W.* sp. (McDowall Range): selina-6-en-4-ol (30.7%), germacrene D-4-ol (18.6%). *W.* sp. (Palmerston): spathulenol (22%). *W.* sp. (Russell) elemol (19.2%)	Monimiaceae	2009, [189]
Xylopia maccreae (F.Muell.) L.S. Sm., *Xylopia* sp. (Bertiehaugh Homestead C. Dalliston CC173)	*X. maccreae*: bicyclogermacrene (34%), β-cubebene, β-caryophyllene, germacrene D. *Xylopia* sp. (Bertiehaugh Homestead): spathulenol (31%), globulol, viridiflorol, caryophyllene oxide	Annonaceae	1998, [255]
Zygogynum howeanum, *Z. semecarpoides* var. *semecarpoides*, *Z. queenslandianum* subsp. *queenslandianum*, *Z. queenslandianum* subsp. *australe*	*Z. howeanum*: β-caryophyllene (48.0%), α-humulene (16.5%) and (Z)-β-farnesene (3.2%). *Z. semecarpoides* var. *semecarpoides* spathulenol (24.4%). *Z. queenslandianum* subsp. *queenslandianum*: bicyclogermacrene (10.4%), globulol (7.7%), viridiflorol (4.5%), spathulenol (11.5%). *Z. queenslandianum* subsp. *austral*: elemol (5.1%), bicyclogermacrene, spathulenol	Winteraceae	1994, [256]

6. Conclusions

While many Australian essential oils have risen in the marketplace over the last 200 years, there are many others that experienced a rise and fall, or no rise at all. Some of the species grown on mainland Australia and Tasmania were prized, but their populations became threatened, such as *Lagarostrobos franklinii* and *Santalum spicatum*, and they were not easily cultivated as an alternative. Others were marketed with the wrong branding and were given a bad name, such as *Eremophila mitchellii* which earned the vernacular 'bastard sandalwood.'

Many essential oils are comprised of endemic molecules that were described for the first time after isolation from an Australian species. These molecules were often named after the species or genus, such as geijerene or prostantherol. Occasionally, endemic Australian essential oil components are identified in species from other continents too.

The therapeutic or aesthetic value of Australian oils is demonstrated by the Australian Aboriginal people, and by cultures elsewhere that used *materia medica* that have chemical overlap with Australian aromatic species. Australian essential oils are good candidates for antiseptic effects, as anti-inflammatory ingredients, as anti-depressants, and insect repellents.

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