Methyl eugenol: Its occurrence, distribution, and role in nature, especially in relation to insect behavior and pollination

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Abstract

This review discusses the occurrence and distribution (within a plant) of methyl eugenol in different plant species (> 450) from 80 families spanning many plant orders, as well as various roles this chemical plays in nature, especially in the interactions between tephritid fruit flies and plants.

Keywords: allomone, attractant, Bactrocera, chemical ecology, floral fragrance, insect pollinators, plant–insect interactions, plant semiochemicals, sex pheromone, synomone, tephritid fruit flies

Abbreviations: ME, methyl eugenol; RK, raspberry ketone

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1. Introduction

Plants produce a huge array of chemicals, numbering tens of thousands, primarily for defense against herbivores and pathogens as well as for production of floral fragrance to attract pollinators. Among them is a class of phenolics that consists of a group of compounds known as phenylpropanoids. The phenylpropanoids have numerous functions in plants, ranging from structural constituent, growth, and reproductive biochemistry and physiology to chemoeccological interactions with microbes, animals (particularly insects), and neighboring plants.

Methyl eugenol (ME) CAS No. 93-15-12 (Figure 1) is a phenylpropanoid chemical with many synonyms: 4-allylveratrole; 4-allyl-1,2-dimethoxybenzene; eugenyl methyl ether; 1,2-dimethoxy-4-(2-propenyl)benzene; 3,4-dimethoxy-allylbenzene; 3-(3,4-dimethoxyphenyl)prop-l-ene; O-methyl eugenol; and methyl eugenol ether. It is directly derived from eugenol, a product from phenylalanine (an essential amino acid) through caffeic acid and ferulic acid via the shikimate pathway (Herrmann and Weaver 1999). It is a common phenylpropanoid found in many plant species, particularly in spices and medicinal plants. Furthermore, this chemical can be converted to other useful phenylpropanoids either to elemicin or myristicin, and then, in the latter compound, to dillapiole, via the regulation of two genes in Perilla frutescens (Lamiaceae) (Koezuka et al. 1986).

Synthetic ME has been used extensively: a) as a flavoring agent in many types of processed food, soft drinks, and sauces; b) in perfumery; and c) as an essential oil in aromatherapy. From an entomological perspective, synthetic ME has been successfully used in: a) fruit fly surveys (Tan and Lee 1982) and quarantine detection (see reviews by Metcalf and Metcalf 1992; Vargas et al. 2010); b) estimation of native fruit fly populations (Steiner 1969; Newell and Haramoto 1968) and survival rates in natural ecosystems (Tan 1985; Tan and Jaal 1986); c) determining the relationship between fruit phenology and native fruit fly population dynamics (Tan and Serit 1994); d) monitoring movement of native fruit flies between different ecosystems (Tan and Serit 1988); and e) control of tephritid fruit flies (Diptera: Tephritidae) via male annihilation technique through mass trapping (see review by Vargas et al. 2010).

2. Methyl eugenol in nature

The role of ME in citronella grass, Cymbopogon nardus (Poaceae), in the strong attraction of Dacus (currently Bactrocera) fruit flies which also visited other plant species including flowers of papaya and Colocasia antiquorum, was first discovered almost a century ago (Howlett 1915). Sixty years later, ME was found to be the most active attractant for the oriental fruit fly, Bactrocera dorsalis, when compared with 34 chemical analogs (Metcalf et al. 1975). Since then, about 20 plant species from 16 families were reported to contain ME, and the role of chemicals as plant kairomone in dacine fruit fly ecology has been discussed (Metcalf 1990; Metcalf and Metcalf 1992). Additionally, eight plant species containing 0.1-17.9% ME as a natural constituent, and another seven plant species with ME but without quantitative data, were reported by De Vincenzi et al. (2000). Prior to this review, it was reported that a) ME was present in 20 angiosperm and 3 gymnosperm families (Schiestl 2010); and b) ~350 plant species...
belonging to 61 families possessed ME as a constituent component and/or as a component of floral fragrance (Tan et al. 2011).

2.1. Occurrence of methyl eugenol

From an intensive literature search conducted over the first half of 2011, an additional ~100 were added to the 350 plant species to yield a total of over 450 species from 80 families spanning 38 plant orders that contain varying amounts of ME in essential oils from leaves, roots, stems, flowers, or whole plant extracts. The compiled species are presented here in two separate tables. Table 1 shows over 370 species of plants listed alphabetically from 62 families (one fern, two gymnosperms, four monocots, and 55 dicots) having ME content varying from a trace quantity to 99% of essential oils detected in various plant organs, except flowers (which will be presented in Table 2 in section 3.4). The large number of families involved indicates that biosynthesis of ME evolved independently in many of the Plantae orders and families. Families that are represented by 10 or more species in Table 1, in decreasing order, are Asteraceae (47), Apiaceae (44), Lamiaceae (38), Lauraceae (34), Aristolochiaceae (32), Rutaceae (23), Myrtaceae (20), Poaceae (12), Cupressaceae (10), Euphorbiaceae (10), and Zingiberaceae (10). The ME content varies greatly within and between species as well as within and between the plant families. Several species have ME content over 90% in essential oils, namely Croton malambo (Euphorbiaceae), Cinnamomum cordatum (Lauraceae), Melaleuca bracteata, M. ericifolia, M. leucadendra, M. quinquenervia, Pimenta racemosa (all Myrtaceae), Piper divaricatum (Piperaceae), and Clusena anisata (Rutaceae). Furthermore, 68 species possess ME content between 20 and 90% in essential oils of either a whole plant or a part thereof (Table 1). These plant species are likely to involve ME in their chemical defense against pathogens and/or insect herbivores. Most of the plant species listed in the table are either spices, medicinal plants (many with ethnopharmacological properties), or plants of economic importance, especially in the production of essential oils for aromatherapy and perfumery. As such, many more plant species, currently with little or no anthropocentric importance, may contain ME and await discovery and/or chemical analysis.

Methyl eugenol, as a constituent in leaves, fruits, stems, and/or roots, may be released when that corresponding part of a plant is damaged as a result of feeding by an herbivore. If present in sufficiently high concentration, it will immediately deter the herbivore from further feeding on the affected part (see section 3.2.3). In this case, ME acts as a deterrent or repellent. In many plant species, ME is present along with varying amounts of eugenol—ME’s immediate precursor (see section 3.4.2.2 B). Both the compounds are found in most spices.

For plant species with low ME content, this component may be detected only in certain developmental stages. This is demonstrated by the sweet marjoram, Origanum majorana (Lamiaceae), in which ME was detected during the early vegetative and budding stages of four growth stages investigated (Sellami et al. 2009). Similarly, ME was detected in Artemisia abrotanum (Asteraceae) only during the emergence of runners and mass flowering phases among four studied (Table 1). Nevertheless, in Artemisia dracunculus ME was detected at 6.06, 6.40, 38.16, and 7.82 % of essential oil weight during emergence of runners, budding, mass flowering, and seed ripening phases, respectively (Khodakov et al. 2009).
A native Mediterranean plant species with ethnopharmacological properties, *Erodium cicutarium* (Geraniaceae), was shown to contain a relatively high content of ME (10.6%) in leaf hexane extract (Lis-Balchin 1993). Nevertheless, out of approximately 170 chemical components, many of which existed in trace quantities, ME was not detected in some specimens of the same species (Radulovic et al. 2009). This finding probably reflects geographical variation among varieties or populations and not different extraction methods or chemical analyses.

High variation within a plant species in terms of ME content may lead to the identification of distinct chemotypes. To further illustrate varietal differences in plant species, two common *Ocimum* species (Lamiaceae), *O. basilicum* and *O. sanctum*, which are frequently used for culinary and medicinal purposes in Southeast Asian countries in particular, show distinct variations in terms of ME content. 19 accessions/varieties of *O. basilicum* (sweet basil), two wild and 14 cultivated as ornamentals in Sudan, two from Germany, and one from United Arab Emirates, had varying contents of phenylpropanoids—eugenol, ME, and methyl cinnamate—in combined leaf and flower essential oils. As indicated by peak area in essential oils, 12 varieties had highly variable content of eugenol from 0.05 to 43.3%, and for methyl cinnamate, 11 varieties had content from 1.9 to 42.4%, of which seven had over 15%. However, only one variety had 8.7% ME without the other two phenylpropanoids, and three had ME in trace amounts (Abduelrahman et al. 2009). Nevertheless, two varieties of the sweet basil found in Malaysia had no eugenol, but ME content was at 5.6-12.3% in leaf and 3.2-11.1% in inflorescence essential oils (Nurdijati et al. 1996).

*Ocimum sanctum* (holy basil) also varies considerably in terms of ME and eugenol contents in leaf and inflorescence essential oils. Seven varieties of holy basil in Malaysia and Indonesia can be grouped into three chemotypes based on the phenylpropanoid content in leaf essential oils: two as eugenol chemotypes with 66-73% eugenol and 0.5-3.1 % ME, four ME chemotypes with 78-81% ME and 2.7-5.8 % eugenol, and one ME–eugenol chemotype with 52% ME and 27% eugenol (Nurdijati et al. 1996). The phenylpropanoids in the leaves of both sweet and holy basils are not released naturally. They are stored in the numerous oily glands (characteristic of Lamiaceae (formerly Labiatae)). More glands per unit surface area are found on the lower surfaces of leaves in the basils. Healthy leaves on a plant do not attract male *Bactrocera* fruit flies (see 3.3.1. Insect attractant). However, when any part of the plant (especially the leaves) is damaged or squashed, many male fruit flies are attracted to the damaged part, indicating the release of ME and eugenol. Further, it is very interesting to note that the *O. sanctum* leaf (chemotype unspecified) essential oil has lipid–lowering and anti–oxidative effects that protect the heart against hypercholesterolemia in rats fed with a high cholesterol diet (Suanarunsawat et al. 2010).

Additionally, another species of *Ocimum* in Brazil, *O. selloi*, has two chemotypes. Leaf and flower essential oils of chemotype A contained estragole (methyl chavicol) at 80.7 and 81.8% with ME at 0.79 and 1.13% of peak area, respectively, while chemotype B had ME as the major component at 65.5 and 66.2% of peak area in leaf and flower essential oils, respectively, and with no trace of estragole (Martins et al. 1997).
The same species of plant grown in different countries may show high variation in chemical constituents. This was well illustrated by *Alpinia speciosa* (Zingiberaceae) in which leaves collected from Japan contained ME, estragole, and (E)-methyl cinnamate at 2.9, 4.6, and 24.1% of essential oil. The phenylpropanoids were not detected in leaves that originated from Amazonia (Brazil), Martinique (French West Indies), Rio Grande (USA), and China and Egypt (Prudent et al. 1993).

Furthermore, within a variety of a plant species, the quantity of ME may also vary depending on the plant tissue and on the time of harvest. This is elucidated by *Myrtus communis* var. *italica* (Myrtaceae) grown in Tunisia. The quantity of ME varied from 0.4 to 1.9% of leaf essential oil, with > 1% for October, November, and March over a period of 12 months. The monthly ME content of stem oil varied between 0.8 and 3.6%, with January and April > 3%. However, fruits had monthly ME content of 1.1-1.3% for August and September, which then rose to 3% in subsequent months and remained between 3.1-3.6% from October to January (Wannes et al. 2010).

Even during storage, the major components of essential oils may change considerably. This is shown by *Agastache foeniculum* (Lamiaceae), which contained five major components. During storage of the plants for 17 days, estragole decreased from 63.2 to 50%, with a corresponding increase of ME from 28.6 to 41% in plant essential oil (Dimitriev et al. 1981).

It was shown that green parts of *Proiphys amboinensis* (Amaryllidaceae) leaves contained a trace quantity of ME, and during browning of a leaf, the yellow and brown parts contained 0.1 and 0.2-0.3 µg/mg of leaf, respectively, that attracted many male fruit flies (Chuah et al. 1997). The attraction phenomenon has never been observed in the normal browning of the leaves, except on one occasion after a raining shower when an infected leaf attracted many male fruit flies (ME-sensitive *Bactrocera* species) that fed along a yellow–brown border between the green and yellow to brown parts (Figure 2, unpublished observation). The attractant in the browning phenomenon may be induced or produced by microbes as a result of an infection, and this certainly warrants further investigation.

Besides large variation within species, differences between species within a genus frequently occur. For example, the genus *Heterotropa* (Aristolochiaceae) possesses species with ME content ranging from 0.1 to 50% of volatile oil. Many of the 27 species have ME content below 5% of volatile oil, except for *H. fudzinoi* (11%), *H. muramatsui* (20%), and *H. megacalyx* (50%). Eleven species of *Artemisia* (Asteraceae) have ME in trace quantities (e.g., *A. campestris*), whereas *A. dranunculus* has an ME content of 35.8%. Similarly, high variation in ME content exists for genera *Ocimum* (Lamiaceae), *Cinnamomum* (Lauraceae), and *Melaleuca* (Myrtaceae), in which most species are known to have relatively high ME content (Table 1). Strangely, many species in the genus *Croton* (Euphorbiaceae) contain ME in aerial parts (stems and leaves) except *Croton micrans*, which has ME in flowers but not in leaves (Compagnone et al. 2010).

It was found that shading from the direct sunlight also affected the content of phenylpropanoids in leaves. *Ocimum selloi* seedlings from the same population grown under normal sunlight and two different shadings, blue and red, showed a change in
two phenylpropanoids, estragole and ME. The leaf estragole content under full sunlight, blue shading (with transmittance of 400-540 nm), and red shading (with transmittance of > 590 nm), was 93.2, 87.6, and 86.1% (relative percentage of peak area), respectively. While for leaves, the ME content was 0.6% under full sunlight and 1.1% under both types of shading (Costa et al. 2010).

2.2 Distribution of ME in various plant organs
The distribution of ME among plant organs is never even as illustrated by many of the species listed in Table 1. A Brazilian folk medicine plant, *Kielmeyera rugosa* (Caryophyllaceae), possesses ME only in flowers and not in leaves and fruits; the showy flowers are pollinated by large bees (Andrade et al. 2007). *Valeriana tuberosa* (Valerianaceae), a medicinal plant used as a mild sedative, commonly found in Greece, has eugenol and ME in similar quantities (~0.45% of oil) in inflorescences but none in roots, stems, or leaves (Fokialakis et al. 2002).

Another medicinal plant, bay laurel *Laurus nobilis* (Lauraceae), is known to have antibacterial, antifungal, anti-inflammatory, and anti-oxidative properties. It was reported to contain ME in all its aerial parts but in different quantities, such as 3.1, 11.8, 4.7, and 16 % of flower, leaf, bark, and wood essential oils, respectively (Fiorini et al. 1997). Recently, 10 populations of wild bay laurel found in Tunisia had ME at 13.1-33.6, 6.6-17.8, 1.0-16.8, and 3.9-14.3 percentage composition of essential oil in stems, leaves, buds, and flowers, respectively (Marzouki et al. 2009). In another study on the same species, plants from Turkey had ME content that varied considerably between old and young leaves at 1.2 and 0.2% of volatile composition, respectively, while buds had 0.3% and fruits had 0.1% ME, with no ME detected in flowers (Kilic et al. 2004). Additionally, flowers of *Myrtus communis* var. *italica* (Myrtaceae) contained ME at 4.02% of the essential oil as one of seven major components, but as a minor component in leaves and stems at 0.38 and 0.22% of the essential oil, respectively (Wannes et al. 2010).

The amount of ME emitted from flowers of carob tree, *Ceratonia siliqua* (Fabaceae), varies considerably. Whole hermaphrodite flowers did not emit ME, male flowers emitted 2.8% ME of total volatiles, and female flowers of cultivars Galhosa and Mulata emitted 32 and 1.5% of total volatiles, respectively. In this species, the stamens and stigmas did not emit ME, but the nectar disk (source of most volatiles) of hermaphrodite, male, and female flowers emitted 0.8, 1.7, and 4.7-5.7% ME of total volatiles, respectively (Custodio et al. 2006). Whole flowers of *Clarkia breweri* from some plants emit eugenol, isoeugenol, ME, and methyl isoeugenol, while those for other plants do not emit ME and methyl isoeugenol. For flowers that emit all the four phenylpropanoids, the petals emit on average ME, methyl isoeugenol, and eugenol approximately 2.5, 1.8, and 0.5 µg/flower/24 hours, respectively, without any isoeugenol. In contrast, pistils and stamens emit only a single component of methyl isoeugenol and ME in very low quantities (Wang et al. 1997). This and the preceding examples clearly show that the phenylpropanoids are distributed or released unevenly among different parts of individual flowers. All these species show that distribution or release of ME varies even in different parts of individual flowers.

Fruit of *Myrtus communis* var. *italica* showed variation in many of its 48 volatile components during development and ripening.
As to its ME content, it increased slightly during the initial stage of development when the fruit was green in color from 1.14 to 1.26% (wt/wt) during 30 to 60 days after flowering. Then, ME concentration increased two-fold when the fruits were pale yellow from 3.05-3.30% during 90-120 days after flowering. A slight increase was noted when the fruits ripened and turned dark blue (Wannes et al. 2009).

Calamus or sweet flag, *Acorus calamus* (Acoraceae), is a unique medicinal plant in that, unlike many other species in which ME is mainly found in aerial parts, it has ME in the roots. In this species, aerial parts contained only about 1% ME but root essential oil contained up to 80% ME, particularly in the European and Japanese samples (Duke 1985). In this species, the high ME content may be used as chemical defense against root–feeding insects or nematodes.

The distribution of ME within a plant is clearly uneven. In many species, ME may be detected in a specific plant part but not in other parts. Intraspecific chemical variation may be the result of several phenomena, namely: a) adaptation to different pollinator species, b) random genetic drift, c) adaptation to disruptive learning processes in pollinators among non–rewarding flowers, and d) introgression effects involved in hybridization (Barkman et al. 1997). Another possible phenomenon is the selection pressure exerted by herbivores, microbes, and nematodes in their interactions with plants (see section 3.2).

3. Role of methyl eugenol in plants

There are two main theories on the evolution of secondary plant metabolites. First, due to oxidative pressure and the possibility of photo–damage, plants might have developed secondary plant metabolites with antioxidant properties, namely flavonoids, to prevent cellular damage by highly reactive chemicals (Close and McArthur 2002; Treutter 2005). The second theory states that it arose from the relationship between plants and various groups of herbivores or pathogens (Dicke and Hilker 2003; Franceschi et al. 2005), and this latter view is further substantiated in this review.

3.1. Induction of phenylpropanoid biosynthesis due to stress

Phenylpropanoids form a large subclass of chemical compounds within the class of phenolics. All of them are derived from cinnamic acid/p–coumaric acid, which in turn is derived from phenylalanine, an essential amino acid, catalyzed by an enzyme, phenylalanine ammonia lyase (see 3.4.2.B below). This enzyme is the branch–point enzyme between primary (shikimate pathway) and secondary (phenylpropanoid) metabolisms. Many simple and complex phenylpropanoids may be induced in plants by external stresses, such as high ultra–violet light, pathogen attack, and physical wounding, such as that caused by herbivory (see review by Dixon and Palva 1995). The cytochrome-p450s-dependent oxygenases, belonging to a large plant gene family, are involved in primary metabolism, such as in steroid and phenylpropanoid biosynthesis, and secondary metabolism. A similar phenomenon also exists for O-methyltransferase enzymes that are involved in primary metabolism, namely lignin synthesis and secondary metabolism, such as phenylpropanoid biosynthesis (Pichersky and Gang 2000).

Essential oils of three untreated orange varieties of *Citrus sinensis* (Rutaceae)—Hamlin, Pineapple and Valencia—did not contain any ME. But, when treated with
abscission agents to loosen fruits for mechanical harvesting, six phenylpropanoids, namely eugenol, ME, (E)- and (Z)-methyl isoeugenol, elemicin, and isoelemicin, were detected for the first time. Among these compounds, ME was the most abundant component present at 42 ppb in orange juice from the treated fruits (Moshonas and Shaw 1978). This study clearly shows induction of phenylpropanoid biosynthesis in fruit under stress. The role of ME in the treated orange is unclear, however.

### 3.2. Defense

Plants produce a large diversity of chemical compounds to deter phytophagous organisms, especially against insect herbivores and/or pathogens. These chemicals may exist as plant primary constituents or as secondary by-products/metabolites. They have diverse biochemical and physiological activities against a) pathogenic microbes, b) competitive/neighboring plant species, and c) herbivores. Plant chemical constituents that are not secreted naturally, and affect animal behavior in self–defense by acting as a toxicant, antifeedant, deterrent, irritant, repellent, and/or growth regulator, act as para–allomones (an allomone is a naturally secreted chemical that benefits only the releaser in an interaction between two species of organisms).

#### 3.2.1. Microbes

Essential oils and ME have been known for a long time to possess antifungal activity. ME and eugenol have similar antifungal activity against seven species of fungus at 2.0 mM concentration (Kurita et al. 1981). The essential oil of *Echinophora sibthorpiana* (Apiaceae) contains ME, and the oil (~0.1%) or ME alone (at 0.05-0.1%) showed some inhibitory activity against fungi and bacteria (Kivanc 1988). At temperatures 5-15 °C, 1000 ppm ME delayed mold’s initiation of mycelium and spore development in 32 strains: four of *Aspergillus ochraceus*, two *A. niger*, 16 *Penicillium clavigerum*, and 10 *P. expansum* (Kivanc and Akgul 1990). Furthermore, sprays of 0.5% ME on peanut pods and kernels prevented colonization of *Aspergillus flavus*, common mold, and inhibited aflatoxin synthesis in the fungus. Consequently, it was suggested that ME be used to prevent infestation of the fungus in peanuts (Sudhakar et al. 2009).

Fruit essential oil of emblica, *Phyllanthus emblica* (Euphorbiaceae), that contained 1.25% ME among eight major components had high antimicrobial activity against contaminating microbes, such as: a) Gram–positive bacteria, e.g., *Bacillus subtilis* and *Staphylococcus aureus*; b) Gram–negative bacteria, e.g., *Escherichia coli*, and *Salmonella*; c) molds, e.g., *Aspergillus niger* and *A. oryzae*; and d) the budding yeast, *Saccharomyces cerevisiae*. The antimicrobial activity of the oil was mainly due to the presence of ME, β -caryophyllene, β -bourbonene, and thymol (Zhao et al. 2007). Recently, another fruit essential oil of *Eugenia singampattiana* (Myrtaceae) had major constituents, namely, α -terpineol (59.6%), camphene (12.1%), ME (11.5%), and α- pinene (4.7%). A minimum inhibitory concentration (MIC) at 0.2 µL/mL of the essential oil yielded complete inhibition against *Candida albicans* (a form of yeast that causes infections such as "thrush") (Jeya Johti et al. 2009).

The growth of a strain of *Campylobacter jejuni*, a major bacteria species causing gastroenteritis in humans worldwide, was inhibited by essential oil of carrot, *Daucus carota* (Apiaceae), as well as individual component of ME and elemicin at a MIC of
250 µg/mL, which was slightly less effective than methyl isoeugenol at MIC of 125 µg/mL (Rossi et al. 2007).

3.2.2. Nematodes. The pinewood or pine wilt nematode, *Bursaphelenchus xylophilus*, is very damaging to matsutake mushroom cultivation in addition to causing pine wilt. Nematicidal activities against the nematode were demonstrated with LC50 (lethal concentration that induces mortality in 50% of test organisms) values for geranial, isoeugenol, methyl isoeugenol, eugenol, and ME at concentration of 0.120, 0.200, 0.210, 0.480, and 0.517 mg/mL, respectively (Park et al. 2007).

3.2.3. Antifeedant. Plant ME in the growing bud of *Artemisia* capillaries was found to inhibit feeding (100% antifeeding activity on 2 cm diameter leaf disc) by larvae of the cabbage butterfly, *Pieris rapae* subspecies *crucuvera* (Katsumi 1987). In addition, ME was the most potent of seven eugenol analogs in essential oil of *Laurus nobilis* against a noctuid moth white–speck, *Mythimna unipuncta* (Muckensturm et al. 1982).

A fresh water aquatic plant *Micranthemum umbrosum* (Scrophulariaceae) possesses elemicin, a phenylpropanoid as one of two chemicals used in chemical defenses against herbivores, which acts as an antifeedant against generalist consumers such as crayfish (*Procambarus acutus*). To determine the structure–activity relationship among eight naturally occurring phenylpropanoids, bioassays were conducted and showed that ME was most active and much more effective than either eugenol or elemicin in deterring feeding by crayfish (Lane and Kubanek 2006).

3.2.4. Insects. Of the nine major constituents of essential oils, benzene derivatives (eugenol, isoeugenol, ME, safrole, and isosafrole) are generally more toxic and repellent to the American cockroach, *Periplaneta americana*, than the terpenes (cineole, limonene, p-cymene, and α-pinene). Furthermore, ME was most effective in terms of knockdown activity, as well as repelling and killing effects (Ngoh et al. 1998).

Toxicity of ME against larvae of the tobacco armyworm, *Spodoptera litura*, was found to be significant. Larvicidal activity of a residual ME (15 µg/leaf cm²) was 36.0 ± 15.3% and 76.6 ± 11.5% for 24 and 48 hours of exposure, respectively (Bhardwaj et al. 2010). However, as to mosquitocidal impact, ME, found only in leaves of *Magnolia salicifolia* (Magnoliaceae), induced 100% mortality at 60 ppm against 4th instar larvae of the yellow fever mosquito, *Aedes aegypti*, which is responsible for the spread of dengue fever and Chikungnya viruses (Kelm et al. 1997).

In a fumigation study comparing the toxicity of more than a dozen monoterpenes against the rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae), ME and eugenol were moderately toxic compared to the most toxic compound tested, menthone (Lee et al. 2001). The latter was the main chemical component in *Mentha arvensis* (Lamiaceae) var. *piperascens* essential oil, which in turn was the most toxic among 16 medicinal and spice plants tested. Nonetheless, ME was the most potent inhibitor against the acetylcholine esterase (Lee et al. 2001), an enzyme responsible for the hydrolysis of the neurotransmitter acetylcholine, which can eventually lead to paralysis. Similarly, fruit essential oil of *Illicium simonsii* (Aquifoliaceae) that contained β-caryophyllene (10.30%), δ-cadinene (9.52%), and ME (8.94%) as major components had strong fumigant and contact toxicities against
adults of the maize weevil, *Sitophilus zeamais*, with LC$_{50}$ values of 14.95 mg/L air and 112.74 µg/adult, respectively (Chu et al. 2010). Fumigant and repellant effects, leading to almost 100% mortality within 24 hours, were observed on adult brown plant hoppers, *Nilaparvata lugens*, feeding on rice seedlings placed over a filter paper containing ME residue at ~0.15mg/cm$^2$ (Tan, unpublished data).

It is interesting to note that ME as a fumigant was also very toxic to two global pest fruit fly species—the Mediterranean fruit fly, *Ceratitis capitata*, and the melon fly, *Bactrocera cucurbitae* (a cue–lure/ raspberry ketone [RK] responsive species)—compared with basil oil, linalool, estragole, and (E)-anethole, all of which showed no knockdown effect at 0.75% concentration (Chang et al. 2009). After two hours of exposure to ME at concentrations of 0.5 and 0.75%, mortality/ knockdown was 96 and 100% against *C. capitata* and 98 and 97% against *Ba. cucurbitae*. However, ME was less toxic as a fumigant, even though it was a strong attractant, to the oriental fruit fly, *Ba. dorsalis*. Concentrations of 10-100 % induced 35-53% mortality/knockdown against this species (Chang et al. 2009).

### 3.3 Chemical cue

Certain insect species have adapted to using ME as a stimulant or attractant to locate plant host or source for pharmacophagy (consumption of non–nutritive and non–essential chemicals).

#### 3.3.1 Insect attractant

Some insect species are known to be attracted to ME for unknown reasons, while others may be attracted and stimulated to undergo pharmacophagous feeding.

#### 3.3.1. Pest insect species

Two scarabid pest species, *Cetonia aurata aurata* and *Potosia cuprea*, were captured in traps baited with a known attractant consisting of ME, 1-phenylethanol, and (E)-anethole (1:1:1). However, the numbers trapped were significantly increased for both the species with the addition of a synergist, either geraniol or (+)-lavandulol (Vuts et al. 2010). Larvae of the rice stem borer, *Chilo suppressalis*, are attracted to “oryzanone” (p-methylacetophenone), and ME among 30 compounds related to the “oryzanone” also attracted the larvae (Kawano and Saito 1968). Although ME is not present in rice plants, it may be interesting to evaluate the impact of ME on stem borer physiology and behavior.

Two *Dacus* (currently *Bactrocera*) (Diptera: Tephritidae) species of fruit flies were first discovered to be attracted to citronella grass *Cymbopogon nardus* used as a mosquito repellant (Howlett 1912). Subsequently, ME was positively demonstrated to be solely responsible for the attraction (Howlett 1915). Since then, voluminous publications related to fruit fly attraction to ME have appeared. It should be pointed out at this juncture that all *Bactrocera* species may be categorized into three groups based on their response to two potent attractants: cue–lure, a synthetic analog of RK (195 species cue–lure responders, this chemical being a synthetic of RK) and ME (~84 ME responders), and non–responders to the attractants (28 species confirmed and 258 species listed under “lures unknown”) (IAEA 2003). The effects of the attractants on sexual behavior of *Bactrocera* fruit flies have recently been reviewed (Shelly 2010).

ME acts as a precursor or booster to male fruit fly sex pheromonal component(s) in the rectal gland of certain *Bactrocera* species (Nishida et al. 1988, 1990, 1993; Tan and Nishida...
Plant ME, when released, attracts only male fruit flies, although there are two reports of wild females being attracted into traps baited with poisoned synthetic ME (Steiner et al. 1965; Verghese 1998). The attraction of females was probably due to a chemical contamination—perhaps male sex pheromonal components from spontaneous ejaculation induced by the poisoned bait prior to death of captured males. In contrast, no female Bactrocera dorsalis or Ba. umbrosa was ever attracted to or captured in ME-baited clear-traps, without an insecticide, used in the ‘capture–mark–release–recapture’ technique to capture thousands of live wild males for ecological and population studies in areas with high fruit fly infestation (Tan 1985; Tan and Jaal 1986; Tan and Serit 1988, 1994). These field studies further confirm that pure ME is a male attractant, although ME did induce an electrophysiological response in the antennae of Ba. dorsalis females (Siderhurst and Jang 2006) that may be translated into a negative rather than positive attraction response under natural conditions. Male fruit flies do not directly cause harm or damage to plants by just feeding on ME.

Several putative and ME-sensitive sibling species of the Bactrocera dorsalis complex, such as Ba. carambolae, Ba. caryaeae, Ba. dorsalis, Ba. invadens, Ba. kandiensis, Ba. occipitalis, Ba. papayae, and Ba. philippinensis form the most serious group of pests of fruits and vegetables. Males are strongly attracted to and compulsively feed on ME, which acts as a) a sex pheromone precursor in Ba. dorsalis and Ba. papayae—the latter shown to be neither distinct biological nor genetic species from the former (Naeole and Haymer 2003; Tan 2003; Zimowska and Handler 2005), in which ME is converted mainly to (E)-coniferyl alcohol and 2-allyl-4,5-dimethoxyphenol (Nishida et al. 1988; Tan and Nishida 1996, 1998; Hee and Tan 2004); and b) a booster component to endogenously produced sex pheromone in Ba. carambolae, where it is biotransformed to only (E)-coniferyl alcohol (Tan and Nishida 1998; Wee et al. 2007). Recently, it was reported that the extremely invasive species in Africa, Ba. invadens, and in the Philippines, Ba. philippinensis, convert consumed ME to the same ME metabolites in similar ratio as Ba. dorsalis, and they belong to the same species clade, while Ba. zonata biotransformed ME to 2-allyl-4,5-dimethoxyphenol and (Z)-coniferyl alcohol, and Ba. correcta to (Z)-3,4-dimethoxycinnamyl alcohol and (Z)-coniferyl alcohol (Tan et al. 2011 a,b).

Consumption of ME has been shown to significantly improve male mating competitiveness in Ba. dorsalis (Shelly and Dewire 1994, 2000; Tan and Nishida 1996, 1998), Ba. carambolae (Wee et al. 2007), Ba. correcta (Orankanok et al. 2009), and Ba. zonata (Quilici et al. 2004; Sookar et al. 2009). Wild fruit fly males have easy access to natural sources of ME (Tan 2009). Therefore, it would be desirable to feed sterile males with ME in order to compete with wild males “on a level playing field”, before mass release so as to enhance mating success in a sterile insect technique (SIT) program (Shelly et al. 2010).

3.3.1.2. Beneficial insect species. The green lacewing, Ankylopteryx exquisite, was attracted to ME-baited traps set up in two locations in central Taiwan in large numbers (350-800 adults/trap/two weeks during July) (Pai et al. 2004). Additionally, adults of another lacewing, Chrysopa basalis, were captured in plastic traps containing ME (Suda and Cunningham 1970). The reason for their attraction to ME for these predatory insects is
still unclear. This is also the case for the weak attraction of honeybees, *Apis mellifera*, to traps baited with ME in high elevation native forest in Hawaii. The number captured varied with seasons, and it was found that more honeybees were captured in March and between June and August (Asquith and Burny 1998). The numbers trapped certainly did not reflect capture due to chance. Therefore, could the worker honeybees be mistakenly guided into ME traps through previously learned odor of ME resembling floral fragrance of golden shower or other flowers (see below)? Perhaps this question may be satisfactorily answered through proper electrophysiological and chemoecological investigations.

3.4 Methyl eugenol in flowers—ME as attractant and floral reward

Many plants, besides fending off insect herbivores, may require insects to assist in pollination. Recently, Knudsen et al. (2006) reviewed many aspects of floral scent with respect to variation within and between congeneric species belonging to a genus. They listed 12 common compounds, namely limonene, (E)-ocimene, myrcene, linalool, a- and b-pinene, benzaldehyde, methyl 2-hydroxybenzoate, benzyl alcohol, 2-phenylethanol, caryophyllene, and 6-methyl-5-hepten-2-one that are detected in floral scent from over 50% of seed plant families, and also provided a list of 1719 compounds identified from floral fragrances. ME was among the compounds listed and was detected in 21 plant families. Nonetheless, many more plant species produce flowers that possess ME that may be released as a component in floral fragrance. Table 2 shows ~122 species from 42 plant families, many of which (~85 species from 22 families) have ME detected exclusively in flowers or floral fragrances. This further substantiates the notion that synthesis of floral ME evolved independently in different plant families and orders. However, 27 species, namely *Cuminum cyminum*, *Daucus carota*, *Pimpinella affinis*, and *Scandix iberica* (Apiaceae), *Achillea conferta*, *Solidago odora*, and *Tagetes lucida*, (Asteraceae), *Borago officinalis* (Boraginaceae), *Medicago marina* (Fabaceae), *Agastache foeniculum*, *Ocimum basilicum*, *O. gratissimum*, *O. sanctum*, *O. selloi*, *O. suave*, and *Rosemarinus officinalis* (Lamiaceae), *Laurus nobilis* (Lauraceae), *Michelia alba* (Magnoliaceae), *Myrtus communis* and *Syzygium aromaticum* (Myrtaceae), *Piper betel* (Piperaceae), *Cymbopogon flexuosus* (Poaceae), *Rosa damascena* and *R. hybrida* (Rosaceae), *Tamarix boveana* (Tamaricaceae), *Daphne genkwa* (Thymelaceae), and *Lippia alba* and *Lippia schomburgkiiana* (Verbenaceae) also have ME detected in other plant parts (Tables 1 and 2).

Except for several species, neither the role of ME in flowers nor the attraction of fruit flies was mentioned in the published articles. However, if ME is released naturally in an area where *Bactrocera* fruit flies are present, the flowers would have attracted the ME–responsive *Bactrocera* species.

Much of the published work on floral chemical composition with detected ME did not indicate the type of floral visitors or pollinators. While some species of *Dianthus* (Caryophyllaceae) had flowers that bloom at night, these flowers attracted nocturnal insects, such as moths, and bats as visitors/pollinators (Jurgens et al. 2003). Mediterranean flowers of *Dianthus arenarius*, *D. monspessulanus*, *D. superbus*, and *Silene officinalis* are whitish in color and strongly scented (especially during the night), indicating pollination by night–active flower visitors. Another species, *Silene latifora*, in the same family bears night flowers. The
flowers from a European population had no detectable ME, whereas those collected from some plants in a North American population had detectable ME. However, the flowers did not exclude diurnal flower visitors, because unlike some nocturnal *Silene* species, they did not close or wilt during the day following anthesis. Nevertheless, there were clear differences in the floral scent of diurnal butterfly–flowers and moth– or hawkmoth–pollinated nocturnal species. According to Jurgens et al. (2003), the phenylpropanoids such as ME, methyl isoeugenol, elemicin, (Z)-asarone, and (E)-asarone were only found in the nocturnal *Dianthus* species.

Flowers from other families, similar to those of the family Caryophyllaceae, may attract other insects in regions/countries without ME–responsive *Bactrocera* species. Therefore, these flowers are not specifically adapted to fruit fly pollinators even though they possess ME.

### 3.4.1. ME in flowers with unknown purpose

From 16 *Clusia* species (Clusiaceae) under four different taxonomic sections, only two species, *C. parviflora* (section Criuva) and *C. renggerrioides* (section Corylandra) possessed floral ME (Nogueira et al. 2001). The role of ME in the two species is still unknown. This is similar to the often–cited flowers of golden shower or Indian labernum, *Cassia fistula*, that contained ME and attracted the oriental fruit fly, *Ba. dorsalis* (Kawano et al. 1968). Recently, the flower essential oil was reported to contain ME at 7.3% of peak areas and trace amount of eugenol; these compounds were not detected in leaf oil (Tzakou et al. 2007). Unfortunately, there is still no report that the attracted fruit flies are either potential pollinators or just visitors.

In the family Orchidaceae, many species are known to have trace quantities of ME. Since some of them are known to exist in regions with no insect species that are specifically attracted to ME or flowers in the night (Table 2), it is obvious that the ME–sensitive *Bactrocera* species play no role in pollination. However, flowers of the Malayan type of *Phalaenopsis violacea* possess trace quantities of ME and eugenol (Kaiser 1993), and usually attract one to several fruit flies per flower. The trace amount of floral ME is sufficient to attract fruit flies, since ~ 1 nanogram (10⁻⁹ g) of ME spotted on a silica gel TLC plate placed in the field can attract native male flies of the ME–sensitive species, such as *Ba. dorsalis* (Tan and Nishida 2000). The Bornean type of this orchid species, which is currently placed as a different species, *P. bellina*, has none of the phenylpropanoids (Kaiser 1993), although *Cymbopogon flexuosus* (Poaceae) exists as four varieties based on the major component among approximately 75 constituents in inflorescence essential oils. The varieties of *C. flexuosus* (var. arunachalis, var. assamensis, and var. sikkimensis) had citral, citronellol, elemicin, and ME as the major component, respectively. The first two varieties did not possess floral ME. The var. sikkimensis had 32-34% floral ME, while var. assamensis had 0.2-0.4% of essential oils (Nath et al. 2002). As such, the former variety would be more attractive to ME–responsive *Bactrocera* species than the latter. Nevertheless, this attraction of fruit flies as either pollinators or visitors remains to be determined for the two varieties. This is expected as most floral fragrances contain many chemical components (sometimes well over a hundred), and to ascribe the actual role for each of the ingredients, especially those in trace quantities, is extremely difficult, time consuming, and often unrewarding.
their flowers appear very similar in terms of color pattern and morphology to the untrained eye. As such, the observed attraction of fruit flies to *P. bellina* was probably due to the presence of 2,6-dimethoxy-4-(2-propenyl)-phenol. This compound was emitted as a component of floral fragrance at a rate of 12.0 ± 8.5 ng/flower/hour (Hsiao et al. 2006). It is an isomer of 2-allyl-4,5-dimethoxyphenol, which is a relatively strong fruit fly attractant and a component of the oriental fruit fly sex pheromone after ME consumption. Interestingly, *P. violacea* has no special adaptation, such as a movable lip as in *Bulbophyllum* orchids (see section 3.4.2.2 B), to aid in the removal of pollinarium (a composite structure of pollinia containing numerous pollens, a tegula/hamulus stipe, and visidium). This is further substantiated by our observations that the ME–sensitive fruit fly males never removed pollinarium from flowers of *P. violacea*, are mere visitors, and thus do not assist in pollination for this orchid species.

It has been proposed that an additional role of floral fragrance may be in defense to deter or repel insect herbivores/florivores, as many of the floral volatile compounds are also released from leaves in response to herbivore damage (Kessler and Baldwin 2001). This is further substantiated by ME, which is used by plants as a chemical defense as previously discussed in section 3.2. Therefore, floral ME, which appears not to have any specific function in pollination, may be playing a 'silent' role in deterring and/or repelling possible insect florivores.

### 3.4.2. In pollination

Floral fragrance is presumably for the sole purpose of guiding potential pollinators to perform pollination that results in fertilization of flowers. The presence of ME in floral fragrances, even in trace quantities, may be responsible for attracting potential *Bactrocera* pollinators in the tropical/subtropical regions where the ME–responsive species of fruit flies are endemic.

#### 3.4.2.1. For non–orchid flowers

The fruit fly lily *Spathiphyllum cannaefolium* (Araceae) floral spadix has a high content of ME (Lewis et al. 1988), which attracts many ME–sensitive *Bactrocera* male flies to visit and pollinate the flower by transferring white powdery pollens as the flies feed on the spadix. Plants grown in Penang (Malaysia) often attract one or two fruit fly males (Figure 3) as well as stingless bees (*Trigona* species) for pollination (unpublished observation).

Another Araceae species, *Colocasia esculenta*, which contained ME and eugenol (relative quantities not provided), attracted many male *Ba. dorsalis* fruit flies (> 40) to the spadix and bract (Sinchaisri and Areekul 1985). In this species, only the fruit flies feeding on the spadix will pick up powdery pollens and transfer them to the stigmas on the radix.

Flowers of the cannon ball tree *Couroupita guianensis* (Lecythidaceae) contained 3% eugenol with a trace quantity of ME in floral essential oil (Knudsen and Mori 1996). Flowers in tropical South America have been observed to attract many male *Ba. carambolae* fruit flies in Suriname (photograph shown by van Saurers-Muller, personal communication, 2010). However, the flowers obtained from trees grown in the Botanical Garden in Penang have eugenol and no detectable ME, and they attract many stingless bees (*Trigona* species) with an occasional *Ba. dorsalis* as a visitor (unpublished observation).
Paraguay jasmine, *Brunfelsia australis* (Solanaceae), commonly known as "Yesterday–Today–and–Tomorrow", has floral fragrances comprised of monoterpenoids (81% of the identified volatile compounds), with ME in trace quantity in young flowers and 0.1% content of mature flowers. But in the scentless mature flowers of a closely related species, *Brunfelsia pauciflora* (Fabaceae), two sesquiterpenes (γ-muurolene and α-copaene) were present with no detectable ME (Bertrand et al. 2006). Similarly, the only species in the Onagraceae family that emits a floral scent containing substantial ME is *Clarkia breweri* (Table 2); its closely related *Clarkia concinna* is virtually scentless with no detectable ME (Raguso and Pichersky 1995).

### 3.4.2.2. For orchid flowers

Orchids have evolved highly diverse and fascinating mechanisms to attract and entice animals, especially insects, to assist in cross–pollination. In this section, discussion will be confined to orchid flowers that possess or secrete ME that attracts insects to be pollen vectors.

#### 3.4.2.2a. Orchids excluding *Bulbophyllum*

Orchid flowers of *Satyrium microrrhynchum* produce nectar and are visited by several species of flower–visiting insects such as beetles, wasps, and flies, but not various honeybees and solitary bees that are commonly present at the study sites. Two insect species, cetonid beetles, *Atrichelaphinus tigrina* (both sexes) and a pompilid wasp, *Hemipepsis hilaris* (males), have been shown to be pollinators while the other insect visitors do not carry any pollinarium (Johnson et al. 2007). Linalool is the major chemical component in the orchid fragrance and has been shown to attract the pollinators. Although seven phenylpropanoids with ME (at 1.83-4.51%) as the highest component were detected in the flowers from one of three populations studied in South Africa, there was no difference in the type of insect visitors/pollinators observed, as ME also stimulated an electrophysiological response in antennae of the cetonid beetle (Johnson et al. 2007).

The inflorescence of an orchid species, *Gymnadenia conopea*, emits both eugenol and ME at different relative quantities during the day and night (Table 2). It attracts six lepidopteran taxa: three species each of butterflies and moths. Among the lepidopteran visitors caught, two species each of butterflies and moths bore pollinia. This indicates that pollination occurs during the day as well as at night (Huber et al. 2005). Similarly, a closely related species, *Gymnadenia odoratissima*, has 10 lepidopteran taxa, six moth, and four butterfly species as floral visitors, and all the species have been observed to be pollinators confirmed via their bearing of pollinia. There is no overlap of pollinator species between the two orchid species, and eugenol and benzyl acetate, which are among several of the 44-45 volatiles, are physiologically active components in the floral scent of the two species (Huber et al. 2005). In these orchid species, ME is not physiologically active against the lepidopteran species attracted to the orchid flowers and may instead be playing a role in deterring florivores. This certainly warrants further investigation.

#### 3.4.2.2b. Bactrocerophilous *Bulbophyllum* orchids

There are nearly 2000 recognized species of *Bulbophyllum* (Orchidaceae) worldwide. Some species (~30) are known to have adapted to, and are entirely dependent on, *Bactrocera* (Tephritidae: Diptera) fruit flies for pollination without offering the usual nectar as floral reward. These
bactrocerophilous *Bulbophyllum* species might have coevolved with the tephritid fruit flies. They basically make use of either RK, detected in *Bu. apertum* (syn. *Bu. ecornutum*) (Tan and Nishida 2005), zingerone in *Bu. patens* and *Bu. baileyi* (Tan and Nishida 2000, 2007), or ME (examples given below) as a floral attractant and reward for male *Bactrocera* fruit flies (Tan 2009). It is interesting to note that zingerone is the only known compound to attract both RK– and ME–responsive *Bactrocera* species, although it is a relatively weak attractant due to its resemblance to both RK and ME chemical structures (Tan and Nishida 2000).

The possible pathway for the biosynthesis of ME found in *Bulbophyllum* is shown in Figure 4. Starting from phenylalanine, it undergoes a series of intermediary steps involving cinnamic acid, ferulic acid, coniferyl alcohol, coniferyl acetate, and eugenol (Figure 4) (Kapteyn et al. 2007; Ferrer et al. 2008). The eugenol is ultimately biotransformed to ME by the addition of a methyl group to the 'para–hydroxy' group of eugenol catalyzed by an O-methyltransferase (Lewinsohn et al. 2000; Pichersky and Gang 2000).

Here only *Bulbophyllum* flowers that possess and release ME as a component of floral fragrance will be discussed to show that the flowers of some species have coevolved, via special floral architectural modifications to enhance fly pollination, with *Bactrocera* male flies. A nonresupinate flower (with lip/labellum above the floral column) of the ginger orchid, *Bu. patens*, possesses a major component of a fruit fly attractant, zingerone, which is weakly attractive to *Bactrocera* males from both ME–responsive species, such as *Ba. carambolae*, *Ba. dorsalis* and *Ba. umbrosa*, as well as RK–responsive species, namely *Ba. caudata*, *Ba. cucurbitae*, and *Ba. tau*, with trace amounts of ME (Tan and Nishida 2000). It has a see–saw lip that is positioned in a plane above the floral column. When an attracted male *Ba. dorsalis* alights on and continues feeding along the lip, an imbalance will occur, and the fly will suddenly be tipped into the column cavity head first. The fly immediately retreats by moving backwards along the lip still in a closed position, and during this movement it removes the pollinia to initiate pollination. This process is repeated when a fly bearing pollinia lands on another flower (Figure 5) to initiate fertilization by depositing the pollinia onto the stigma.

The fruit fly orchid, *Bulbophyllum cheiri*, with non–resupinate and a solitary flower, does not have its sepals and petals fully spread out but just slightly parted when fully in bloom (Figure 6). It releases ME as its sole major volatile component in its floral fragrance, which attracts only male fruit flies (Tan et al. 2002). The concentration of ME in the various floral parts varies from 107, 95, 91, 44, and 41 ppm for lateral sepals, lip, petals, median sepal, and column, respectively (Tan et al. 2002). Further surveys identified seven more related analogs, including eugenol, (Z)-methyl isoeugenol, (E)-methyl isoeugenol, (E)-coniferyl alcohol (CF), 2-allyl-4,5-dimethoxyphenol (DMP), 5-allyl-1,2,4-trimethoxybenzene (euasarone), and (E)-3,4-dimethoxycinnamyl acetate (Nishida et al. 2004). It is interesting that the two major sex pheromonal components of *Ba. dorsalis*, CF and DMP, are also found in the orchid flowers. Many male flies of *Ba. dorsalis* with one or two *Ba. umbrosa* visit a newly bloomed flower in the morning. Usually, the first fly visitor removes the pollinia from the flower (Figures 6 and 7). Here the movable floral see–saw lip plays an important role in suddenly tipping a probing fly into the floral
column cavity when an imbalance occurs due to the shifting of the fly's weight. This way the fly, during its retreat, either removes or deposits pollinia on the floral stigma. Headspace analysis of the flower indicates a high ME peak in the morning, a much smaller one between 12:00 and 14:00, and no ME detected after 14:00 (Tan et al. 2002). In spite of this, one or two male *Ba. dorsalis* flies can still be seen on a *Bu. cheiri* flower up until approximately 18:30 (personal observations).

The wine red orchid, *Bu. vinaceum*, bears resupinate (lip/labellum below the floral column) and a solitary flower, which has a spring–loaded lip kept in a closed position to protect its sexual organs, especially the pollinarium with a stiff hamulus (derived from the entire distal portion of the rostellum that is prolonged into a stalk). The major floral volatile components identified are ME, CF, DMP, and (E)-3,4-dimethoxycinnamyl acetate, whereas the minor components are eugenol, euasarone, (E)-3,4-dimethoxy cinnamyl alcohol, and (Z)-coniferyl alcohol. The bouquet of floral phenylpropanoids attracts ME–sensitive species, particularly *Ba. dorsalis* with one or two *Ba. unimacula* in the highlands of Sabah (Tan et al. 2006). An attracted male fly normally lands on one of the petals before climbing onto and forcing the “spring loaded” floral lip that has the highest concentration of the phenylpropanoids, into the open position. This action reveals the floral sexual organs. The architecture of the lip and location of attractants compel the fly to align itself precisely along the lip’s longitudinal axis. As the fly probes and feeds, it passes the point of imbalance, causing the lip to spring back to its normal closed position. This catapults the fly head first into the column cavity, and its dorsum strikes the protruding sticky base of the hamulus and adheres to it. The momentum of the fly and the structural morphology of the long stiff hamulus act in tandem to pry out the pollinia from its anther cover. Pollinarium removal (Figure 8) is a precise and very quick process assisted by the specially modified spring lip, which plays an essential and important role in pollination. In this orchid species, ME is the main component in the floral fragrance and plays a pivotal role in the true mutualism between the flower and fruit fly pollinator, in which both receive reproductive benefits. Interestingly, both CF and DMP detected in the flowers are also sex pheromonal components of male *Ba. dorsalis* after consuming ME. Although CF and DMP attract and arrest females during courtship at dusk, and thus would serve as specific female attractants, the flower has never been observed to attract female fruit flies, not even during dusk when they are most sensitive to these chemicals (Tan et al. 2006). This evidence, and that of *Bu. cheiri*, may substantiate and indicate the outcome or culmination of a co–evolutionary process between the orchid species and *Bactrocera* pollinators.

The 'raised dot Bulbophyllum', *Bu. elevatopunctatum*, has relatively high content of ME 78.5 ± 21.6 mg (mean ± standard deviation; n = 10) per flower as a major floral volatile (unpublished data). The solitary and resupinate flower does not have a spring—loaded lip like that present in *Bu. vinaceum*, but a simple hinged one kept at an acute angle with respect to the floral column by the fused lateral sepals. When an attracted male fruit fly moves on to the lip that is prevented from moving away from the column to a fully opened position, it will very quickly be jerked into the floral column cavity, thereby hitting the hamulus and dislodging the pollinia from the anther and its cover. Upon its retreat, the
fly removes the pollinarium to initiate pollination (Figure 9).

In the aforementioned *Bulbophyllum–Bactrocera* association, each *Bulbophyllum* species has specifically adapted and evolved precise lip mechanism to entice fruit flies and enhance pollination through the offer of ME as an attractant as well as a floral reward. Furthermore, both organisms gain direct reproductive benefits, exhibiting a true mutualism; the orchid flower gets pollinated without having to offer nectar as reward, and the fruit fly boosts its pheromone and defense system as well as its sexual competitiveness by feeding on the ME produced by the flower as floral reward to its potential pollinator.

4. Methyl eugenol and human health

When present in human blood serum after a meal, ME is rapidly eliminated and excreted (Schecter et al. 2004). ME has ill effects on human health as a known carcinogen and mutagen, probably because of its conversion to a hydroxy analog at the allylic position (De Vincenzi et al. 2000). Further, safrole, estragole, and ME found in herbs and spices are weak animal carcinogens as demonstrated by the formation of DNA adducts in cultured human cells (Zhou et al. 2007).

Recent research by Choi et al. (2010) indicated that ME may have positive effects on human health as well. Based on their studies, ME may reduce cerebral ischemic injury through suppression of oxidative injury and inflammation (Choi et al. 2010). The chemical also decreased activation of an enzyme, caspase-3, and the death of cultured cerebral cortical neurons through oxygen–glucose deprivation for one hour. Additionally, it was shown that ME elevated the activities of superoxide dismutase and catalase, thereby markedly reducing superoxide generation in the ischemic brain and decreasing intracellular oxidative stress. Furthermore, ME also reduced the production of pro–inflammatory cytokines in the ischemic brain (Choi et al. 2010).

Studies on rodents showed that minimal ME within a dose range of 1-10 mg/kg body weight, which is about 100-1000 times the anticipated human exposure to ME as a result of spiced and/or flavored food consumption, did not pose a significant cancer risk (Smith et al. 2002). Further, toxicological studies in animals demonstrated that orally administered relatively high–bolus doses of ME resulted in hepatic neoplasms. Nevertheless, the detected level of ME in biomonitoring studies indicated that human exposure was several orders of magnitude lower than the lowest dose utilized in the bioassay (Robison and Barr 2006). Arguably, a single high dose may cause any number of ill or side effects in animals.

Conclusions

In this review, the occurrence of ME in over 450 species of plants belonging to 80 families under 48 orders compiled from numerous published papers is listed. The distribution of ME in various plant organs within a species is definitely uneven and varies greatly according to growth stage as well as plant variety/chemotype. Similarly, even in flowers, the distribution and release of ME by various floral parts can vary considerably depending on the physiological stage and time of day.

The various roles of ME in nature especially related to the chemical defense of plants, such as antifungal, antibacterial, antinematodal, or toxicant roles against pathogens and insect herbivores, as well as its functions as an insect antifeedant/repellant and in pollination are
reviewed. In particular, ME has been shown to act as floral synomone in the coevolution of orchid species in the genus Bulbophyllum with fruit flies. More research should be conducted to fully understand the biochemical, physiological, and/or chemoecological basis for these bitrophic interactions between plants and insects mediated by ME.

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Figure 1. Chemical structures of methyl eugenol (ME) and its analogs. High quality figures are available online.

Figure 2. Male fruit flies (*Bactrocera dorsalis* and *Bactrocera umbrosa*) feeding along yellow–brown border of an infected leaf of *Proiphys amboinensis*. High quality figures are available online.

Figure 3. A male *Bactrocera umbrosa* feeding on *Spathiphyllum cannafolium* spadix. High quality figures are available online.

Figure 4. A possible biosynthetic pathway of methyl eugenol in an orchid flower of a bactrocerophilous *Bulbophyllum* species. PAL, phenylalanine ammonia lyase; CCR, cinnamoyl-CoA reductase; CAD, cinnamyl alcohol dehydrogenase; CFAT, coniferyl alcohol acyltransferase; EGS, eugenol synthase; EOMT, eugenol O-methyltransferase. High quality figures are available online.

Figure 5. A male *Bactrocera dorsalis* bearing pollinia on see-saw lip of *Bulbophyllum patens*. High quality figures are available online.
Figure 6. Male fruit flies, *Bactrocera dorsalis*, congregating and licking on a fully bloomed *Bulbophyllum cheiri* flower. High quality figures are available online.

Figure 7. Male *Bactrocera dorsalis* bearing pollinia of *Bulbophyllum cheiri*. High quality figures are available online.

Figure 8. Flower of *Bulbophyllum vinaceum* with its spring-loaded lip in a closed position and a pollinarium-bearing fruit fly, *Bactrocera dorsalis*. High quality figures are available online.

Figure 9. A male *Bactrocera dorsalis* bearing a pollinarium just removed from the *Bulbophyllum elevatopunctatum* flower (P.T. Ong). High quality figures are available online.
Table 1. Plant family (order) and species containing methyl eugenol (ME)*.

| Species (Synonyms) | Common name | Remark** | Reference |
|--------------------|-------------|----------|-----------|
| *Acantus* (Megastomata) | *Acanthaceae* - *Acanthus* family (Lamiales) | Plant attracts the oriental fruit fly and volatile oil contained 8.0% ME. | Kishihara & Naito 1980 |
| *Stratiotes* (Garrica) | *Stratiotes* (Garrica) | Benzylidene leaf stem at pre- and post-flowering stages had ME 0.01 and 0.16% of EO, resp. | Wayant et al. 1992 |
| *Aceraceae* - *Calamo* family (Araliaceae) | *Acer* calamus | ME 35% (1.9%) plant EO had 1.9% ME, root EO of up to 80% ME in European & Japanese samples. | Severin et al. 1977, De Vincenzi et al. 2006, Dain 1985 |
| *Aceraceae* - *Calamo* family (Araliaceae) | *Acer* calamus (L.), *Ficus* (C.aurantia) | ME (84.5%) in EO from chinensis. | Koo et al. 2003 |
| *Amaranthaceae* - *Amaranthus* family (Amaranthaceae) | *Allium* cepa | Green leaf had ME in it, but during leaf growing, yellow and brown parts had 0.1 and 2.5% piperine. | Chua et al. 1997 |
| *Amaranthaceae* - *Sida* family (Amaranthaceae) | *Allium* cepa (L.) | Leaf EO contained ME, Fruit EO of 10 from 26 Cvs had ME in it. | Covino & et al. 1990, Piao et al. 2005 |
| *Pinaceae* (Mastix) | *Pinus* elliottii | ME of needle EO from 4 areas tr and 0.18% in another area in Sardinia, Italy, leaves and fruits had ME at 1.97 & 0.79% of EO, resp. | Barra et al. 2007, Finch & Hushar 1992 |
| *Ficus* (Mastix) | *Ficus* microcarpa | ME (6.3%) in EO from chinensis. | Adey et al. 1991 |
| *Annonaceae* - *Custard-apple* family (Magnoliaceae) | *Annona* squamosa | ME tr amount in fruit volatiles. | Piao et al. 2002 |
| *Annona* squamosa (L.) | ME 2.3% of leaf EO. | Brey et al. 1997 |
| *Copaifera* (Mastix) | *Copalium* grandiflorum | ME 1.4% & 4.0% in bark and leaf EO, resp. | Fournier et al. 1997 |
| *Parasolus* (Mastix) | *Parasolus* grandiflorum | ME (64%) as major component. | Brey et al. 1997 |
| *Amaranthaceae* - *Custard-apple* family (Magnoliaceae) | *Amaranthus* (L.) | ME detected. | Degen 1998 |
| *Amaranthaceae* - *Custard-apple* family (Magnoliaceae) | *Amaranthus* (L.) | ME 0.3% of EO only in leaves of 1 of 4 populations of *Amaranthus* (Magnoliaceae). | Katsumi et al. 2001 |
| *Amaranthaceae* - *Custard-apple* family (Magnoliaceae) | *Amaranthus* (L.) | ME of 3.2% of EO, but ME 9.9% of EO. | Sato et al. 2002 |
| *Amaranthaceae* - *Custard-apple* family (Magnoliaceae) | *Amaranthus* (L.) | ME of 9.9% of EO, but ME 3.2% of EO. | Sato et al. 2002 |
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| *Amaranthaceae* - *Custard-apple* family (Magnoliaceae) | *Amaranthus* (L.) | ME of 9.9% of EO, but ME 3.2% of EO. | Sato et al. 2002 |
| Plant Name                  | Description                                                                 | Reference                          |
|----------------------------|-----------------------------------------------------------------------------|------------------------------------|
| *Pimpinella barbata*       | Aerial parts contained ME & alismicin at 34% & 6.9% of EO, resp.             | Fakhrui & Soebol; 2006              |
| *Pimpinella acrylina*      | Sam & leaf EO contained 0.1% ME                                             | Tabacans et al. 2005a               |
| *Pimpinella obtusata*      | Leaves contained ME at 70.6% of EO                                         | Tabacans et al. 2005b               |
| *Pimpinella polyacta*      | Fruit & leaf & stem EO had 23.1% & 29.6% ME, resp. Leaf EO has ME 23.1% of oil. | Tabacans et al. 2005c,b             |
| *Pimpinella rhodocephala*  | Leaves had <5% ME of EO                                                    | Tabacans et al. 2005b              |
| *Pterisanthus scoparius*   | Stem EO had ME (5.6%) as 1 of 4 major components, seed & stem EE had 1.6 & 5.9% ME, resp. | Verite et al. 2004, Bouttargane et al. 2004 |
| *Ferocarbonea gulosissima* (Anahuama* ramusissima) | Seed EO (15%) - with ME, Root, aerial parts and seeds had 0.4, 0.3-0.7 and 1.0% of EO, resp.  | Bolanton & Kleinman 1977, Sokovic et al. 2008 |
| *Pungoos epilobioides subsp. hansinaensis* | ME (0.6%) of fruit EO                                                        | Sajadi et al. 2003                  |
| *Pungoos florindea*        | Fruit EO contained ME (0.07%).                                             | Masumura et al. 2007               |
| *Pungoos florindea*        | Fruit EO from two localities - one had 0.1% ME, but none in the other.      | Basler et al. 2000                  |
| *Pungoos recidivans*       | ME at 2.2% of fruit EO                                                      | Ouvet et al. 2000                   |
| *Scatophyris scutata*      | Fruits contained estragole (90.5% of EO) with 0.2% ME.                      | Kaya et al. 2007                    |
| *Semenovia tridenticola*   | ME (9%) of aerial parts EO.                                                 | Masoudi et al. 2002                 |
| *Thapsia melastoma*        | ME (55-65%) major component in fruit EO of two plant types, ME 6.4% in type II & none in type I plants. | Avato et al. 1992, Avato & Smitt 2000 |
| *Thapsia villosa*          | Polyphloid plants of type 4 & 5 with 2n ~ 44 & 66, resp, had ME and limonene as major components via TLC; ME varied from 0.03 to 0.04% in fruit EO, whereas type 5 had 33-66% ME, ME in 5 tetralong & 4 hexaploid specimens at 33.3 - 66.1% & 45.7 - 62.5%, resp. | Smitt 1995, Avato et al. 1996a, Avato et al. 1996b. |
| *Turubonea amara* (Melanocollina amara) | Trace quantity of ME in fruit EO from same specimens in Cape Verde Islands. | Grosso et al. 2009                  |
| *Turubonea antralba*       | Trace quantities of ME in fruit EO from same specimens in Cape Verde Islands. | Grosso et al. 2009                  |
| *Trachyspermum capitatum*  | ME in quantity in dried fruit EO                                            | Chaiwala et al. 1993                |
| *Zescheria parviflora*     | ME (0.4%) in EO of dried aerial parts                                       | Yusa et al. 2003                    |
| *Aspynaceae - Daphne family (Gennulina)* | ME (0.0%)), eugenol (0.3%) and (Z)-methyl-1-isoeugenol (0.2%) in root EO. | Miyazawa et al. 2004                |
| *Aquilegialea - Holly family (Aquifoliaceae)* | ME (98%) of 5 major components of leaf EO, ME not detected, isorhodin methylxyloglucanol (0.5%). | Cook & Howard 1966, Kim et al. 2009 |
| *Bilicium asiaticum* (L. Willd) *japonicum* *j. shikiumi* & *j. sutori* | ME (98%) of 5 major components of leaf EO, ME not detected, isorhodin methylxyloglucanol (0.5%). | Cook & Howard 1966, Kim et al. 2009 |
| *Bilicium brevifolium*     | ME detected in fruit EO                                                      | Howe et al. 2000                    |
| *Bilicium kiwokolubali*    | Fruit EO contained ME (~0.1 to 2.1%).                                       | Howe et al. 2000                    |
| *Bilicium purpureiflorum* (Swamp star anise, Yellow star anise tree) | Leaf and branch EO dominated by 68 14 ± 0.88% safrole, 13.18 ± 0.01% limonene, and 11.89 ± 0.87% ME. | Tucker and Masaroue 1997            |
| *Bilicium samarae*         | 8.9% ME & 1.8% elemicin in fruit EO                                         | Chu et al. 2010                     |
| *Bilicium variegatum*      | Fruit EO contained trans-anethole (90.1%) and ME (0.4%).                   | Hussain et al. 1990                 |
| *Aristolochiaceae - Birthwort family (Piperaceae)* | ME 11% in volatile oil.                                                      | Saito et al. 1967b                  |
| *Asarum canadense*         | ME 15% in volatile oil                                                      | Saito et al. 1967b                  |
| *Asarum densiclavus*       | ME 15% in volatile oil                                                      | Saito et al. 1967b                  |
| *Asarum缶*                | ME (10.9%) & a-amanita (58.8%) major components in root EO; methyl isoeugenol (33.3%) in leaf EO | Zhang et al. 2000                   |
| *Asarum heterotropoides* [Xi xin] | ME (47%) in root extract; ME in EO of subterranean & epiphyllous parts 21-39% & 1-6-9-9%, resp, and ME highest during sprouting & after flowering. | Konoge et al. 1978, Wang et al. 1997 |
| *Asarum heterotropoides var. spondulits* | ME a major component in volatile oil of the Korean 'Xi xian'. | Saito et al. 1967a                  |
| *Asarum latifolium*        | ME 8% and safrole 39% of EO.                                                | Saito et al. 1967b                  |
| *Asarum rubellum* [Chinese wild ginger] | EO contained ME; ME (0.47%) in root EO.                                     | Tian et al. 1981b, Han et al. 2008  |
| *Asarum rubellum* [Cinnamomum] | ME 78% of EO.                                                                | Saito et al. 1967b                  |
| *Asarum rubellum* [Mackean] | ME 26% of EO.                                                                | Saito et al. 1967b                  |
| *Asarum rubellum* [Manhucreum] [Xi Xian] | ME 59% of EO.                                                                | Saito et al. 1967b, Tian et al. 1981a |
| *Heterotropha chlorophyll* | ME 1% of volatile oil.                                                      | Saito et al. 1967b                  |
| *Heterotropha aspera*      | ME 2%, elemicin 0.1% and safrole 96% of volatile oil.                       | Saito et al. 1967e                  |
| *Heterotropha aromatica*   | ME 0.1% of volatile oil.                                                    | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 8% of volatile oil.                                                      | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 0.2% of volatile oil.                                                    | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 0.1% of volatile oil.                                                    | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 1% of volatile oil.                                                      | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 0.5% of volatile oil.                                                    | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 2% of volatile oil.                                                      | Saito et al. 1967b                  |
| *Heterotropha aromatica*   | ME 11% of volatile oil.                                                     | Saito et al. 1967e                  |
| *Heterotropha aromatica*   | ME 1% of volatile oil.                                                      | Saito et al. 1967b                  |
| Heteroptera hexadactyla | ME 3% of volatile oil | Saki et al. 1967c |
|-------------------------|-----------------------|------------------|
| Heteroptera hexadactyla var. perfecta | ME 41% of volatile oil | Saki et al. 1967c |
| Heteroptera kruisiana | ME 1% of volatile oil | Saki et al. 1967a |
| Heteroptera kusunoki | ME 0.1% of volatile oil | Saki et al. 1967d |
| Heteroptera megacantha | ME 5% of volatile oil | Saki et al. 1967d |
| Heteroptera muranouchi | ME 20% of volatile oil | Saki et al. 1967e |
| Heteroptera nankensis | ME 0.3% of volatile oil | Saki et al. 1967d |
| Heteroptera nipponica | ME 3% of volatile oil | Saki et al. 1967d |
| Heteroptera nipponica var. kusunoki | ME 0.5% of volatile oil | Saki et al. 1967d |
| Heteroptera nipponica var. rhaphydon | ME 4% of volatile oil | Saki et al. 1967d |
| Heteroptera ohioua | ME 2% of volatile oil | Saki et al. 1967c |
| Heteroptera rigicrens | ME 0.2% of volatile oil | Saki et al. 1967d |
| Heteroptera sakawama | ME 3% of EO | Saki et al. 1967c |
| Heteroptera satsumensis | ME 1% of volatile oil | Saki et al. 1967e |
| Heteroptera savatieri | ME 2% of volatile oil | Saki et al. 1967d |
| Heteroptera takari | ME 21% of volatile oil | Saki et al. 1967d |
| Heteroptera takaori var. dilatata | ME 1% of volatile oil | Saki et al. 1967d |
| Heteroptera tanenensis | ME 2% of volatile oil | Saki et al. 1967d |
| Heteroptera tanae | ME 1% of volatile oil | Saki et al. 1967e |
| Heteroptera yakusimenensis | ME 1% of volatile oil | Saki et al. 1967a |
| Hexaexys urifolius | Root & leaf EO contained safrole & ME at ratios of 58.2%: 19.9% & 69.9%: 5.8%, resp. | Hayashi et al. 1983 |
| Hexaexys nitens | Root EO contained safrole and ME in traces, and no ME in leaf EO | Hayashi et al. 1983 |

**Asteraceae - Aster family** (Asterales)

**Achillea conferta**

Among 48 volatile components - ME (2.7%) of aerial parts EO. 
Saeidnia et al. 2005

**Achillea geophila**

Dried flowering; herbar parts EO had tr quantity of ME. 
Baser et al. 2001b

**Achillea kryetoglia**

(0.0-0.7%) and eucalypt (0.4-0 6%) TIC of EO of aerial parts. 
Baser et al. 2001a

**Achillea lycochrous**

ME (0.3%) and eucalypt (0.8%) TIC in EO of aerial parts. 
Baser et al. 2001a

**Achillea millefolium** [Common yarrow]

Plants from 2 of 14 different locations in Lithuania contained ME (0.07-0.14%) in leaf EO. 
Gudatytė & Venskutonis 2007

**Achillea monoeckra**

ME in leaf EO decreased from 0.6% to 0% at temperatures (100-175 °C) during water extraction. 
Gogus et al. 2006

**Achillea oxyodon**

Aerial parts contained 0.2% ME of EO. 
Emanzhi et al. 2006

**Agarum conyzae** [Whiteweed, Great Weed]

ME 18% of plant (without roots) EO. 
Rao & Nagam 1973

**Anthemis melaleuca**

Air-dried plant EO had 0.4% ME. 
Saroglou et al. 2006

**Anthemis tinctoria var. maritima**

ME (1.1%) in EO of air-dried plant materials. 
Saroglou et al. 2006

**Anthemis vernalis spa. vernalis**

Air-dried plant EO contained 0.1% ME 
Saroglou et al. 2006

**Artemisia scoparia** [Greater Burdock]

PO of dried ripe fruits contained 0.1% of ME. 
Zhao et al. 2009

**Artemisia annua** [Annual or sweet wormwood]

2 CVs - 1 has ME & eugene at 0.2 & 0.3% of EO, resp, and tr in the other. 
Geel et al. 2008

**Artemisia absinthium**

3 of 4 vegetative phases - emergence of turner and mass flowering phases ME was 1.5% & 0.3% in weight of EO. 
Klodzko et al. 2009

**Artemisia capilaris** [Yin Chen Hao, Chinese moina]

Growing buds contained ME. 
Yano 1987

**Artemisia campestris var. glutinosus** [Western Sagewort]

ME in tr amount in EO of aerial parts. 
Juteau et al. 2002

**Artemisia demissa**

ME (0.5%) in oil. 
http://www.etna.eurov.eu

**Artemisia dracunculus** [Tarragon]

ME 280 ± 95.8 ppm in EO of field grown plants; EO of aerial parts had ME (35.8%) and methyl chavicol (16.2%), aerial parts EO had ME (1.8%). 
Rimelcy et al. 2004; Lopez-Lut et al. 2008; Nord et al. 2005

**Artemisia filifolia** [Filatov wormwood]

ME - 0.2% in weight of aerial parts EO 
Atashkoeva et al. 1999

**Artemisia glabellata**

4.6% ME and 0.2% eugene in dried plant EO. 
Bicchi et al. 1985

**Artemisia herba-alba (A. inculta) [Desert wormwood]

Combined flowers, leaves, and stems contained ME and estragole at 0.7 and 0.5% of EO, resp. 
Hudak & Aburam 2006

**Artemisia pallens** [Davana]

ME and eugene detected. 
Gulati & Khan 1979

**Artemisia persicina** [Davana]

ME (0.4%) in EO (0.4%) of the dried plant. 
Sadeghpour et al. 2004

**Artemisia scoparia** [Red-stem wormwood]

EO of aerial parts contained ME (27.3%). 
Basheer et al. 1997

**Artemisia subaerata**

Leaf EO deminated by 11.2% eugene, 9.4% ME and 9.0% camphor. 
Shatat et al. 2002

**Artemisia vulgaris** [mugwort or common wormwood]

Plants from France had ME at 3-4, 6-8 and 1% of FO in vegetative, flowering-buds & flowering stages, resp. 
Jerkovic et al. 2003

**Baccharis griseovaginata**

ME (0.5%) in EO of aerial parts. 
Hadad et al. 2007
| Species                                | ME                                      | References                          |
|----------------------------------------|-----------------------------------------|-------------------------------------|
| *Bathineta rubicundum*                  | 0.92% of aerial parts EO                | Allou et al. 2008                    |
| *Cnemadocera calcuttana*               | One to two *Cnemadocera* spp. that had ME - 0.5% of aerial parts EO | Karamentes et al. 2008              |
| *Drosophila aescula* (Thymophylla aescula) | ME (4.1%), angonin (0.3%), β-xylopyranosyl (0.1%)                        | Talia et al. 1997                    |
| *Feltaco maruta*                       | ME (0.4%) of leaf EO                    | Ashraft et al. 2008                  |
| *Gelsemium sempervirens* (Galga)       | EO of aerial parts contained ME (1.257%), eugenol (6.7%), & 4-vinylguaiacol (5.34%) | Halabi et al. 2005                   |
| *Heliopsis ocularis* (Chloris's eye)   | ME (0.5%) of one major component of EO | Javindia et al. 2006                  |
| *Ophrysopsida gianfoliis*              | EO of aerial parts from Andes, Chile, contained 8% ME | Nienow et al. 2009                    |
| *Pachyrhizus erosus* (P. multispinosus) | ME (3.1%) in fresh ripe EO              | Suliman et al. 2006                  |
| *Plauclavia sagittalis* (Wingstem camphorweed, lacuna, madreavado) | Leaf and stem EOs contained 23 terpenoids - including ME. | Tartar 1982                           |
| *Rhamnus occidentalis* (Redbark buckthorn) | ME of aerial parts contained 14.4 and 8% of ME, etc. | Bonnafond et al. 2007                 |
| *Sambucus nigra* (Black elder, European elder) | 4 epoxyresins - two had ME 50.78 (0.35) and 121.05 (0.04) g/g dry wt in EO, and two with no ME. | Ganci et al. 2010                      |
| *Sedum rubra* subs. var. texanum (Texas Goldmoss) | ME (0.5%) of fresh feedstock obtained from dry leaves of *Sedum rubrum* | Tucker et al. 1999                    |
| *Tajetra heleni*                        | Major components - carotene and ME at 45 and 27% in EO, resp. | Hethelyi et al. 1987                  |
| *Taliesis flaxifolia* (T. mutata)      | Plant EO had estragole (61.3%) and E-nemethole (36.6%) with 0.0% ME | Hossain et al. 1990                   |
| *Tagetes patula*                       | Plant EO contained 3.9% ME              | Ruff et al. 2002                      |
| *Tagetes patula* var. chilensis*       | ME (0.2%) in EO of aerial parts.        | Senator & Die Fehr 1999               |
| *Tagetes patula*                       | ME (3.2%) in EO of aerial parts.        | De Fehr et al. 2005                   |
| *Tanacetum parthenium* (T. parthenium) | Flowering aerial EO contained camphor (46.2%) with 0.1% ME; leaves and inflorescences contained 9.9 + 3.3 mg/kg. | Pineda et al. 2010; Christensson et al. 1999 |
| *Tamoxoacanthus turbinatus* (Cardoon) | ME (4.5%) 38% of both oil and 38% of wood bark EO | http://www.cma.europa.eu          |
| *Trema montana* (Balsaminaceae)        | Dried plant EO contained 5.41% β-sitosterol and 3.12% ME. | Viguero et al. 2007                   |
| *Wedelia biflora* var. varia*          | ME among 28 compounds detected in leaf and stem oils | Mancini 1980                           |
| *Bignonia caerulea* (Bignonia/Trompeter-creeper family) | *Lamiales*) | | |
| *Tetraclisia rampens* (Poinciana tree) | ME (0.24%) and eugenol (0.96%) of inner bark EO | Park et al. 2003                      |
| *Borassus flabellifer* (Borassaceae)    | (order: unlined asterid I)              | | |
| *Borassus flabellifer* (Borassaceae)    | Leaves EO content at 1.5% of EO or 4.5 µg/g fresh weight | Mubendi et al. 2009                   |
| *Brahmia caerulea* (Brassicales)       | ME (0.9%) in headspace sample of fresh leaf volatiles | Jawetz et al. 2002a                    |
| *Bursareinaeae* (Bursareinaeae) family (Capsulinae) | *B. sericea* (Indian frankincense) | | |
| *Ceratocephala seminanita* (B. seminanita) | Gum resin contained ME (3.7%) and | | |
| *Cassia acutifolia* (Indian saffron)    | 24 hexadecanols which were absent in other *Bursareinaeae* species. | Harn et al. 2005                      |
| *Cassia spicata* (B. spicata)          | ME (300-700 ppm) in oil.               | http://www.cma.europa.eu          |
| *Cassia occidentalis* (Wild cinnamon)  | Fruit EO contained traces of ME which was not detectable in seeds. | Hoffet et al. 2005                   |
| *Cassia occidentalis* (Wild cinnamon)  | Bark yielded eugenol, ME, asarone etc. | Martin 1980                           |
| *Capparaceae* - Capparidae family (Brassicaceae) | *Capparis spinosa var. spinosa* | ME (0.3%) of shoot EO and not detected in fruits | Oxun & Chalakhi 2007          |
| *Cistaceae* - *Cistaceae* family (Malvales) | *Cistus albidus* (Rock rose) | 6 of 15 populations in Greece had ME (0.1-0.95%) in EO of aerial parts during flowering. | Demetres et al. 2002 |
| *Chenopodiaceae* - *Chenopodiaceae* family (Malpighiales) | *Chenopodium berlandieri* | ME (0.6%) | |
| *Chenopodium berlandieri* (Brazilian rod propolis) | ME (13%), methyl eugenol (4%), 4-methoxy (18%), α-terpineol (26%), and E-isoegenol (11%) in non-polar fraction. | Trushcheva et al. 2006              |
| *Hypericum peruvianum* (Hypericaceae) | ME (4.92%) in EO of aerial parts | Hochi et al. 2008                      |
| *Chrombataea* - *Chrombataea* family (Myrtales) | Terminalia catappa (Tropical almond fruit, Sea almond) | Headspace extraction using SPME and PTV extraction. | Sider & Jung 2006 |
| *Cornaceae* - *Cornaceae* family (Cornales) | *Cornus officinalis* (Japanese cornel, Japanese cornelian cherry) | Fruit EO contained ME (7.4%), isoascorone (7.1%), β-phenylpropyl alcohol (4.1%) & cinnamic acid (3.2%). | Miyazawa & Kameoka 1989 |
| *Cupressaceae* - *Cupressaceae* family (Pinales) | | | |
| *Juniperus communis* | Leaf EO contained in quantity of ME | Adams et al. 2007                     |
| *Juniperus communis* | ME (4.53%) in plant EO. | Adams et al. 1994                      |
| *Juniperus communis* var. cuneata (Chinese juniper) | ME (4.53%) in plant EO. | | |
| *Juniperus communis* var. cuneata (Chinese juniper) | Trace amount of ME in two varieties - Azzedine & Dinh 2010 | Adams et al. 1994                      |
| Family                      | Species                        | ME (primary) | FF (secondary) |
|-----------------------------|--------------------------------|--------------|---------------|
| Jasminaceae - Psychotria family (Psychotriaceae) | Tan and Nishida | 0.9-1% in leaf EO. | 0.83-0.85% in leaf EO. |
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| Species/Genus/Species | Source of Essential Oil | Type of Essential Oil | Content | References |
|-----------------------|------------------------|-----------------------|---------|------------|
| *Ocimum basilicum* (Lamiaceae) | Leaf, stem, and flowers | Leaf, stem, flowers, and fruits | 1.1% | M. E. Zaidi et al., 2010 |
| *Mentha piperita* (Lamiaceae) | Leaves, flowers, and stems | Leaf, stem, flowers | 0.01% | D. J. Kharat et al., 2009 |
| *Cinnamomum zeylanicum* (Lamiaceae) | Leaves | Leaf | 0.5% | C. C. Arts et al., 2009 |
| *Citrus aurantium* (Rutaceae) | Fruits and leaves | Fruits | 0.3% | D. J. Kharat et al., 2009 |
| *Citrus limon* (Rutaceae) | Fruits and leaves | Fruits | 0.2% | D. J. Kharat et al., 2009 |
| *Eugenia caryophyllata* (Myrtaceae) | Leaves | Leaf | 0.02% | D. J. Kharat et al., 2009 |
| *Eucalyptus globulus* (Myrtaceae) | Leaves | Leaf | 0.1% | D. J. Kharat et al., 2009 |
| *Sesame* (Sesamum indicum) | Seeds | Seed | 0.5% | D. J. Kharat et al., 2009 |

Note: The content is given as a percentage of the total oil.
| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Coelopa flavipes*       | EOs of leaf and stem contained 8.0-16.0% of ME and 1.5-6.0% of E. | ME and E. comp. |
| *C. violaeformis*        | EOs of leaf and stem contained 1.5-4.0% of ME and 0.5-3.0% of E. | ME and E. comp. |
| *C. furcata*             | EOs of leaf and stem contained 2.5-5.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *C. amurensis*           | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *C. kikuchii*            | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *C. koreana*             | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *C. ochracea*            | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Magnoliaceae** - Magnoliaceae Family (Magnoliidae)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Magnolia denudata*      | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. grandiflora*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. liliiflora*          | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Myrtaceae** - Myrtaceae Family (Myrtales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Myrtus communis*        | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. rubra*               | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Poaceae** - Poaceae Family (Poales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Oryza sativa*           | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. truncatula*          | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Rosaceae** - Rosaceae Family (Rosales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Malus pumila*           | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. domestica*           | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Santalaceae** - Santalaceae Family (Santalales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Santalum album*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *S. paniculatum*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Tannins** - Tannins Family (Leguminosae)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Tanellus arborescens*    | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*          | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Taxaceae** - Taxaceae Family (Taxales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Taxodium distichum*     | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. virginiana*          | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Zygophyllaceae** - Zygophyllaceae Family (Zygophyllales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Zygophyllum dumosum*    | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Zygophyllaceae** - Zygophyllaceae Family (Zygophyllales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Zygophyllum dumosum*    | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |

**Zygophyllaceae** - Zygophyllaceae Family (Zygophyllales)

| Species (Scientific Name) | Description | EOs and Components |
|--------------------------|-------------|--------------------|
| *Zygophyllum dumosum*    | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
| *M. officinalis*         | EOs of leaf and stem contained 3.0-6.0% of ME and 0.5-1.0% of E. | ME and E. comp. |
Meliflua leuconeura [Cajuput tree]
One of three chemotypes had ca. 99% ME in leaf EO; EO of aerial parts contained ME (96.6 ± 0.7%).
Brophy & Lapsak 1988, Silva et al. 2008

Meliflua quinquenervia [Metalacea trees, paperbark tea trees]
Two chemotypes rich in ME (up to 99 percent).
Ramanoujina et al. 1994

Myristica fragrans [Armany]
ME (0.2%) a minor component in leaf EO.
Malagon et al. 2003

Myrtus communis [Myrt]
Myrt berry oil 2.3% ME; leaf & ripe fruit ME 2.3% & 0.64% of EO, while ripe fruit had no detectable ME; ME content 2.3% in Myrt EO, fruits & leaves from 1st station had ME at 0.6 & 0.8% of EOs, resp, in 2nd ME 1.1% of leaf EO and none in fruits.
Mazza 1983, Boileau & Limone 1992; De Vincenzi et al. 2000; Flaminii et al. 2004

Pimenta aconcagua [Wild cinnamon, Bay-rum tree, Bayberry or Jamaica barberry,]
Chavutu, eugenol, and ME form 67-70% of leaf and berry EO.
Ryan 1991

Pimenta dioica ['E. officinalis'] [Allspice, Pimento, Jamaica pepper]
ME (48.3-67.9%) main component of Mexican pimento berry EO; EO high in eugenol (64.29%) and ME (20.55%) contents; fruity & non-fruitty truns contained ME (0.08 ± 0.13%) & eugenol (79.8 ± 83.7%) of leaf EO, resp.
Garcia- Figado et al. 1997, Zabala et al. 2009, Meszi & Brown 2007

Pimenta officilzilis [Pimento]
ME (5.0.8.6%) of EO.
De Vincenzi et al. 2000

Pimenta racemosa ['Bay rum tree']
ME in leaf EO for var. grisea (0.50 - 92.60%) and var. hispaniolana (0 - 63.88%); ME 8.9% of fruit EO.
Tucker et al. 1991, Ruff et al. 2002

Pisonia corymbosa [Guava]
ME and eugenol were major volatile components; ME (4.5%) in leaf oil and fruits.
De Faria et al. 1972, http://www.ema.europe.eu

Psidium cattleianum [Strawberry guava]
Red variety of fruit contained ME and eugenol among >154 volatile.
Veinini et al. 1998

Psidium guajava [Guava]
ME (0.2%) of fruit EO.
Pasterny et al. 2000

Syzygium aromatica ['Eugenia caryophyllata, E. caroophylla'] [Clove]
Leaf EO had eugenol (76.8%) and caryophyllene (17.4%) as major components with tr ME; ME (0.12%) of EV containing eugenol (76.8%).
Broverman et al. 2004; Dzamic et al. 2009

Orthodoxaceae - Orchid family (Asparagales)

Braulio calechensis
EO contained ME (8.0%).
qu/M. Masa & Andrade 2009

Jumelia fragrans ['false run orchid']
ME in minute quantity of leaf EO.
Slum & Smijka 1992

Papaveraceae - Peppermint family (Ranunculales)

Escholzia fleursa
EO had 40.5% ME.
http://www.ema.europe.eu

Piperaceae - Pine family (Piperales)

Pinus ponderosa [Northern American pine]
ME (0.0%) in needle (leaf) EO.
Krauze-Baranowska et al. 2002

Piperaceae - Pepper family (Piperales)

Piper auritum
Leaf EO contained ME (0.8%), safrole (91.3%) and myristin (4.8%) in leaf EO.
Bromo-Sanchez et al. 2009

Piper balteum ['Brotte, Brotte pepper, Sirich]
Two C14s; Gary 0.15-0.2% EO - ME (4.1-6.9%) and eugenol (82.2-90.5%).
Sherma et al. 1983

Piper capermeum
Aerial parts EO contained 0.2% ME.
Martini et al. 1998

Piper divaricatum ['Piper colaumbimum']
ME (17-93%) and sucrose (2.0-68%) main constituents in EO.
qu/M. Masa & Andrade 2009

Piper guineense ['West African black pepper']
Berry EO rich in glycoside/propynol - ME (1.5%) & eugenol (0.07%), white and black berries EO's contained 0.11 & 0.22%, resp.
Ekundayo et al. 2008, Irootwi et al. 2002b

Piper jenumiellum
Leaf EO contained limonene, isosafrole, ME and carvone.
Diaz et al. 1986

Piper nigrum ['Black pepper']
EO one of twelve identified polar compounds in oil of black pepper; berry contains 0.92% ME.
Russel & Jennings 1969, Irootwi et al. 2002b

Piper nubianum
Leaf EO had ME (1.1%).
Meirri et al. 2001

Piper pseudocladus
EO 0.08% of aerial parts EO.
Ferrer et al. 2010

Plumbaginaceae - Leadwort family (Caryophyllales)

Limnotria echinata
Aerial parts EO had ME & eugenol at 0.01% and 0.75% of volatiles.
Sadana et al. 2008a

Peaace - Grass family (Poales)

Bothriochloa inspersa
One of 10 Bothriochloa sibog species contained ME (1.5%) in whole plant EO.
Scrimato et al. 2009

Bromus hordeaceus [Soil brome]
Trans methyl cinnamate (31.2%), ME (30.3%) & eugenol (19.1%) of plant EO.
Kaluzna-Czapinska 2007

Cymbopogon absinthum
ME (13.4%) and limonene (25%) as major components in BO.
Singh & Sinha 1976/c/ Akhila 2009

Cymbopogon flexuosus ['Lemon grass]
ME (20%) in EO.
Atul & Brada 1976

C. flexuosus var Skimus
ME (23%) in EO.
Maniure & Khuda et al. 1986

Cymbopogon hieracifolius [hieracifolius grass]
Khao grass - ME of major component.
Artiur & Qadri 1987

Cymbopogon hookerii
6.0-6.8% oil yield - contained ME (75.85%).
Robita et al. 1986

Cymbopogon microstachyus
eO had ca. 69% phyllyl progenoids with ME (19.5%), valerian (25.3%) & methyl isoneugenol (4.3%).
Muthlin et al. 1990

Cymbopogon nardus [Citronella grass]
ME major component, ME (4.1%) with traces of eugenol and ethyl isoeugenol.
Howdall 1915, Akhila 2009

Cymbopogon toruliflorus [Ozarkinka, Ozarkvalaya]
EO (55%) in EO.
Liu et al. 1981

Cymbopogon winterianus ['Java citronella']
EO (20-40) pm of whole plant (1%) EO. EO contained tr quantities of ME and eugenol.
http://www.ema.europe.eu, Akhila 2009

Elemonus hensii
ME (0.6% of EO) in roots and not detected in other aerial parts.
Silu et al. 2006

Lolium perenne
ME (16.6%), eugenol (24.1%) & trans methyl cinnamate as major components in plant EO.
Kaluzna-Czapinska 2007

Podocarpaceae - Podocarpus family (Podales)

Dacrydium franklinii ['Lagarostrobus franklinii'] ['Hino pine heartwood']
Was contained eugenol, ME ether, elemenic, and conifer alcohols.
Baggaley et al. 1967

Lagarostrobus franklinii [Hino pine]
Wood EO had 57-74% ME, 21-18% E-methyl isoeugenol & 22-24% elemen.
Brophy et al. 2000

Lolium perenne ['Porellus eye grass']
Eugene (4.3%), E-methyl cinnamate (18.5%) & ME (16.0%) in plant EO.
Kaluzna-Czapinska 2007
| Family                  | Species/Genus                        | Description/Remark                                                                 |
|------------------------|--------------------------------------|------------------------------------------------------------------------------------|
| Polygonaceae – Buckwheat family (Caryophyllales) | *Fagopyrum tataricum* [Chinese rhubarb] | Rhubarb IEO contained 5.4% ME.                                                      |
|                        | *Rheum rhaponticum* [Rhubarb]        | Mean value of ME in rhubarb IEO varied from 2-7%.                                    |
| Rosaceae – Rose family (Rosales)           | *Paeonia suffruticosa* [Chinese peony] | 0.4% & 0.1% ME in fruit peel and fresh EO, resp.                                    |
|                        | *Punica granatum* [Pomegranate]      | ME (<1%) found in fruits of four peach varieties and two breeding lines.            |
|                        | *Rosa damascena* (Hybrid of *Rosa gallica* and *Rosa moschata*) ['Damask rose'] | Rose oil contained 0.1–1.9% ME and 0.2–1.8% esugenol, ME (5.5%) in Chinese rose oil using SPME technique. |
|                        | *Rosa hemisphaerica* ['Sulphur rose'] | ME 0.3% of EO.                                                                      |
|                        | *Rosa hybrida* CV 'Meying'            | ME (0.79%) and esugenol (0.84%) in Korean rose oil.                                  |
| Rubiaceae – Madder family (Gentianales)   | *Rubia cordifolia* [Common Indian Madder] | ME (1.2%) of peel area to root EO.                                                  |
| Rutaceae – Rue family – (Sapindales)      | *Aegle marmelos* ['Bael, Buchu']      | Plant EO contained 1.4% ME.                                                         |
|                        | *Citrus aurantium var. murraya* ['Chinotto'] | Fresh fruits were unripe to yield dried peel which possessed tr ME in EO.         |
|                        | *Citrus paradisi* ['Grapefruit']     | Grapefruit juice contained 0.02 ppm of ME.                                          |
|                        | *Chlorophora antiscia*               | Leaf EO contained 92.7% ME.                                                         |
|                        | *Chlorophora excava* ['Pink Varaspe'] | Elerical (65.02%) and ME (12.55%) as major components of leaf EO.                 |
|                        | *Chlorophora indica*                 | Fruit peel EO contained 0.43% ME.                                                   |
|                        | *Citrus limonia* ['Orange']           | Short oil contained ME.                                                             |
|                        | *Daucus carota* ['Bitter melon']     | ME (0.7%) in EO of aerial parts.                                                     |
|                        | *Dimorpera indica* ['Melicope melicope'] ['Hand aspen'] | One of three chemotypes had ME (51.67%) and methyl cinnamol (5.13%).             |
|                        | *Eriodictyon glaucum*                 | 234 mg of ME from 10.2 g hesperetin extract concentrate of aerial plant parts.     |
|                        | *Eriodictyon trachyphyllos* ['Redb. Wax-flower'] | ME and esugenol in tree.                                                            |
|                        | *Fagara anatolica* ['East African sassafras'] | ME (6.8%) in pericarp EO.                                                          |
|                        | *Haplophyllum myrtifolium*            | Plant EO had 10.8% ME and 19.1% esugenol.                                          |
|                        | *Heliotropium orientale*              | EO of leaves and branches - esugenol & ME.                                          |
|                        | *Lecanora ambiguus* ['Eriodictyon ambiguus'] | ME - 1.1% of leaf EO.                                                               |
|                        | *Lunaria scapiata*                   | Berries contained ME among other monoterpenes.                                      |
|                        | *Malva parviflora* ['Polya argentea'] ['Moksha'] | Leaf EWEO distillate contained p-methoxyphenylbenzene (ca 40%) with lesser quantities of ME, limonene, methyl isoeugenol and estragole. |
|                        | *Melicope berlesei*                  | Leaf EO of this medicinal plant with antimicrobial activity contained ME (209 mg of 450 g powdered leaves). |
| Sapotaceae – Sapodilla family (Erialeae)    | *Manilkara zapota* ['A. zapota'] ['Sapodilla, Chico'] | ME (0.5%) in fruit EO which had 61 volatiles – 0.03 mg/kg of fruits.            |
| Sapotaceae – Pipturus family (Erialeae)     | *Sapotacae*                           | ME (0.3%) in EO of aerial parts.                                                     |
| Saururaceae – Lizard-tail family (Pteridales) | *Anemopsis californica* ['Tarba maina'] | ME ca 0.5% in rhizomes & dried roots; leaf EO contained 6.5-7.3% ME, ME (55%) in New Mexico root EO, ME (55%) of rhizome & root EO. |
| Saururaceae – Lizard-tail family (Pteridales) | *Saururus chinensis*                  | ME (< 2%) in EO of dried aerial parts.                                               |
| Scrophulariaceae – Figwort/Snapdragon family (Lamiales) | *Bocconia frutescens* | Whole plant EO had camphor (30.6%) and ME (28.3%) as major components; ME (35.9%) and camphor (28.1%). |
| Scrophulariaceae – Figwort/Snapdragon family (Lamiales) | *Lamprophyllia geffreyi* ['Lamprophyllia racemosa'] | Aerial parts (flowers not included) contained ME at 0.3% and /% of EO. |
| Solanaceae – Nightshade/Potato family (Solanales) | *Cyphomandra betacea* ['Solanum betacea'] ['Tamarillo, Tree tomato'] | Fruit pulp volatiles contained <100 g/kg of ME.                                    |

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| Family                        | Species/Description               | Essential Oil Components                                                                 | Reference(s)                                      |
|-------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------|
| *Mandragora officinarum*      | Mandrake, Hog apple, Ground lemon | ME (0.40%), eugenol (2.37%), and E-isoegenol (1.03%) in fruit EO                        | Flesher & Flesher 1994                          |
| *Tamarrus - Taxus* family     | *Taxus baccata*                   | Aerial parts, leaf and stem EOs had 0.89%, 0.22% & tr ME, resp.                       | Saitoana et al. 2003b                           |
| *Theaceae* - Tea family       | *Camellia sinensis* (Chinese tea) | ME (0.053 - 0.814) as ratio of peak area to that of internal standard in 5 samples of tea EO | Pripdievo et al. 2010                           |
| *Thymelaeaceae - Moezeum family* (Malvales) |                        |                                                                                       |                                                  |
| *Dogmae group*                | ME (4.5%) in aerial parts EO      |                                          | Ueyama et al. 1990                              |
| *Verbenaceae* - Verbena family (Lamiales) |                        |                                          |                                                  |
| *Abietis trophilla* (Lemsn verbanal) | Dried leaves contained eugenol & ME at 0.5-0.6% & 0.3-1.2% of EO, resp. | Grabus et al. 2003                            |
| *Ligustus alba* (Biaue lippota, Annee verbanal) | ME small amounts.               |                                          | Svedens & Baurmeier 1990                        |
| *Ligustus grandifolius*       | 14 plant samples had eugenol 0.1-0.6% of EO but only 2 with tr ME. |                                           | Manu et al. 2005                                 |
| *Vitaceae* - Grape family     | *Vitis montifolia* (Muscadine, Scuppernong berries) | ME in ripe berries from three CVs - Fry, Jumbo and Watergate. | Horvat & Seeter 1984                           |
| *Winteraceae* - Winter's Bark Family (Cornell) |                        |                                          |                                                  |
| *Drumy 2bracteata*            | Fresh leaves collected in Dec., May and Oct. contained 0.5, 0.2 and 0% of ME, resp. and no ME in dried leaf, stem, bark and unripe fruit. |                                           | Limberger et al. 2007                           |
| *Zingiberaceae* - Ginger family (Zingiberidae) |                        |                                          |                                                  |
| *Afinger galangal* (Langsa galangal) (Greater galangal) | ME and e-copepepe appeared as single peak (3.6%) of EO of fresh rhizomes, ME 0.9% of rhizome EO. |                                           | De Pooter et al. 1985, Pripdievo et al. 2009     |
| *Afinger officinans* (Galanga, galangal, galangale) | 1.6% and 3.5% ME in EO of fresh and dried rhizome, resp.; ME 3.3% and eugenol 0.5% of rhizome EO |                                           | Tran Ngoc et al. 2001, Pripdievo et al. 2009     |
| *Afinger spectans* (Chinote Beauty, Aoumou, Variagated Dwarf) | ME in stem & leaves; only leaves from Japan, among 6 countries of origins, had ME, estragole & methyl cinnamate at 2.9, 4.6 & 0.1% of EO, resp. |                                           | Fujita & Yamashita 1973, Prudent et al. 1993    |
| *Boesenbergia sp.* (species unknown) | Plant attracted the oriental fruit fly and volatile oil contained 1% ME |                                           | Kottibhramrongsook 1980                         |
| *Curcuma aromatica* (Manava aromatica) (The narrow leaved Tumeric) | Rhizome EO from Central India had ME (10.3%) |                                           | Srivastava et al. 2006                         |
| *Elshisera cokkunnum* (Cademense) | ME and eugenol among the ten most abundant volatile compounds in seed EO; plant EO contained 0.1% ME |                                           | Abo-Khatiw & Kubo 1987 et Kubo et al. 1991, De Vincenzo et al. 2000 |
| *Elongera cevural* (Wax flower) | ME (47.4%) and Z & E -methyl isoeugenol (18.8%) in rhizome EO |                                           | Leedae-Valinovna et al. 1993                   |
| *Elongera bugenurum* | Rhizome oil contained methyl chavicol (49.9%) & ME (32.3%) |                                           | Bhuyan et al. 2010                             |
| *Zingiber zingiber* | ME (54.7%), e-piperine (10.6%) & E-methyl isoeugenol (8.68%) found in rhizome oil. |                                           | Jackson et al. 2006 (postur) |}

* excluding flower/floral fragrance, and quantitative data given if available;  
**% = percentage of peak areas (if not stated), cv = cultivar, EO = essential oil, resp = respectively, SPME= Solid phase micro extraction, TLC = Thin layer chromatography, tr = trace, v. = variety, wt = weight.
### Table 2. Plant family (order) and species containing methyl eugenol [ME] in flowers*.

| Species (Synonym) | Common name | Remark on ME presence** | Reference |
|-------------------|-------------|--------------------------|-----------|
| Amaryllidaceae | *Amaryllis* | Floral EO contains ME as a minor component | Dobson et al. 1997 |
| Narcissus | [Bosquet] | Flower EO contains ME as a minor component | van Dorp et al. 1993 |
| Narcissus tazetta | *N. tazetta* | Flowers contained ME as a minor component | van Dorp et al. 1993 |
| Narcissus tazetta | *N. tazetta* | ME a minor component of flower EO | Ebert et al. 1988, van Dorp et al. 1993 |
| Annonaceae | *Custard apple family* (Magnoliidae) | Dried flower oil via controlled pressure drop method contained 0.4% ME & 0.5% eugenol, while steam distillation contained 0.1% ME & 0.18% eugenol of EO (% water) | Kristiawan et al. 2008 |
| Apocynaceae | *Carrot family* (Apiales) | 0.22% of volatiles collected during flowering via Tenax GC sorbed | Paramonov et al. 2000 |
| Cumin | *Cuminus* | ME (0.08%) & eugenol (0.79%) in floral EO | Bertaeh et al. 2010 |
| Datura stramonium | *Datura stramonium* | Blooming umbels have tr quantities of ME and eugenol in EO | Staniszewska & Kulka 2001 |
| Dryopteris affinis | *Dryopteris affinis* | ME (2.3%) & E-methyl isoeugenol (0.7%) in inflorescences and undetected in other plant parts | Flamini et al. 2008 |
| Euphorbia affinis | *Euphorbia affinis* | Floral EO contains 0.9-0.2% ME among 55 volatiles | Byrde et al. 1998 |
| Pimpinella sativa | *Pimpinella sativa* | Inference and seed EO contain 2.2% and 2.5% ME, resp. while seeds from 2nd locality contain ME (9.7%) | Askari & Sofi 2006 |
| Portenschlagia julii | *Portenschlagia julii* | ME at 0.3% of EO in flowering aerial parts | Solovic et al. 2008 |
| Scrophularia | *Scrophularia* | Flowers contain estragols (93.8% of EO) with 0.3% ME | Kaye et al. 2007 |
| Seseli | *Seseli* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Areaceae | *Areca palm family* (Arecales) | ME (0.1%) in floral fragrance | Schoedt et al. 2002 |
| Catharanthus roseus | *Catharanthus roseus* | Flowers contain ME and eugenol in floral sebaceous and bract. Photo showed >30 oriental fruit flies on visible side of a flower | Sinding & Antekut 1985 |
| Spantylphium cinnamomifolium | *Spantylphium cinnamomifolium* | Flower spike contains ME (20%), methyl chavicol, p-methoxybenzyl acetate, & benzyl acetate as major components. | Lewis et al. 1988 |
| Arecaceae | *Palm family* (Arecales) | ME varied 0.1-0.6% and 0.09-2.5% during staminate & pistillate phases, resp. & ME and eugenol peaked at 11:15-13:00 hour. | Knutson et al. 1999 |
| Geonoma polyandra | *Geonoma polyandra* | ME detected in tr amount and eugenol (8.2%) in floral EO | Kameoka & Wang 1980 |
| Jacqylla schizandra | *Jacqylla schizandra* | Eucalyptus (2%) & ME (0.7%) as ME in flower EO. | Kameoka & Wang 1980 |
| Asparagaceae | *Agave century plant family* (Asparagales) | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Dracaena fragrans | *Dracaena fragrans* (Corn plant, Chinese money tree, or Cordatum Dracena) | Head-space analysis of leaves using two adsorbents; twister and tenax-TE showed ME at 0.015 and 0.002%, resp. | Ishikawa & Tani 2007 |
| Podococ鞄us abies | *Podococ鞄us abies* | Floral absolute oil contained ca 20% E- and methyl eugenol, and ca 15% of ME and eugenol | Ishikawa & Tani 2007 |
| Asteraceae | *Aster family* (Asteridae) | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Asclepias | *Asclepias* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Astilba velutina | *Astilba velutina* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Anthemis alba | *Anthemis alba* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Nolitangus odoratissima | *Nolitangus odoratissima* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Zygophyllum dumosum | *Zygophyllum dumosum* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Zygophyllum dumosum | *Zygophyllum dumosum* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Boraginaceae | *Borage or Forget-me-not family* (Boraginaceae) | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Borago officinalis | *Borage, Starflower* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Brassicaceae | *Cabbage/Mustard family* (Brassicales) | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Malus prunifolia | *Malus prunifolia* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |
| Sisymbrium irio | *Sisymbrium irio* | ME in whole flowering tops EOs varied with altitude - 0.1% at 300 m but up to 0.4% at 2000 m in Russian Altai (Baker) | Tkachov et al. 2006 |

*ME = methyl eugenol, EO = essential oil.
**Table adapted from: Tkachov et al. 2006.*
| Family                     | Genus                          | Description                                                                 |
|---------------------------|--------------------------------|-----------------------------------------------------------------------------|
| Caryophyllaceae – Pink Family (Caryophyllae) | Dinantia aromatica  | Floral volatiles emitted were eugenol (4.2%), ME (2.0%), elemicin (1.3%) & methyl isoeugenol (0.1%) besides methyl benzoate (42.1%) | Jürgens et al. 2003 |
|                           | Dinantia aromapilosus         | ME (1.4%), elemicin (1.5%) emitted as part of floral volatiles.            | Jürgens et al. 2003 |
|                           | Dinantia suberosa             | Emitted floral volatiles contain cym-1-octene (49.8%), ME (0.2%) and elemicin (0.2%). | Jürgens et al. 2003 |
|                           | Dinantia syringoides          | Floral volatiles emitted contain methyl benzoate (85.7%), eugenol (0.3%) and tr of ME. | Jürgens et al. 2003 |
|                           | Thunbergia laiata f. White champaca | ME (60-65%) in single flower volatiles from a North American population but not detected in European populations. | Dottet et al. 2005 |
| Chrysanthemaceae – Manoeetian family (Euphorbiaceae) | Chrysanthemum parthenium | ME (0.8%) and 13.3-(3-methoxy)-benzene (0.5%) in fresh leaf EO. | Nozawa et al. 2001 |
|                           | Chrysanthemum indicum         | ME (2.0%), camphor (1.1%) and eugenol (0.3%) in fresh leaf EO.              | Nozawa et al. 2001 |
|                           | Chrysanthemum frutescens      | ME (0.2%) found in blue palatinate flower EO but not in leaf and fruit EOs. | Andrade et al. 2007 |
| Cynancheae – Cyad family (Cycadaceae) | Cycas revoluta | Estragole (67.0 - 92.7%) with small amounts of anethole, methyl salicylate, ME & ethyl benzoate released from male & female cones. | Azuma & Kato 2006 |
| Euphorbiaceae – Spurge Family (Euphorbiaceae) | Casinum rivale | ME (0.1%) in floral EO but not detected in leaf EO.                  | Compagnone et al. 2010 |
| Fabaceae – Pea Family (Fabales) | Acacia auriculiformis | Flowers contained ME and eugenol at 0.3 and 15.5% of EO. | Lambarque et al. 1998 |
|                           | Acacia auriculiformis var. auriculiformis (Roman Cascas) | Flowers contained traces of ME and eugenol at 11.2% of EO. | Lambarque et al. 1998 |
|                           | Cunila undulata (Roseau) | Flowers contained ME and eugenol at 9.4% of EO. | Lambarque et al. 1998 |
|                           | Coriaria volkensiae | ME (4%) in leaves, flowers, and fruits of plants identified as ME in flower EO contained 2.7% ME and tr of eugenol. | Nozawa et al. 2001, Trakou et al. 2007 |
|                           | Coromandelia olitoria (Carob tree) | Male whole flowers contained ME (2.8%) and female whole flowers 3.2 and 1.5% in Gallosa and Malusa Cvs. | Cusidó et al. 2006 |
| Malvaceae – Malva Family (Malvaceae) | Medicago sativa (Coastal medick, Sea medick) | EO of reproductive parts contained ME (21.4%) & eugenol (1.5%), and vegetative parts contained eugenol (4.9%) & ME (1.7%). | Flumian et al. 2003 |
|                           | Tagetes erecta (Zinnia flower) | Flower volatiles contained ME in 5% ME, and kenosis 3 folds of night, and higher with increase temperature (10 – 20°C). | Jakobsen & Olsen 1994 |
| Lamiales – Mint Family (Lamiidae) | Salvia satureioides (Salvia fruticosa) (Needle bush) | Cassie (floral distillate) contained ME. | Duke 1981 |
|                           | Vicia faba (Broad bean) | Headspace volatiles of cultivar Marns Bead flowers contained ME (0.2%), eugenol (0.66%), cumarin alcohol (0.77%), and methyl isoeugenol (0.02%). | Griffiths et al. 1999 |
| Asteraceae – Astereae Family (Asteraceae) | Agastache foeniculum (Anise hyssop) | ME in inflorescences & leaves increased from 28.6 to 41% in EO during 17 day storage. A putative hybrid of A. rugosa & A. foeniculum possessed ME (2.4%) in inflorescence EO. | Dmitriev et al. 1981, Wilson et al. 1992 |
|                           | Ocimum basilicum | ME 3-11% of inflorescence EO in two vas. | Nihlström et al. 1996 |
|                           | Ocimum gratissimum | ME 3-11% of inflorescence EO in two vas. | Samsbury & Sofosina 1971 |
|                           | Ocimum gratissimum var. Ovata | ME 3-11% of inflorescence EO in two vas. | Nihlström et al. 1996 |
|                           | Ocimum sanctum (Holy basil; red basil) | ME contents in 4 var high in ME 54-77% and 2 var high in eugenol 1.7 – 2.3% of inflorescence EO; ME in EO of leaf, stem in inflorescence 72.5%, 75.3%, 83.7%, resp. | Nihlström et al. 1996, Kothari et al. 2005 |
|                           | Ocimum melissafolium (Pepper basil) | Leaf and flower EOs in accession A had ME at 0.79 and 1.13%, resp. | Marinis et al. 1997 |
|                           | Ocimum sativum | ME (66.18%) in flower oil. | Marinis et al. 1997 |
|                           | Rosmarinus officinalis | Rosmarin oil obtained from pale blue flowers contained < 0.01% ME. | http://www.amea.ac.in |
**Malvaceae – Mallow family (Malvales)**

*Okra* ***[Okra]**
Hat-pollinated flowers contained 0.8% ME in floral volatiles

Knudsen & Tollsten 1996

*Vitis vinifera*** [Grape]
Flowers in spring, ME 0.4% and 0.5% of EO, resp.

Nicolini et al. 1994

**Melastomataceae – Mahogany family (Melastomatales)**

*Cardiospermum** [Heartseed]
Flowers in one campus of Para, Brazil had 8.4% ME in floral volatiles

Aoki et al. 2001

**Moraceae – Morinda family (Morinaceae)**

*Morinda officinalis*** [Medicine Apple]
Fresh flowers had 32 components with ME 0.3% and 0.7% of EO, resp.

Bauer & Kurkcuoglu 1998

**Myrtaceae – Myrtle family (Myrtales)**

*Myrtus communis*** [Myrtle]
Flowers from Western and Central Albanian had ME at 0.76 and 1.08% of EO, resp. ME 4% of EO 1 of 7 major floral components in var. tunetana.

Amissible 2000; Wenas et al. 2010

**Nyssaceae – Olive family (Lamiales)**

*Syringa vulgaris*** [Bach or Common Lilac]
ME (tr) in floral EO, ME present in floral volatiles.

Wu et al. 2008; Lamparski 1985; Knoben et al. 2008

**Oenograciaceae – Evening Primrose family (Oenograciaceae)**

*Charadha broweri*** [Flower family]
ME and isoME derived from eugenol and iso-eugenol via the action of iso-eugenol O-methyltransferase (IEMT), birch line E contains valerianol (15.5%), methyl iso-eugenol (0.68%), iso-eugenol (0.99%), and iso-eugenol (1.26%), but absent in birch line I.

Wang et al. 1997; Radjouze & Pickerns 1995

**Orchidaceae – Orchid family (Orchidaceae)**

*Angraecum sorrelii*** [Angraecum scapigera var. angustifolium]
Traces of ME in orchid flower (Madagascar)

Katsur 1993

**Psidaceae – Strawberry family (Psidaceae)**

*Psidium guajava*** [Guava]
ME (5.6%) major components and four other phenylpropanoids (in much smaller quantities) in floral volatiles

Tan et al. 2002; Nishida et al. 2000

**Piperaceae – Pepper family (Piperaceae)**

*Piper betle*** [Betel]
Flower EO had safrole as a major phenol, followed by hydroxychavicol, eugenol, ME, iso-eugenol, valerianol, 3-methyl chavicol.

Chin & Sun 1990

**Psidaceae – Psidium family (Psidaceae)**

*Psidium guajava*** [Guava]
EO (1.9%) in volatile oil of fresh flowers.

Katsur 1993

**Rhamnaceae – Rhamnus family (Rhamnaceae)**

*Rhamnus cathartica*** [Spinach]
Few minor phenylpropanoids and phenolates by cotton leaf beetles – ME in flower (1.5%); female flowers: 0.9%

Johnson et al. 2007

**Rutaceae – Rutaceae family (Rutaceae)**

*Cinnamomum*** [Cinnamon]
ME 2.5% of ME in floral volatiles.

Williams & Whitman 1985

**Rosaceae – Rosaceae family (Rosaceae)**

*Prunus serrulata*** [Redbud]
ME (1.5%) in floral volatiles.

Katsur 1993

**Rutaceae – Rutaceae family (Rutaceae)**

*Citrus sinensis*** [Lemon]
Floral volatiles of ME 0.1% of EO in flower volatiles.

Nishi et al. 2002

**Salicaceae – Willow family (Salicaceae)**

*Salix alba*** [Willow]
ME (1%) in floral volatiles.

Katsur 1993

**Sapotaceae – Sapodilla family (Sapotaceae)**

*Manilkara zapota*** [Poster]
ME (1.5%) in floral volatiles.

Katsur 1993

**Verbascum – Verbenaceae family (Verbenaceae)**

*Verbascum*** [Verbascum]
ME (1.5%) in floral volatiles.

Katsur 1993
### Rhizophoraceae – Mangrove family (Malpighiales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Rhizophora stylosa | Floral ME & eugenol at 6.8 & 27.2% of volatiles, resp. and floral scent had ME in traces – flowers visited by bees and others. | Azuma et al. 2002 |

### Rosaceae – Rose family (Rosales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Prunus mume [Japanese apricot] | ME present as minor component among 22 non-polar constituents of flowers. | Matsuda et al. 2003 |
| Rosa centifolia | ME (1.4%) in EO | Ohlott 1978 |
| Rosa chinensis [China rose] | ME and isoeugenol as minor floral components in var. spontanea. ME at 0.65, 0.64 & 0.59% of volatiles in CVs Diorama, Grand Mogul & Lady Hillingdon, resp. only Diorama emitted ME (0.51% of volatiles). | Wu et al. 2003, Joichi et al. 2005 |
| Rosa damascena [Damask Rose] | ME (1.4%) in EO, ME increased with time of fermentation (3-36 hrs). 0 - 4.34% of EO. | Ohlott 1978, Baydar et al. 2008 |
| Rosa damascena sommervillo cv ‘Quatre Saisons’ | Free ME detected in petals volatiles, and detected volatiles emitted rhythmically, with maximum peaks coincided at 8-10 hour. | Picone et al. 2004 |
| Rosa hybrida | Petals contained ME; ME (0.2%) detected only in floral EO of ‘Sandra’ using U.18 (tessaduct indene) cartridge. | Lavid et al. 2002, Kim et al. 2000 |
| Rosa phaeacantha | Tr of ME and eugenol in petals fragrance. | Yomogida 1992 |
| Rosa rugosa | Floral EO contained ME (6.88%), Volatiles from flower and pollen contain >20% ME and eugenol 4% -<20% of highest peak; ME and eugenol among 12 major components in pollen & pollen plus volatiles. | Wu et al. 1985, Dobson et al. 1987, Dobson & Bergstrom 2000 |
| Rosa sericea X rosa rugosa | Floral fragrance contained 0.30% eugenol and 0.68% ME. | Chen et al. 1987a |

### Solanaceae - Nightshade/Potato family (Solanales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Physalis angulata [Paraguay jasmine] | ME 1% and 0.1% in young deep purple and mature white flowers, resp. with linalool and (E)-cinnamene as major components. | Bertrand et al. 2006 |

### Tamaricaceae – Tamarix family (Tamaricaceae)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Tamarix chinensis var. nana | ME (tr) and eugenol (0.38%) in floral EO. | Saitama et al. 2008b |

### Thymelaeaceae – Mercuria family (Malvales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Duphy genkwa | Flower EO contained 127 compounds, 0.1% ME (4.5%) and eugenol (tr) | Ueyama et al. 1990 |

### Valerianaceae – Valerian family (Dipsacales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Valeriana nihonensis | Inflorescence contained 0.4% and 0.6% of EO for eugenol and ME, resp. which were not found in other plant parts | Fekete et al. 2002 |

### Verbenaceae - Verbena/Vervain family (Lamiales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Lippia citriodora cv 'kavach' [Bushy Mexican Lippia] | Linalool in leaf (67%) & inflorescence (79%) with 0.1% ME & 0.5% eugenol of inflorescence EO, but absent in leaf EO. | Mishra et al. 2010 |
| Lippia odoratissima Lippia schomburgkiana [Orange rum diacynum] | Three chemotypes – only type A collected from 3 different sites in Columbia had ME 0.01-0.01% in aerial parts EO. | Stashenko et al. 2010 |

### Zingiberaceae – Ginger family (Zingiberales)

| Genus/Species | Description | Reference |
|---------------|-------------|-----------|
| Hedychium coronarium [White ginger lily] | ME tr amount in flower EO with F. & Z-methyl isoeugenol 0.45 & 0.06% of peak area. | Matsunoto et al. 1993 |

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* quantitative data given if available.
** symbols and abbreviations as in Table 1.