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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 chemoecological 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-1-ene; O-methyleugenol; 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 dillapiol, 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 basil 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 basil. 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 preceeding 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/neighbors 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 μ L/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 *crucivora* (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 Chikungunya 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 LC₅₀ values of 14.95 mg/L air and 112.74 µg/adult, respectively (Chu et al. 2010). Fumigant and repellent 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/cm² (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.

3.3.1.1. 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 repellent (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

1995, 1996, 1998). 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. caryae*, *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, α - and β -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 flosuosus* (Poaceae), *Rosa damascena* and *R. hybrida* (Rosaceae), *Tamarix boveana* (Tamaricaceae), *Daphne genkwa* (Thymelaceae), and *Lippia alba* and *Lippia schomburgkiana* (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 latifolia*, 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. renggerioides* (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.

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.

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

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. violaceae*, 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 Sauers-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 conopsea*, 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. *Bactrocera* *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

bactroceroophilous *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 (eugarone), 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 (Schechter 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/repellent 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 chemoeological basis for these bitrophic interactions between plants and insects mediated by ME.

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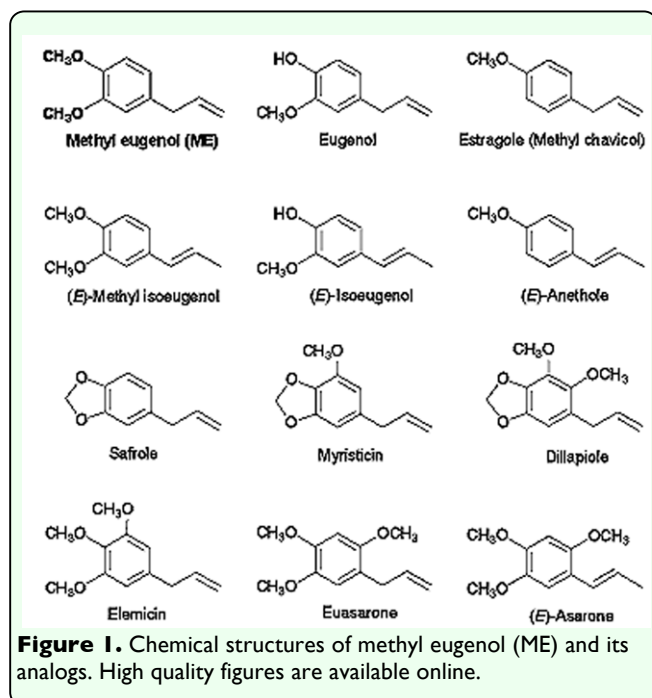


Figure 3. A male *Bactrocera umbrosa* feeding on *Spathiphyllum cannaefolium* spadix. High quality figures are available online.



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.

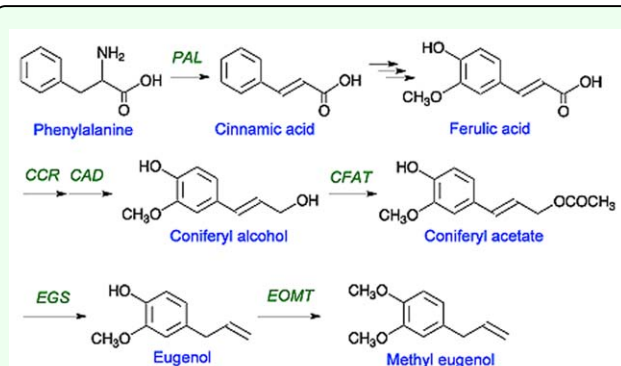


Figure 5. A male *Bactrocera dorsalis* bearing pollinia on see-saw lip of *Bulbophyllum patens*. High quality figures are available online.



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 elevatopuntatum* flower (P.T. Ong). High quality figures are available online.

Table 1. Plant family (order) and species containing methyl eugenol (ME)*.

Species (Synonym)	Common name	Remark**	Reference
Acanthaceae - Acanthus family (Lamiales)			
<i>Justicia ventricosa</i>		Plant attracted the oriental fruit fly and volatile oil contained 8.0% ME.	Kittibamruangsook 1980
<i>Strobilanthes callosus</i> (<i>Carvia callosa</i>)		Combined leaf & stem at pre- and post-flowering stages had ME 0.04 and 0.16% of EO, resp.	Weyerstahl et al. 1992.
Acoraceae - Calamus family (Acorales)			
<i>Acorus calamus</i> [Sweet flag]		ME present (1.0%); plant EO had 1.0% ME; root EO of up to 80% ME in European & Japanese samples.	Saxena et al. 1977; De Vincenzi et al. 2000; Duke 1985
<i>Acorus gramineus</i> [Japanese sweet flag]		ME (0.64 %) in EO from rhizomes.	Koo et al. 2003
Amariyllidaceae - Amaryllis/ Daffodil family (Asparagales)			
<i>Proiphys amboinensis</i> (<i>Eurycles amboinensis</i>) [Cardwell/Christmas Lily]		Green leaf had ME in tr, but during leaf browning, yellow and brown parts had 0.1 and 0.2-0.3 µg/mg.	Chuah et al. 1997
Anacardiaceae – Sumac family (Sapindales)			
<i>Mangifera indica</i> [Mango]		Leaf EO contained ME; Fruit EO of 10 from 20 CVs had ME in tr.	Craveiro et al. 1980; Pino et al. 2005
<i>Pistacia lentiscus</i> [Mastic tree]		ME of aerial parts 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; Fleisher & Fleisher 1992
<i>Spondias mombin</i> (<i>S. lutea</i>) [Hog plum]		Fruit EO contained 2 ppm of ME and 3 ppm of α -copaene.	Adedeji et al. 1991
Annonaceae – Custard-apple family (Magnoliales)			
<i>Annona glabra</i> [Pond apple]		ME tr amount in fruit volatiles.	Pino et al. 2002
<i>Annona squamosa</i> [Sugar apple, Sweetsop]		ME 2.3% of leaf EO.	Joy & Rao 1997
<i>Guatteria wachenheimi</i> (<i>Guatteria microsperma</i>)		ME 1.4% & 0.4% in bark and leaf EOs, resp.	Fournier et al. 1997
<i>Pseuduvaria mulgraveana</i> var <i>glabrescens</i> [Mulgrave's Yellowwood]		Leaf EO with ME (61%) as major component.	Brophy et al. 2004
Apiaceae - Carrot family (Apiales)			
<i>Anthriscus cerefolium</i> [Garden chervil, Chervil]		ME detected.	Degen 1998
<i>Bupleurum chinense</i> [Chai hu, Thorowax, Saiko]		EO of dried root contained ME (0.1%) and eugenol (0.9%).	Zhao et al. 2009
<i>Critium maritimum</i> [Sea fennel, rock samphire]		ME (0.3% of EO) only in leaves of 1 of 4 populations of Amorgos Island, Greece.	Katsouri et al. 2001
<i>Cuminum cyminum</i> [Cumin]		Root EO 1.52% ME, and leaf & stem EO had 1.22% ME.	Bettaieb et al. 2010
<i>Daucus carota</i> [Wild carrot]		ME (1.23%) in plant EO; 0.2% ME in leaf EO that had antibacterial activity due to (<i>E</i>)-methyl isoeugenol; subsp. <i>sativus</i> var <i>Flakker</i> had ME (1.2 - 2.1%) in leaflet EO but tr in var <i>Nantes</i> ; subsp. <i>maximus</i> fruit EO had 1.97 & 37.2% of ME & <i>E</i> -methyl isoeugenol, resp.	Kameoka et al. 1989; Rossi et al. 2007; Kainulainen et al. 1998; Saad et al. 1995
<i>Daucus glaber</i> (<i>D. litoralis</i>) [Coastal carrot]		ME 1.55% and 2.51% in leaf and fruit EO, resp.	Mansour et al. 2004
<i>Diploaenia cachrydifolia</i>		ME & <i>E</i> -methyl isoeugenol detected only in root EO at 0.8 & 1.1%, resp.	Ozcan et al. 2004
<i>Echinophora platyloba</i>		ME (0.02%) in EO of aerial parts; aerial parts at rosette, budding & flowering stages had ME at 2.2, 0.9 & 0.6% of EO, resp.	Hassapouraghdam et al. 2009; Ghani et al. 2009
<i>Echinophora sibthorpiana</i> [Tarhana herb, Cortuk spice]		ME major component in aerial parts EO, & 0.05-0.1% ME inhibited yeast & moulds growth; ME (50.4%) the major component in EO from Iran.	Kivanc 1988; Ahmad et al. 1999
<i>Echinophora tenuifolia</i> subsp. <i>Sibthorpiana</i> [Turkish hyssop]		ME 49.86% (EO 1.3%); Fruit EO (1.0-2.2%) contained ME (18-59%), as one of three main components; ME (24.7%) in EO of fully bloom aerial parts; ME (28.6 % of EO) 2 nd major component.	Tanker et al. 1976; Baser 2002; Akgul & Chialva 1989; Georgiou et al. 2010
<i>Eremocharis triradiata</i>		ME (69.8%) main constituent of EO of aerial parts with 58 compounds.	Senatore et al. 1997
<i>Foeniculum vulgare</i>		ME and methyl isoeugenol 0.07% and 0.12% in leaf EO, resp; fruits had ME and eugenol 0.18% and 0.52% of EO, resp; ME in aerial parts at 0.9% of EO.	Chowdhury et al. 2009; Găinar & Bala 2006; Shatar & Altantsetseg 2000
<i>Foeniculum vulgare</i> subsp. <i>piperitum</i> [Sweet Fennel]		One form contained 15 % ME and 41 % g-asarone.	Krüger et al. 2005 (unpublished)
<i>Glehnia littoralis</i> [Beach/ American silvertop]		ME (0.09 – 3.19%) in four out of eight plant parts EO.	Miyazawa et al. 2001
<i>Heracleum transcaucasicum</i> [Common hogweed]		ME (0.3%) in EO of aerial parts.	Firuzi et al. 2010
<i>Hippomarathrum cristatum</i> [Wild marathron]		Phenylpropanoids (4.9% of EO) with myristicin 4.4% & ME in tr.	Ozek et al. 2007
<i>Levisticum officinale</i> [Lovage]		Seed EO contained 0.1-0.2 % ME.	Bylaite et al. 1998
<i>Libanotis montana</i>		ME (0.6%) of EO.	Kapetanios et al. 2008
<i>Ligusticum mutellina</i> (<i>Mutellina purpurea</i>) [Alpine Lovage]		Myristicin (27-39%) main component of fruit, herb & root EOs with 0.12% ME in fruit EO & tr in latter two EOs.	Brandt & Schultze 1995
<i>Ligusticum scoticum</i> [Scotch lovage/ parsley]		Aerial parts EO contained ME 0.043%	Jean et al. 1990
<i>Lomatium graveolens</i> [King desertparsley]		ME 0.2% of aerial parts EO.	Beauchamp et al. 2009
<i>Lomatium junceum</i> [Rush biscuitroot]		ME 0.1% of aerial parts EO.	Beauchamp et al. 2009
<i>Myrrhis odorata</i> [Cicely or Sweet Cicely]		Plant EO contained <i>E</i> -anethole (85.48%) and ME (9.08%).	Hussain et al. 1990
<i>Osmorhiza longistylis</i> [Aniseroot, licorice root, or wild anise]		Plant EO contained <i>E</i> -anethole (95.43%) and ME (0.04%).	Hussain et al. 1990
<i>Petroselinum crispum</i> (<i>Apium petroselinum</i>) [Garden parsley, Parsley]		Aerial parts (leaves and fruits) contained ME and eugenol 3.8% & 0.7% of EO, resp.	Shatar & Altantsetseg 2000
<i>Pimpinella affinis</i>		ME 2.3 & 9.7% in seed EO from two populations in Iran.	Askari & Sefidkon 2006
<i>Pimpinella anisum</i> (<i>Anisum vulgare</i>) [Anise]		14 sample of seed EOs varied in ME (0 - 1.18%) and methyl chavicol (0 -2.67%).	Arslan et al. 2004

<i>Pimpinella barbata</i>	Aerial parts contained ME & elemicin at 34% & 6.9% of EO, resp.	Fakhari & Sonboli 2006
<i>Pimpinella corymbosa</i>	Stem and leaf EO contained 0.1% ME.	Tabanca et al. 2005a
<i>Pimpinella olivieroides</i>	Leaves contained ME at 70.6% of EO.	Tabanca et al. 2005b
<i>Pimpinella puberula</i>	Fruit and leaf & stem EOs had 23.1% and 29.6% ME, resp.; Leaf EO has ME 23.1 % of oil.	Tabanca et al. 2005a,b
<i>Pimpinella rhodantha</i>	Leaves had <5.0% ME of EO.	Tabanca et al. 2005b
<i>Pituranthos scoparius</i>	Stem EO had ME (5.6%) as 1 of 4 major components; seed & stem EOs had 1.6 & 5.9% ME, resp..	Verite et al. 2004; Boutaghane et al. 2004
<i>Portenschlagiella ramosissima</i> (<i>Athamania ramosissima</i>)	Seed EO (15%) - with ME; Root, aerial parts and seeds had 0.4, 0.3-0.7 and 1.0% of EO, resp.	Bohannon & Kleiman 1977; Sokovic et al. 2008
<i>Prangos asperula</i> subsp. <i>haussknechtii</i>	ME (0.6%) of fruit EO.	Sajjadi & Mehregan 2003
<i>Prangos ferulacea</i>	Fruit EO contained ME (0.07%).	Massumi et al. 2007
<i>Prangos heyneae</i>	Fruit EOs from two localities - one had 0.1% ME but none in the other.	Baser et al. 2000
<i>Prangos uechtritzi</i>	ME at 2.2% of fruit EO.	Ozcan et al. 2000
<i>Scandix iberica</i>	Fruits contained estragole (90.5% of EO) with 0.2% ME.	Kaya et al. 2007
<i>Semenovia tragoides</i>	ME (5%) of aerial parts EO.	Masoudi et al. 2002
<i>Thapsia maxima</i>	ME (59-63%) major component in fruit EO of two plant types; ME 6.8% in type II & none in type I plants.	Avato et al. 1992; Avato & Smitt 2000
<i>Thapsia villosa</i>	Polyploid 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 0.4% in fruit EO, whereas type 5 had 33-66% ME; ME in 5 tetraploid & 4 hexaploid specimens at 33.3 – 66.1% & 45.7 – 62.5%, resp.	Smitt 1995; Avato et al. 1996a; Avato et al. 1996b.
<i>Tornabenea annua</i> (<i>Melanoselinum annuum</i>)	Trace quantities of ME in fruit EO from some specimens in Cape Verde Islands.	Grosso et al. 2009
<i>Tornabenea insularis</i>	Trace quantities of ME in fruit EO from some specimens in Cape Verde Islands.	Grosso et al. 2009
<i>Trachyspermum copticum</i>	ME tr quantity in dried fruit EO.	Chialva et al. 1993
<i>Zeravschania pastinacifolia</i>	ME (0.1%) in EO of dried aerial parts.	Yassa et al. 2003
Apocynaceae - Dogbane family (Gentianales)		
<i>Periploca sepium</i>	ME (0.05%), eugenol (0.39%) & (Z)-methyl isoeugenol (0.02%) in root EO.	Miyazawa et al. 2004
Aquifoliaceae – Holly family (Aquifoliales)		
<i>Illicium anisatum</i> (<i>I. religiosum</i> , <i>I. japonicum</i> , <i>I. shikimmi</i> and <i>I. skimmi</i>)	ME (9.8%) 1 of 5 main components of leaf EO; ME not detected, instead methoxyeugenol (0.5%).	Cook & Howard 1966; Kim et al. 2009
<i>Illicium brevistylum</i>	Tr ME detected in fruit EO.	Howes et al. 2009
<i>Illicium lanceolatum</i>	Fruit EO contained ME (< 0.1 to 2.1%).	Howes et al. 2009
<i>Illicium parviflorum</i> [Swarm star anise, Yellow anise tree]	Leaf and branch EO dominated by 68.14 ± 0.88% saffrole, 13.18 ± 1.01% linalool, and 11.89 ± 0.87% ME.	Tucker and Maciarello 1997
<i>Illicium simonsii</i>	8.9% ME & 1.8% elemicin in fruit EO.	Chu et al. 2010
<i>Illicium verum</i> [Star anise]	Fruit EO contained trans-anethole (90.11%) and ME (0.43%).	Hussain et al. 1990
Aristolochiaceae – Birthwort family (Piperales)		
<i>Asarum canadense</i> [Snake root]	ME 11% in volatile oil.	Saiki et al. 1967b
<i>Asarum caulescens</i>	ME 15% in volatile oil.	Saiki et al. 1967b
<i>Asarum forbesii</i>	ME (10.3%) and a-asone (58.8%) major components in root EO; methyl isoeugenol (33.3%) in leaf oil.	Zhang et al. 2005
<i>Asarum heterotropoides</i> [Xi xin]	ME (47%) in root extract; ME in EO of subterranean and upterranean parts 21-39% & 1.4-9.6%, resp, and ME highest during sprouting & after-fruiting.	Kosuge et al. 1978; Wang et al. 1997
<i>Asarum heterotropoides</i> var <i>seoulensis</i>	ME a major component in volatile oil of the Korean 'Xixin'.	Saiki et al. 1967a
<i>Asarum leptophyllum</i>	ME 8% and saffrole 36% of EO.	Saiki et al. 1967b
<i>Asarum sieboldii</i> [Chinese wild ginger]	EO contained ME; ME (0.47% in root EO).	Tian et al. 1981b; Han et al. 2008
<i>Asarum sieboldii</i> var <i>cincoliferum</i>	ME 78% of EO.	Saiki et al. 1967b
<i>Asiasarum dimidiatum</i> Maekawa	ME 26% of EO.	Saiki et al. 1967b
<i>Asiasarum heteropoides</i> var <i>mandshuricum</i> [Liao Xixin]	ME 59% of EO.	Saiki et al. 1967B; Tian et al. 1981a
<i>Heterotropa albivenium</i>	ME 1% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa asaroides</i>	ME 2%, elemicin 0.3 % and saffrole 94% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa aspera</i>	ME 0.1% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa constricta</i>	ME 4% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa controversa</i>	ME 0.2% of volatile oil.	Saiki et al. 1967b
<i>Heterotropa costata</i>	ME 0.1% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa crassa</i>	ME 1% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa curvistigma</i>	ME 0.3% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa faurie</i>	ME 2% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa fudzinoi</i>	ME 11% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa hayatana</i>	ME 1% of volatile oil.	Saiki et al. 1967c

<i>Heterotropa hexaloba</i>	ME 3% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa hexaloba</i> var <i>perfecta</i>	ME 41% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa kiusiana</i>	ME 1% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa kurosawae</i>	ME 0.1% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa megacalyx</i>	ME 50% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa muramatsui</i>	ME 20% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa nankaiensis</i>	ME 0.3% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa nipponica</i>	ME 3% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa nipponica</i> var <i>kaoyana</i>	ME 0.5% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa nipponica</i> var <i>rachypodion</i>	ME 4% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa oblonga</i>	ME 2% of volatile oil.	Saiki et al. 1967c
<i>Heterotropa rigescens</i>	ME 0.2% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa sakawana</i>	ME 3% of EO.	Saiki et al. 1967c
<i>Heterotropa satsumensis</i>	ME 1% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa savatieri</i>	ME 2% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa takaoi</i>	ME 21% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa takaoi</i> var <i>dilatata</i>	ME 1% of volatile oil.	Saiki et al. 1967d
<i>Heterotropa tamaensis</i>	ME 2% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa unzen</i>	ME 1% of volatile oil.	Saiki et al. 1967e
<i>Heterotropa yakusimensis</i>	ME 1% of volatile oil.	Saiki et al. 1967e
<i>Hexastylis arifolia</i>	Root & leaf EOs contained safrole & ME at ratios of 58.2% : 19.9% and 69.9% : 5.4%, resp.	Hayashi et al. 1983
<i>Hexastylis mimus</i>	Root EO contained safrole and ME in traces, and no ME in leaf EO.	Hayashi et al. 1983
Asteraceae - Aster family (Asterales)		
<i>Achillea conferta</i>	Among 48 volatile components - ME (2.7%) of aerial parts EO.	Saeidnia et al. 2005
<i>Achillea goiocephala</i>	Dried flowering herbal parts EO had tr quantity of ME.	Baser et al. 2001b
<i>Achillea ketenoghui</i>	ME (0.6-0.7%) and eugenol (0.4-0.6% TIC of EO of aerial parts.	Baser et al. 2001a
<i>Achillea lycanica</i>	ME (0.3%) and eugenol (0.8%) TIC in EO of aerial parts.	Baser et al. 2001a
<i>Achillea millefolium</i> [Common yarrow]	Plants from 2 of 14 different locations in Lithuania contained ME (0.07-0.14%) in leaf EO.	Gudaityte & Venskutonis 2007
<i>Achillea monocephala</i>	ME in leaf EO decreased from 0.6% to zero with temperature (100-175 °C) during water extraction.	Gogus et al. 2006
<i>Achillea oxydonta</i>	Aerial parts contained 0.2% ME of EO.	Esmaili et al. 2006
<i>Ageratum conyzoides</i> [Whiteweed; Goat weed]	ME 1.8% of plant (without roots) EO.	Rao & Nigam 1973
<i>Anthemis melanollepis</i>	Air-dried plant EO had 0.4% ME.	Saroglou et al. 2006
<i>Anthemis tinctoria</i> var <i>parnassica</i>	ME (1.2%) in EO of air-dried plant materials.	Saroglou et al. 2006
<i>Anthemis wernerii</i> ssp. <i>wernerii</i>	Air-dried plant EO contained 0.1% ME.	Saroglou et al. 2006
<i>Arctium lapp</i> [Greater Burdock]	EO of dried ripe fruits contained 0.1% of ME.	Zhao et al. 2009
<i>Artemisia annua</i> [Annual or sweet wormwood]	2 CVs - 1 has ME & eugenol at 0.2 & 0.3% of EO, resp, and tr in the other.	Goel et al. 2008
<i>Artemisia abrotanum</i>	2 of 4 vegetative phases – emergence of runner and mass flowering phases ME was 1.58 & 0.30 % in weight of EO.	Khodakov et al. 2009
<i>Artemisia capillaris</i> [Yin Chen Hao; Chinese moxa]	Growing buds contained ME.	Yano 1987
<i>Artemisia campestris</i> var <i>glutinosa</i> [Western Sagewort]	ME in tr amount in EO of aerial parts.	Juteau et al. 2002
<i>Artemisia demissa</i>	ME (8.5%) in oil.	http://www.ema.europa.eu
<i>Artemisia dracunculoides</i> [Tarragon]	ME 280.1 ± 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%).	Ribnicki et al. 2004; Lopes-Lutz et al. 2008; Kordali et al. 2005
<i>Artemisia filatovae</i> [Filatov wormwood]	ME - 0.2% in weight of aerial parts EO.	Atazhanova et al. 1999
<i>Artemisia glabella</i>	4.6% ME and 0.2% eugenol in dried plant EO.	Bicchi et al. 1985
<i>Artemisia herba-alba</i> (A. <i>inculta</i>) [Desert wormwood]	Combined flowers, leaves, and stems contained ME and estragole at 0.7 and 0.5% of EO, resp.	Hudaib & Aburjai 2006
<i>Artemisia pallens</i> [Davana]	ME and eugenol detected.	Gulati & Khan 1979
<i>Artemisia persica</i> [Davana]	ME (0.46%) in EO (0.40%) of the dried plant.	Sadeghpour et al. 2004
<i>Artemisia scoparia</i> [Red-stem wormwood]	EO of aerial parts contained ME (27.5%).	Basher et al. 1997
<i>Artemisia subdigitata</i>	Leaf EO dominated by 11.2% eugenol, 9.4% ME and 9.0% camphor.	Shatar et al. 2002
<i>Artemisia vulgaris</i> [mugwort or common wormwood]	Plants from France had ME at 5.4, 6.8 and 1.0% of EO in vegetative, flower-buds & flowering stages, resp.	Jerkovic et al. 2003
<i>Baccharis grisebachii</i>	ME (0.5%) in EO of aerial parts.	Hadad et al. 2007

<i>Bubonium imbricatum</i>	ME 0.02% of aerial parts EO.	Alilou et al. 2008
<i>Centaurea calcitrapa</i>	One of ten <i>Centaurea</i> spp. that had ME - 0.5% of aerial parts EO.	Karamenderes et al. 2008
<i>Dyssodia acerosa</i> (<i>Thymophylla acerosa</i>) [Prickleleaf dogweed]	ME (0.1%), eugenol (0.3%), β -carphyllene (0.1%) and α -humulene (tr) in plant EO.	Tellez et al. 1997
<i>Felicia muricata</i> [White Felicia]	ME (0.4%) of leaf EO.	Ashafa et al. 2008
<i>Gundelia tournfortii</i> [Galgal, Tumbleweed, Tumble thistle]	EO of aerial parts contained ME (12.57%), eugenol (6.7%), & β -caryophyllene (5.94%).	Halabi et al. 2005
<i>Imula oculus-christi</i> [Christ's eye]	ME (9.6%) one of five major components of EO.	Javidnia et al. 2006
<i>Ophryosporus pinifolius</i>	EO of aerial parts from Andes, Chile, contained 1% ME.	Niemeyer 2009
<i>Pluchea arabica</i> (<i>P. laxa</i> , <i>P. multiflora</i>)	ME (9.15%) in fresh twigs EO.	Suliman et al. 2006
<i>Pluchea sagittalis</i> [Wingstem camphorweed, lucera, madreclavo]	Leaf and stem EOs contained 23 terpenoids - including ME.	Talenti 1982
<i>Rhaponiticum acaule</i> (<i>Leuzea acaulis</i> or <i>Centaurea chamaer-haponicum</i>)	EOs of capitula and aerial parts contained 11.4 and 10.6% of ME, resp.	Boussaada et al. 2007
<i>Santolina insularis</i> [Crespolina maggiore]	4 chemotypes - two had ME 50.78 (± 0.35) and 121.05 (± 94.03) $\mu\text{g/g}$ dry wt in EO, and two with no ME.	Gnavi et al. 2010
<i>Solidago odora</i> [Sweet Golderod, Texas Goldenrod]	Varieties <i>f. inodora</i> and <i>f. odora</i> contained 4.37 \pm 3.20 and 5.77 \pm 2.61%, resp; and the former also contained <i>E</i> -ethyl isoeugenol (12.89%) and <i>E</i> -isoeugenol (3.08%).	Tucker et al. 1999
<i>Tagetes lucida</i>	Major components - estragole and ME at 45 and 20% in plant EO, resp.	Hethelyi et al. 1987
<i>Tagetes filicifolia</i> (<i>T. minuta</i>)	Plant EO had estragole (61.3%) and <i>E</i> -anethole (36.6%) with 0.01% ME.	Hussain et al. 1990
<i>Tagetes lucida</i> [Mexican/Spanish/Texas tarragon, sweet mace]	Plant EO contained 3.9% ME.	Ruff et al. 2002
<i>Tagetes mandonii</i> ["chick chimpa"]	ME 0.2% in EO of aerial parts.	Senatore & De Feo 1999
<i>Tagetes terniflora</i>	ME (2.2%) in EO of aerial parts.	De Feo et al. 2005
<i>Tanacetum parthenium</i> [Feverfew]	Flowering aerial parts EO contained camphor (46.2%) with 0.1% ME; leaves and inflorescences emitted 9.9 \pm 3.3 ng/24h.	Pavela et al. 2010; Christensen et al. 1999
<i>Vamillosmopsis arborea</i> [Candeia]	ME 5.9% of bark oil and 36% of wood bark EO.	http://www.ema.europa.eu
<i>Vernonia smithiana</i> (<i>Hilliardiella smithiana</i>) ["Umwanzuranya"]	Dried plant EO contained 5.41% β -elemicin and 3.12% ME.	Vagionas et al. 2007
<i>Wedelia paludosa</i> var <i>vialis</i>	ME among 28 compounds detected in leaf and stem oils.	Mancini 1980
Bignoniaceae - Bignonia/Trumpet-creeper family (Lamiales)		
<i>Tabebuia impetiginosa</i> [Pink Trumpet tree]	ME (0.24%) and eugenol (0.96) of inner bark EO.	Park et al. 2003
Boraginaceae – Borage or Forget-me-not family (order= unplaced asterid I)		
<i>Borago officinalis</i> [Borage, Starflower]	Leaves ME content at 1.5% of EO or 4.5 $\mu\text{g/g}$ fresh weight.	Mhamdi et al. 2009
Brassicaceae – Mustard family (Brassicales)		
<i>Eruca sativa</i> (<i>Eruca vesicaria subsp. sativa</i> , <i>Brassica eruca</i>) [Rocket/Rucola salad]	ME (0.9%) in headspace sample of fresh leaf volatiles.	Jirovetz et al. 2002a
Burseraceae – Torchwood/ Frankincense family (Sapindales)		
<i>Boswellia serrata</i> [Indian frankincense]	Gum resin contained ME (3.7%) and methylchavicol (8.9%), which were absent in other <i>Boswellia</i> species.	Hamm et al. 2005
<i>Canarium indicum</i> [Blume galip]	ME (300-700 ppm) in oil.	http://www.ema.europa.eu
<i>Dacryodes edulis</i> [Safou, African pear]	Fruit EO contained traces of ME which was not detectable in seeds.	Jirovetz et al. 2005
Canellaceae – Canella family (Canellales)		
<i>Canella winterana</i> (<i>Canella alba</i>) [Wild cinnamon]	Bark yielded eugenol, ME, asarone etc.	Gracza 1980
Capparaceae – Caper family (Brassicales)		
<i>Capparis spinosa</i> var <i>spinosa</i>	ME 0.3% of shoot EO and not detected in fruits.	Ozcan & Chalchat 2007
Cistaceae – Rock-rose family (Malvales)		
<i>Cistus salvifolius</i> [Rock rose]	6 of 15 populations in Greece had ME (0.1-0.9%) in EO of aerial parts during fruiting.	Demetzos et al. 2002
Clusiaceae – Mangosteen family (Malpighiales)		
<i>Clusia scrobiculata</i> [Brazilian Red Propolis]	<i>E</i> -anethol (13%), methyl eugenol (14%), <i>E</i> -methyl isoeugenol (18%), elemicin (26%) and <i>E</i> -isoelemicin (11%) in non-polar fraction.	Trusheva et al. 2006
<i>Hypericum aegypticum</i>	Dried plants had ME at 0.5 and 0.6% of EO in ssp. <i>aegypticum</i> and ssp. <i>marroccum</i> , resp.	Crockett et al. 2007
<i>Hypericum tomentosum</i>	ME (1.92%) in EO of aerial parts.	Hosni et al. 2008
Combretaceae – Indian Almond family (Myrtales)		
<i>Terminalia catappa</i> [Tropical almond fruit; Sea almond]	Headspace extraction using SPME and Porapak Q showed fruit volatiles contained 31 \pm 1 and 6 \pm 2 % ME, resp.	Siderhurst & Jang 2006
Cornaceae – Dogwood family (Cornales)		
<i>Cornus officinalis</i> [Japanese cornel, Japanese cornelian cherry]	Fruit EO contained ME (7.4%), isoasarone (7.1%), β -phenylethyl alcohol (4.1%) & elemicin (3.2%).	Miyazawa & Kameoka 1989
Cupressaceae – Cypress family (Pinales)		
<i>Juniperus angosturana</i>	Leaf EO contained tr quantity of ME	Adams et al. 2007
<i>Juniperus chinensis</i> var <i>kaizuca</i> [Chinese Juniper]	ME (4.4-5.3%) in plant EO.	Adams et al. 1994
<i>Juniperus flaccida</i> [Drooping Juniper]	Trace amount of ME in two varieties - <i>flaccida</i> & <i>poblana</i> .	Adams et al. 1984

<i>Juniperus gracilior</i> var <i>urbaniana</i> [Graceful Juniper]	ME (0.9%) in leaf EO.	Adams 1997
<i>Juniperus lucayana</i> [Lucayan juniper, Barbados-cedar]	Leaf EO ME (8.2%) from Bahama Islands, but tr amount of ME from Cuba.	Adams et al. 1987
<i>Juniperus scopulorum</i> Sarg.	ME (15.5%) in leaf EO.	Adams et al. 1981
<i>Juniperus virginiana</i> [Red juniper, Eastern red cedar]	Leaf oil - mainly sabiene with ME (tr-12.1%), saffrole (tr-18.9%), and elemicin (1-12.3%); in var silicicola & virginiana - 8.2 & 2.9% ME in leaf EO, resp.	Vinutha & Von Rudloff 1968; Adams 1994
<i>Picea koraensis</i> [Korean spruce]	Oleoresin contained moderate amounts of ME.	Khan et al. 1983
<i>Pinus funebris</i> (<i>P. densiflora</i>) [Japanese red pine]	ME one of four main monoterpenes.	Khan et al. 1984
<i>Pinus nigra</i> Arnold	ME 0.05% - 0.17% in pine needle EO varied according to season.	Sezik et al. 2010
<i>Sequoiadendron giganteum</i> [Giant sequoia, Sierra/Sierran redwood]	ME 2.1% and 0.9% in distilled residue and total leaf EO; new foliage had no saffrole, eugenol, ME and elemicin which constituted ca. 10% of the oil from the mature foliage.	Gregonis et al. 1968; Levinson et al., 1971
<i>Thuja orientalis</i> (<i>Biota orientalis</i>)	Root and stem wood oils contained 2.1 & 1.3%, resp.	Singh & Yadaw 2005
Ebenaceae – Ebony family (Ericales)		
<i>Diospyros malabarica</i> (<i>Diospyros embryopteris</i>) [Thimbiri]	Fruit EO contained 1.3% ME among several phenylpropanoids (36.7%).	Viswanathan et al. 2002
<i>Doryphora sassafras</i> [Sassafras]	Leaf and bark EO contained ME (27-47%), saffrole (15-30%) and camphor (15-19%).	Brophy et al. 1993
Equisetaceae – Horsetail family (Equisetales)		
<i>Equisetum hiemale</i> / <i>hyemale</i> (<i>E. prevatum</i>) [Horsetail, Scouring rush]	EO from dried aerial parts contained ME (0.1%).	Zhao et al. 2009
Ericaceae – Heath family (Ericales)		
<i>Rhododendron simi</i>	Leaves contained ME at 0.1% of EO, and no detectable ME in flowers.	Zhao et al. 2006
Euphorbiaceae – Spurge family (Malpighiales)		
<i>Croton aff. zehneri</i>	EO contained ME.	Craveiro et al. 1978
<i>Croton cuneatus</i>	ME (25.9%) and methyl isoeugenol (1.2%) of aerial parts EO.	Suárez et al. 2005
<i>Croton grewoides</i>	ME (10.6%) and (<i>E</i>)-methyl isoeugenol (4.7%) in leaf EO, the latter (30.0%) and ME (4.6%) in stem EO.	Silva et al. 2008
<i>Croton jimenezii</i>	Leaf EO of plants from a location had ME (29.5%), while ME was absent from another location in Costa Rica.	Ciccio and Segnini 2002
<i>Croton malambo</i> [Malambo/Matias bark]	ME 65.4% of bark EO; 94.2% in leaf EO; 420g heartwood oil yielded 166g ME (i.e. ca 40% EO).	Suárez et al. 2005 & 2008; Bracho & Crowley 1966
<i>Croton matourensis</i>	EO contained ME (14.2%), elemicine (7.6%). & isoelemicine (11.3%).	Reinaldo et al. 2010
<i>Croton nepetaefolius</i>	Main components in EO were cineole, ME and terpineol; ME 6.6% of leaf EO.	Magalhães et al. 1998; Abdon et al. 2002
<i>Croton palanostigma</i>	17.2, 16.3, 24.1, and 25.6% ME in EOs of leaves, fruits, branches and bark, resp. <i>E</i> -methyl isoeugenol found in EO of branches (15.3%) and bark (25.6%).	c/f Maia & Andrade 2009
<i>Croton parvifolius</i>	EO contained small amounts of ME.	De Etcheves et al. 1981
<i>Phyllanthus emblica</i> (<i>Emblca officinalis</i>) [Indian gooseberry]	Fruit EO ME (1.25 %), β -caryophyllene, β -bourbonene and thymol - four components with antimicrobial activity; 1.80% and 3.34% ME in fruit EO, resp.	Zhao et al. 2007; Liu et al. 2009
Fabaceae – Pea family (Fabales)		
<i>Acacia caven</i> . [Molina]	ME and eugenol found in oil.	Talenti et al. 1981
<i>Hedysarum polybotrys</i> [Milk-vetch Root]	ME (9.6%) of EO.	Chen et al. 1987b
<i>Medicago marina</i> [Coastal/sea medick]	ME content of aerial parts EO in vegetative and reproductive phases was 1.7% and 20.4%, resp.	Flamini et al. 2003
<i>Monopteryx uqudu</i>	Major components of EO - ME (39.0%), elemicin (29.6%) and methyl chavicol (13.7%).	c/f Maia & Andrade 2009
Fagaceae – Beech family (Fagales)		
<i>Quercus petraea</i> [Sessile oak]	Wood EO contained ME, eugenol and isoeugenol with mean values of 0.21, 0.75 and 0.25 μ g/g, resp.	Guchu et al. 2006
<i>Quercus robur</i> [Pedunculate oak]	Wood EO contained ME, eugenol and isoeugenol with mean values of 0.52, 1.14 and 0.15 μ g/g, resp.	Guchu et al. 2006
Geraniaceae – Geranium family (Geraniales)		
<i>Erodium cicutarium</i> (<i>Geranium cicutarium</i>) [Redstem filaree, Common Stork's-bill]	ME (10.6%) one of four major components in EO.	Lis-Balchin 1993
<i>Pelargonium grossularioides</i> [gooseberry]	ME (11.2%) one of four major components in EO.	Lis-Balchin 1993
<i>Pelargonium odoratissimum</i> [Apple geranium]	ME (31.7-79.8%) in leaf EO.	Lis-Balchin & Roth 2000
<i>Pelargonium sidoides</i> [Kalwerbossie; Rabassam]	Leaf oil contained 4.3% ME and 3.6% elemicin.	Kayser et al. 1998
<i>Pelargonium x fragrans</i> (<i>Geranium fragrans</i>) [Mabel grey]	ME (10.2%) in EO.	Lis-Balchin & Roth 2000
Lamiaceae – Mint family (Lamiales)		
<i>Agastache foeniculum</i> [Anise hyssop / Lavender hyssop]	ME in leaf and inflorescence increased from 28.6 to 41% of EO during 17 day storage; ME 0.5 - 1.48% of total leaf oil.	Dimitriev et al. 1981; Charles et al. 1991
<i>Agastache rugosa</i> [Korean mint]	ME 0.09-9.08% of total leaf oil; ME (83.5-92.2 %) in EO.	Charles et al. 1991; Fujita & Fujita 1973
<i>Agastache rugosa</i> x <i>A. Nepetoides</i>	0.09 - 1.74% of ME in total leaf oil, but absent in <i>A. nepetoides</i> .	Charles et al. 1991;
<i>Coleus aromaticus</i> [Amboinese coleus]	ME minor component.	Baslas & Kumar 1981
<i>Collinsia amata</i> . [horse balm]	EO contained 80% ME.	http://www.ema.europa.eu
<i>Dracocephalum moldavica</i> [Dragonhead]	Plant EO contained ME (0.3 - 2.0%) and methyl isoeugenol (1.2 - 3.0%); aerial parts EO contained 0.1% of ME in oil.	Hussein et al. 2006; Shatar & Altantsetseg 2000
<i>Hyptis suaveolens</i>	Weed attracted the oriental fruit fly and volatile oil contained 1.2% ME.	Kittibarmuangsook 1980
<i>Hyssopus officinalis</i> [Hyssop]	ME 38.3% & 0.4% in Montenegro and Serbia plants, resp; ME (0.54%) in EO; plant ME in 3 forms, 4 genotypes each, in Yugoslavia with blue, pink & white flowers had 0.1 - 3, 0.2 - 3 & 0.2 - 4% of plant EO, resp.	Mitić & Đorđević 2000; De Vincenzi et al., 2000; Chalchat et al. 2001

<i>Hyssopus officinalis</i> subsp. <i>aristatus</i>	One of three strains grown in Italy had ME (43.9%) as main component.	Piccaglia et al. 1999
<i>Lepechinia urbani</i>	Leaf EO had ME (1.26%) and α -copaene (13.82%).	Zanoni & Adams 1991
<i>Mentha piperita</i> (M. <i>balsamea</i>) [Peppermint]	Aerial parts contained 0.1% ME of EO.	Shatar & Altantsetseg 2000
<i>Micromeria cristata</i> subsp. <i>phrygia</i> P. H. Davis	ME (0.1%) with borneol (27-39%) and camphor (9-15%) as main components in EO of herbal parts.	Tabanca et al. 2001
<i>Moschosma</i> (<i>Ocimum</i>) <i>polystachya</i> [Musk basil; Swamp basil]	Oil rich (0.6%) with ME (39.3%) and methyl isoeugenol (8.4%).	Thoppil 1997
<i>Mosla scabra</i>	45 volatiles in EO with ME as one of five major components.	Lin & Hua 1989
<i>Ocimum americanum</i> [American basil; Hoary basil; Lime basil]	ME from less than 1 to more than 25% peak area of EO.	Viña & Murillo 2003
<i>Ocimum basilicum</i> [sweet basil]	ME (0.9 - 4.2%) in EO; ME (24.7%) in EO (Fijian variety).	Randriamiharisoa et al. 1986; Brophy & Joga 1986
<i>Ocimum campechianum</i> (O. <i>micranthum</i>) [Least basil; Mosquito bush]	Eugenol & ME major components; ME (2.91%) in plant EO, ME (12.0%) and eugenol (9.0%) as major components in leaf EO.	Khosla et al. 1980; Carovic-Stanko et al. 2010; Benitez et al. 2009
<i>Ocimum canum</i> [Schrubby basil]	ME (1.14%), in aerial parts EO.	Burralhep et al. 2007
<i>Ocimum carnosum</i> (O. <i>selloi</i>) [Fertility-control herb; Uruguayan basil]	Elemicin (38.5-59.2%) and ME (29.2%) major constituents.	Sobti et al. 1981
<i>Ocimum citriodorum</i> (O. <i>basilicum</i> x O. <i>americanum</i>) [Lemon basil]	Leaf EO contained E- & Z-citral (79.2%), linalool (4.7%), geraniol (2.1%) and ME (2.0%).	Nor Azah et al. 2006
<i>Ocimum gratissimum</i> [African basil; Clove basil; East Indian basil; Tree basil]	Leaf EO dominated by monoterpenes, eugenol (68.8%) & ME (13.21%); Leaf and floral EOs contained ME (1.7%); 1 of 3 types in Brazil had ME (46.8%).	Matasyoh et al. 2007; Sainsbury & Sofowora 1971 c/f Maia & Andrade 2009
<i>Ocimum minimum</i> [Bush basil; Greek basil; Fine-leaved basil]	ME ca 1% of peak area of EO; ME increased from 1.59 to 1.95% in 24 hour after mechanical wounding.	Viña & Murillo 2003; Zabarás & Wyllie 2001
<i>Ocimum sanctum</i> (O. <i>temiflorum</i>) [Holy basil; red basil]	ME & eugenol varied with growth & development; ME 78-81% of leaf EO; ME 72.5%, 75.3%, 83.7% and 65.2% in oils from whole herb, leaf, stem and inflorescence, resp.	Dey & Choudhuri 1985; Nudijati et al. 1996; Kothari et al. 2005
<i>Ocimum selloi</i>	Leaf EO 0.10-0.12% ME; two accessions in Brazil, one with estragole and ME at 80.7 and 1.13%, resp. & the other ME at 63.08% with no estragole.	Moraes et al. 2002; Martins et al. 1997
<i>Ocimum suave</i> (O. <i>gratissimum</i> var <i>gratissimum</i>) [Vietnamese basil]	EO of aerial parts contained mainly elemicin (9.8-38.5%), eugenol (1-33.1%), & cis-methyl isoeugenol (6.8-19.3%) with tr amount of ME.	Ngassoum et al. 2003
<i>Ocimum urticifolium</i> (O. <i>suave</i>)	ME (tr - 87.0%) and eugenol (0.1-93.0%) in EO of leaves plus flowers. 12 chemotypes - 3 dominated by one component only - ME, eugenol and trans-methyl isoeugenol.	Ntezurubanza et al. 1988
<i>Origanum majorana</i> (<i>Majorana hortensis</i>) [Sweet majoram]	Aerial parts EOs during early growth and budding stages contained 0.37 & 0.04% of ME, resp. but not during late growth and fully flowering stages.	Sellami et al. 2009
<i>Orthosiphon stamineus</i> [Misai Kucing]	ME (3%) and eugenol (8.3%) in dried leaf EO.	Sukari & Takahashi 1988
<i>Platostoma africanum</i>	Plants divided into ME and eugenol chemotypes.	Chalmont et al. 2001
<i>Rosemarinus officinalis</i> [Rosemary]	Leaf EO has ME (0.12 - 1.46%); leaf and twig had tr ME and eugenol 0.1-0.2% of EO.	Ibanez et al. 1999; Elamrani et al. 2000
<i>Salvia macrochlamys</i>	EO of aerial parts contained ME (0.1%) among >100 compounds.	Tabanca et al. 2006
<i>Salvia officinalis</i> [Common sage]	In vitro shoot EO contained 19.8% ME; fruits contained ME and eugenol at 1.45 and 1.01% of EO, resp.	Avato et al. 2005; Taarit et al. 2009
<i>Salvia recognita</i>	EO of aerial parts had ME (0.4%) of >100 compounds.	Tabanca et al. 2006
<i>Salvia rhytidia</i> [Persian sage]	Aerial parts EO contained ME (0.8%) and α -copaene (5.3%).	Sajjadi & Ghannadi 2005
<i>Salvia verbenaca</i>	ME 7.7-9.4% in EO of aerial parts collected in 2 Tunisia sites.	Taarit et al. 2010
<i>Satureja Montana</i> [Winter savory]	ME 25-415 ppm of plant.	http://www.emea.eu.int
<i>Scutellaria barbata</i> [Ban-Zhi-Lian]	ME (5.6%) in aerial parts EO.	Yu et al. 2004
<i>Thymus gwyoni</i>	ME (0.1%) in EO of fresh aerial parts.	Hazzit et al. 2006
<i>Thymus hymenalis</i>	Aerial parts EO had ME at 0.01% and tr at vegetative and flowering stages, resp.	Jordan et al. 2006
<i>Thymus serpylloides</i> subsp. <i>serpylloides</i> [thyme of the Sierra]	ME in tr quantity for individual plant EO during flowering but for fruiting plant 0.62% and 0.69% in 1989 & 1990, resp.	Arrebola et al. 1994
<i>Thymus vulgaris</i> [Thyme]	ME (0.21%) of aerial parts EO; ME (0.1%) of aerial parts EO.	Ozcan & Chalchar 2004; Shatar & Altantsetseg 2000
<i>Vernonia smithiana</i> ["umblonyana"]	Aerial parts EO contained 3.12% ME.	Vagionas et al. 2007
Lardizabalaceae - Lardizabala family (Ranunculales)		
<i>Akebia quinata</i> [Chocolate vine]	Fruit and stem EOs contained ME at 1.1% and 0.3%, resp.	Kawata et al. 2007
Lauraceae - Laurel family (Laurales)		
<i>Aniba camelilla</i> [Cascalpreciosa]	EO of stem bark contained 2.9% ME; ME in EO of bark 21.3-34.7% and of wood 10.5-23.0%; ME (9.26%) and eugenol (3.97%) in trunk bark EO.	Oger et al. 1994; c/f Maia & Andrade 2009; Vilegas et al. 1998
<i>Aniba guianensis</i> [Chachajo]	Wood contained ME; ME and methyl isoeugenol among 6 major components of trunk wood EO.	Von Guelow et al. 1973; Von Bulow et al. 1973
<i>Aniba hostmanniana</i>	Bark EO - 0.3% ME & 94.5% asarone.	Gottlieb & DaRocha 1972
<i>Aniba pseudocoto</i>	EO contained ME.	c/f Maia & Andrade 2009
<i>Aniba puchury-minor</i>	Bark EO contained ME (43.1%), ME not detected in leaves.	c/f Maia & Andrade 2009
<i>Cinnamomum camphora</i> var <i>linaloolifera</i>	Fruit EO contained ME (40.9-51.2%), safrole (23.9-53.2%).	Gu et al. 1990
<i>Cinnamomum cecidodaphne</i> (C. <i>glaucescens</i>) [Sugandha kokila]	Chemotypes A, B and C with ME, ME(45%)+safrole(20%), & safrole as major constituents, resp; fruits contained 0.6% ME of total EO.	Birch, 1963 c/f Ravindran et al. 2003; Adhikary et al. 1992
<i>Cinnamomum cordatum</i>	ME - 4.4% and 92.1% in leaf and bark EOs, resp.	Jantan et al. 2002
<i>Cinnamomum cultilawan</i> [Cinnamon kulit lawan]	Chemotypes A, B and C with safrole, safrole (35-53%) + ME (41-50%), and eugenol as major constituents, resp.	Spoon-Spruit, 1956 c/f Ravindran et al. 2003
<i>Cinnamomum doederleinii</i>	Shoot EO (0.08%) - contained eugenol (2.3%) and ME (0.7%).	Fujita et al. 1974
<i>Cinnamomum glanduliferum</i> [Nepal camphor tree]	Chemotypes A, B and C with safrole, ME, and ME (45%) + safrole (25%) as major constituents, resp.	Ravindran et al. 2003
<i>Cinnamomum loureiri</i> [Vietnamese cinnamon]	ME detected from root, bark, and heart wood oils.	Asakawa et al. 1971
<i>Cinnamomum pedomaculatum</i> (C. <i>japonicum</i>) [Japanese Cinnamon]	Chemotypes A and B with Safrole (60%) + eugenol, and eugenol + ME as major constituents, resp.	Birch. 1963 c/f Ravindran et al. 2003

<i>Cinnamomum parthenoxylon</i> [Yellow cinnamon]	Wood oil (1.0% yield) - ME (45%) and safrole (20%).	Yaacob et al. 1990
<i>Cinnamomum rhyncophyllum</i>	EO of leaf, bark and wood contained 0.2, 1.6 and 4.4% ME, resp.	Jantan et al. 2004
<i>Cinnamomum rigidissimum</i>	Stump EO contained 61.7% safrole and 28.6% ME.	Lu et al. 1986
<i>Cinnamomum sintok</i>	Chemotypes A, B, C, and D with eugenol, eugenol + ME, ME + safrole and safrole as major components, resp.	c/f Ravindran et al. 2003
<i>Cinnamomum subavenium</i>	ME (75.9%) in leaf EO.	Ho et al. 2008
<i>Cinnamomum tshijianum</i>	Stem bark oil contained 7.4% ME.	Ali & Jantan 1999
<i>Cinnamomum lamala</i>	ME and eugenol detected in leaf EO.	Dighe et al. 2005
<i>Cinnamomum tenuipilum</i>	Leaf EO showed 9 chemical types - ME type contained 69 - 89% ME.	Cheng et al. 1993
<i>Cinnamomum zeylanicum</i> (<i>Cinnamomum verum</i>)	ME in leaf and stem bark EO 0.1% and tr amount, resp.	Senanayake et al. 1978
<i>Laurus azorica</i> (L. canariensis) [Loireiro, Louro]	ME tr quantity in leaf EO.	Pedro et al. 2001
<i>Laurus nobilis</i> [Bay, Bay laurel, Laurel tree]	Plant contained ME with antifeeding activity; ME (8.1%); EO of berries contained 1.0-1.4% ME; Leaf EO of 3 regions of Turkey had ME at 1.96, 3.39 & 0.41%.	Muckensturm et al. 1982; Caredda et al. 2002; Marzouki et al. 2008; Sangun et al. 2007
<i>Laurus novocanariensis</i> [Madeira/Canary Laurel]	Spring & fall leaves contained ME at 0.8% & 0.2 % of EOs, resp, & only unripe fruits had ME - 0.4%.	Rodilla et al. 2008
<i>Licaria pichury</i> - major [Pichury/Pichurim bean; Sassafras nuts]	Seed oil contained safrole (36.1-51.3%); eugenol (3.3 - 4.1%) and ME (2.9 - 3.60%).	Carlini et al. 1983; Maia et al. 1985
<i>Lindera neesiana</i> ["Siltumur"]	Fruits contained myristicin and ME at 4.41% and 1.94% of EO, resp.	Comai et al. 2010
<i>Nectandra polita</i>	54 g of solvent wood extract yielded 0.06g eugenol, 0.04g ME.	Suarez et al. 1983
<i>Ocotea caparrapi</i> [Caparrapi Olive tree]	ME & myristicin (major components).	Suarez & Enrique 1980
<i>Ocotea pretiosa</i> [Sassafras tree]	ME (0.1-78%) in wood oil.	http://www.ema.europa.eu
<i>Persea americana</i> [Avocado]	Leaf EO contained estragole (78.12%) and ME (3.37 %).	Sagrero Nieves & Bartley 1995
<i>Ravensara aromatica</i> (<i>Ravensara anisata</i>) [Clove nutmeg, ravensara]	EO contained 0.10% ME; leaf EO from Madagascar contained methyl chavicol (79.7%) & ME (8.5%); high variation in ME (tr to 81.6%) and methyl chavicol (1.4 - 94.5%) contents in leaf EO between and within forest localities in Madagascar.	Franchomme & Peneol 1995; Ramanoelina et al. 2006; Andrianolisoa et al. 2006
<i>Sassafras albidum</i> [Sassafras]	ME (1.10%) of root bark oil.	Kamdern & Gage 1995
<i>Umbellularia californica</i> [California bay/Laurel]	Leaf EO contained ME (5.4%) and isoeugenol (0.1%).	Buttery et al. 1974
Magnoliaceae – Magnolia family (Magnoliales)		
<i>Magnolia demickata</i> (<i>M. heptapeta</i>) [Lily tree, Yulan magnolia, Tulip tree]	EO of magnoliae flos (dried buds) contained 0.01-0.10% ME.	Jeong et al. 2009
<i>Magnolia liliflora</i> [Lily magnolia]	EO of magnoliae flos contained 0.00-0.22% ME.	Jeong et al. 2009
<i>Magnolia salicifolia</i> [Willow-leaved Magnolia]	EO contained large amounts of ME and safrole; leaf ME induced 100% mortality of 4 th instar larvae of <i>Aedes aegypti</i> at 60 ppm.	Nagasawa et al. 1969; Kelm et al. 1997
<i>Michelia alba</i> [White Champaca; White Sandalwood]	EO contained ME and eugenol; leaf EO contained 0.22% ME & 0.1% estragole among >100 components.	Wang 1979; Ueyama et al. 1992
<i>Michelia hedyosperma</i>	Safrole 95% and ME, linalool & (+)-limonene.	Wu et al. 1981
<i>Talauma gios</i>	Major constituents of the fruit pulp and kernel oils were safrole (70.2% & 72.9%) and ME (24.2% & 18.5%).	Dung et al. 1997
Malvaceae – Mallow family (Malvales)		
<i>Tilia argentea</i> (<i>T. tomentosa</i>)	ME 0.2% and 0.1% of bract and leaf EOs, resp, but no ME in flowers.	Toker et al. 1999
Monimiaceae – Monimia family (Laurales)		
<i>Antherosperma moschatum</i>	Two subspecies, <i>moschatum</i> & <i>integrifolium</i> , had ME (55 - 87%) as the major component.	Brophy et al. 2009
<i>Doryphora sassafras</i> [Sassafras]	ME (27-47%), safrole (15-30%) and camphor (15-19%) in leaf & bark EOs.	Brophy et al. 1993
<i>Peumus boldus</i> [Boldo; Boldina]	ME (4.3%) of leaf EO.	http://www.emea.eu.int
Moraceae – Fig/Mulberry family (Rosales)		
<i>Pourouma cecropifolia</i> (<i>P. multifida</i>) [Amazon Grape]	Peeled fruits contained ME and eugenol each at 0.2% of EO with 0.23% of a-copaene.	Pino & Quijano 2008
Musaceae – Banana family (Zingiberales)		
<i>Musa acuminata</i> [Banana]	ugenol, 5-methoxyeugenol, elemicin & ME contributed to the mellow aroma of ripe bananas. ME-glycoside (0.66-1.07 %) in glycosidic extracts.	Engle et al. 1990
Myristicaceae – Nutmeg family (Magnoliales)		
<i>Myristica fragrans</i> [Nutmeg]	Many volatiles among them were safrole, ME, and eugenol; ME 0.1-17.9% in nutmeg EO; ME (0.3-17.9%) & it increased with time from 7.8 to 15% when whole nutmegs were ground and stored up to 48h.	Sammy & Nawar 1968; De Vincenzi et al. 2000; Kuo et al. 1983; Sanford & Heinz, 1971
<i>Virola surinamensis</i>	ME in leaf EO, circadian variation 0 - 0.43% of total peak area, and seasonal variation - ME (0.43%) in February and in June 0.12-0.2%.	Lopes et al. 1997
Myrtaceae – Myrtle family (Myrtales)		
<i>Amomyrtella guili</i>	ME (48.5%) and (<i>E</i>)-methyl isoeugenol (6.7%) in leaf EO.	Weyerstahl & Marschall 1992
<i>Backhousia myrtifolia</i> [Cinnamon myrtle, Grey myrtle, Ironwood]	Three chemotypes: a) ME (86.4%) with 1% <i>E</i> -methyl isoeugenol, & 4.1% elemicin, b) <i>E</i> -methyl isoeugenol (74%) with 4.9% ME & 4.6% elemicin, and c) elemicin (91.5%) with ME 4.0% & 0.4% <i>E</i> -methyl isoeugenol	Brophy et al. 1995
<i>Choricarpa leptopetala</i>	Leaf EO contained small amounts (< 3%) of ME, methyl isoeugenol and elemicin; leaf EO contained ME (0.07%), methyl isoeugenol (0.36%), elemicin (1.35%).	Brophy et al. 1994; Brophy & Goldsack 1994
<i>Eucalyptus globulus</i> (<i>E. glauca</i>)	Leaves had ME at 0.15-0.51% of EO, but no ME in bud, fruit & stem.	Chalchat et al. 1995
<i>Eugenia singampattiana</i>	Fruit EO contained ME (11.52%).	Johti et al. 2009
<i>Melaleuca alternifolia</i> [Narrow-leaved paperbark/ Tea-tree]	ME tr amount in EO.	Brophy et al. 1989
<i>Melaleuca bracteata</i> [Black T-tree, River tea-tree]	ME 97.7% of leaf EO.	Aboutabl et al. 1991
<i>Melaleuca ericifolia</i> [Swamp paperbark]	ME 96.84% of EO.	Farag et al. 2004

<i>Melaleuca leucadendra</i> [Cajuput tree]	One of three chemotypes had ca 99% ME in leaf EO; EO of aerial parts contained ME (96.6 ± 0.7%).	Brophy & Lassak 1988; Silva et al. 2008
<i>Melaleuca quinquenervia</i> [Melaleuca trees, paperbark tea trees]	Two chemotypes rich in ME (up to 99 percent).	Ramanoelina et al. 1994
<i>Myrcianthes rhopaloides</i> [Arrayan]	ME (0.2%) a minor component in leaf EO.	Malagon et al. 2003
<i>Myrtus communis</i> [Myrtl]	Myrtle berry oil 2.3% ME; leaf & unripe fruit ME 2.3% & 0.04% of EO, while ripe fruit had no detectable ME; ME content 2.3% in Myrtl EO; fruits & leaves from 1st station had ME at 0.6 & 0.8% of EOs, resp, in 2 nd - ME 1.1% of leaf EO and none in fruits.	Mazza 1983; Boelens & Jimenez 1992; De Vincenzi et al. 2000; Flamini et al. 2004
<i>Pimenta acris</i> [Wild cinnamon, Bay-rum tree, Bayberry or Jamaica bayberry;]	Chavicol, eugenol, and ME form 65-70% of leaf and berry EO.	Ryan 1991
<i>Pimenta dioica</i> (<i>P. officinalis</i>) [Allspice, Pimento, Jamaica pepper]	ME (48.3-67.9%) main component of Mexican pimento berries EO; EO high in eugenol (64.29%) and ME (20.55%) contents; fruiting & non-fruiting trees contained ME (0.08 & 0.13%) & eugenol (79.8 & 83.7%) of leaf EO, resp.	Garcia-Fajardo et al. 1997; Zabka et al. 2009; Minott & Brown 2007
<i>Pimenta officinalis</i> [Pimento]	ME (5.0-8.8%) of EO.	De Vincenzi et al. 2000
<i>Pimenta racemosa</i> [Bay rum tree]	ME in leaf EO for var grisea (0.30 - 92.60%) and var hispaniolensis (0 - 63.88%); ME 8.9% of fruit EO.	Tucker et al. 1991; Ruff et al. 2002
<i>Pseudo-caryophyllus guili</i>	ME and eugenol were major volatile components; ME (5%) in leaf oil and fruits.	De Fenik et al. 1972; http://www.ema.europa.eu
<i>Psidium cattleianum</i> [Strawberry guava]	Red variety of fruit contained ME and eugenol among >154 volatiles.	Vernin et al. 1998
<i>Psidium guajava</i> [Guava]	ME (0.2%) of fruit EO.	Paniandy et al. 2000
<i>Syzygium aromaticum</i> (<i>Eugenia caryophyllu</i> , <i>E. caryophyllata</i>) [Clove]	Leaf EO had eugenol (76.8%) and β -caryophyllene (17.4%) as major components with tr ME; ME (0.12%) of EO with eugenol (78.6%).	Jirovetz et al. 2006; Dzamic et al. 2009
Orchidaceae – Orchid family (Asparagales)		
<i>Brassia chikirikeya</i>	EO contained ME (8.8%).	c/f Maia & Andrade 2009
<i>Jumellea fragrans</i> [False rein orchid]	ME in minute quantity of leaf EO.	Shum & Smadja 1992
Papaveraceae – Poppy family (Ranunculales)		
<i>Escholtzia flava</i>	EO had 40.5% ME.	http://www.ema.europa.eu
Pinaceae – Pine family (Pinales)		
<i>Pinus ponderosa</i> [North American pine]	ME (0.6%) in needle (leaf) EO.	Krauze-Baranowska et al. 2002
Piperaceae – Pepper family (Piperales)		
<i>Piper auritum</i> [Root beer plant, Vera cruz pepper]	ME (0.8%), saffrole (91.3%) and myristicin (4.8%) in leaf EO.	Bueno-Sanchez et al. 2009
<i>Piper betle</i> [Betel; Betel pepper; Sireh]	Two CVs gave 0.15-0.2% EO - ME (4.1-6.9%) and eugenol (82.2-90.55%).	Sharma et al. 1983
<i>Piper capense</i>	Aerial parts EO contained 0.2% ME.	Martins et al. 1998
<i>Piper daricatum</i> (<i>Piper columbrinum</i>)	ME (17-93%) and eugenol (2.0-46.0%) main constituents in EO.	c/f Maia & Andrade 2009
<i>Piper guineense</i> [West African black pepper]	Berry EO rich in phenylpropanoids – ME (1.53%) & eugenol (0.07%); white and black berries EOs contained 0.11 & 0.22%, resp.	Ekundaya et al. 1988; Jirovetz et al. 2002b
<i>Piper lenticulosum</i>	Leaf EO contained limacine, isosaffrole, ME and sarisan.	Diaz et al. 1986
<i>Piper nigrum</i> [Black pepper]	ME – one of twelve identified polar compounds in oil of black pepper; berries contained 0.92% ME.	Russell & Jennings 1969; Jirovetz et al. 2002b
<i>Piper solmsianum</i>	Leaf EO had ME (1.10%).	Moreira et al. 2001
<i>Piper xylosteoides</i>	ME 0.08% of aerial parts EO.	Ferraz et al. 2010
Plumbaginaceae - Leadwort family (Caryophyllales)		
<i>Limonium echioides</i>	Aerial parts EO had ME & eugenol at 0.01% and 0.75% of volatiles.	Sardana et al. 2008a
Poaceae – Grass family (Poales)		
<i>Bothriochloa perforata</i>	One of 16 <i>Bothriochloa</i> sibling species contained ME (1.8%) in whole plant EO.	Scrivanti et al. 2009
<i>Bromus hordeaceus</i> [Soft brome]	Trans methyl cinnamate (31.2%), ME (30.3%) & eugenol (19.1%) of plant EO.	Kaluzina-Czaplinska 2007
<i>Cymbopogon distans</i>	ME (13%) and limonene (29%) as major component in EO.	Singh & Sinha 1976 c/f Akhila 2009
<i>Cymbopogon flexuosus</i> ([Lemongrass])	ME (20%) in EO.	Atal & Bradu 1976
<i>C. flexuosus</i> var <i>Skimensis</i>	ME (23%) in EO.	Manzoor-i-Khuda et al. 1986
<i>Cymbopogon pwarancusa</i> [Iwarancusa grass]	Khawi grass - ME one of major components.	Ansari & Qadry 1987
<i>Cymbopogon khasianus</i>	0.6-0.85% oil yield - contained ME (75-85%).	Rabha et al. 1986
<i>Cymbopogon microstachys</i>	EO had ca 60% phenyl propanoids with ME (19.5%), elemicin (25.3%) & methyl isoeugenol (4.2%).	Mathela et al. 1990
<i>Cymbopogon nardus</i> [Citronella grass]	ME major component; ME (4.1%) with traces of eugenol and ethyl iso-eugenol.	Howlett 1915; Akhila 2009
<i>Cymbopogon tortilis</i> [Ogarukaya, Okarukaya]	ME (55%) in EO.	Liu et al. 1981
<i>Cymbopogon winterianus</i> [Java citronella]	ME (20-60 ppm) of whole plant (1%) EO; EO contained tr quantities of ME and eugenol.	http://www.ema.europa.eu ; Akhila 2009
<i>Elyonurus hensii</i>	ME (0.6% of EO) in roots and not detected in other aerial parts.	Silou et al. 2006
<i>Lolium perenne</i>	ME (16.6%), eugenol (24.1%) & trans methyl cinnamate as major components in plan EO.	Kaluzina-Czaplinska 2007
Podocarpaceae – Podocarpus family (Pinales)		
<i>Dacrydium franklinii</i> (<i>Lagarostrobos franklinii</i>) [Huan pine heartwood]	Wax contained eugenol, ME ether, elemicine, and coniferyl alcohol.	Baggaley et al. 1967
<i>Lagarostrobos franklinii</i> [Huan pine]	Wood EO had 57-74% ME, 2-18% <i>E</i> -methyl isoeugenol & 22-24% elemicin.	Brophy et al. 2003
<i>Lolium perenne</i> [Perennial ryegrass]	Eugenol (24.1%), <i>E</i> -methyl cinnamate (18.5%) & ME (16.6%) in plant EO.	Kaluzina-Czaplinska 2007

Polygonaceae – Buckwheat family (Caryophyllales)		
<i>Rheum palmatum</i> [Chinese rhubarb]	Rhizome EO contained 5.4% ME.	Miyazawa et al. 1996
<i>Rheum rhubarbarum</i> [Rhubarb]	Mean values of ME in stalk EO varied from 2-7%.	Dregus & Engel 2003
Rosaceae – Rose family (Rosales)		
<i>Pseudocdonia sinensis</i> [Chinese quince]	0.4% & 0.1% ME in fruit peel and fresh EO, resp.	Mihara et al. 1987
<i>Prunus persica</i> [Peach]	ME (<1%) found in fruits of four ripe peach CVs and two breeding lines.	Horvat et al. 1990
<i>Rosa damascena</i> . (Hybrid of <i>Rosa gallica</i> and <i>Rosa moschata</i>) [Damask rose]	Rose oil contained 0.1- 1.9 % ME and 0.2 – 1.8 % eugenol; ME (3.56%) in Chinese rose oil using SPME technique.	Mostafavi & Afzali 2009; Jirovetz et al. 2004
<i>Rosa hemisphaerica</i> [Sulphur rose]	ME 0.3% of EO.	Safaei-Ghomi et al. 2007
<i>Rosa hybrida</i> CV Mi-hyang	ME (0.79 %) and eugenol (0.84 %) in Korean rose oil.	Cho et al. 2006
Rubiaceae – Madder family (Gentianales)		
<i>Rubia cordifolia</i> [Common/Indian Madde]	ME (1.2% of peak area) in root EO.	Miyazawa & Kawata 2006
Rutaceae – Rue family – (Sapindales)		
<i>Agathosma pungens</i> [Bookoo, Buchu]	Plant EO contained 1.4% ME.	Viljoen et al. 2006
<i>Chloroxylon swietenia</i> [Ceylon/East Indian Satinwood or Buruta]	3.15 and 12.12 % ME in leaf and stem EO, resp.	Kiran et al. 2007
<i>Citrus aurantium</i> var <i>myrtifolia</i> [Chinotto]	Fresh fruits were air dried to yield dried peel which possessed tr ME in EO.	Chialva & Doglia 1990
<i>Citrus paradise</i> [Grapefruit]	Grapefruit juice contained 0.02 ppm of ME.	http://www.lal.ufl.edu/rouseff/Website2002/Subpages/flavor_phenolics.htm
<i>Clausena anisata</i>	Leaf EO contained 92.7% ME.	http://www.ema.europa.eu
<i>Clausena excavata</i> [Pink Wampee]	Elemicin (65.02 %) and ME (12.95%) as major components of leaf EO.	Lim, 2005
<i>Clausena indica</i>	Fruit peel EO contained 0.43% ME.	Zhou et al. 2008
<i>Coleonema album</i> [Breath of heaven]	Shoot oil contained ME.	Berger et al. 1990
<i>Dictamnus hispanicus</i>	ME (3.7%) in EO of aerial parts.	Merle et al. 2006
<i>Diosperma melanophloia</i> (<i>Melicope melanophloia</i>) [Hard aspen]	One of three chemotypes had ME (51-67%) and methyl chavicol (5-13%).	Brophy et al. 1997
<i>Eriostemon fitzgeraldii</i>	234 mg of ME from 10.2 g n-hexane extract concentrate of aerial plant parts.	Sarker et al. 1995
<i>Eriostemon trachyphyllus</i> [Rock Wax-flower]	ME and eugenol in tree.	Lassaak & Pinhey 1969
<i>Fagara macrophylla</i> [East African satinwood]	ME (4.68 %) in pericarp EO.	Reish et al. 1986
<i>Haplophyllum myrtifolium</i>	Plant EO had 10.8% ME and 19.1% eugenol.	Saglam et al. 2001
<i>Helietta parvifolia</i> [Barreta]	EO of leaves and branches - eugenol & ME.	Dominguez et al. 1971
<i>Leionema ambiens</i> (<i>Eriostemon ambiens</i>)	ME - 1.1% of leaf EO.	Brophy et al. 2006
<i>Lovunga scandens</i>	Berries contained ME among other monoterpenes.	Aggarwal et al. 1983
<i>Melicope anisata</i> (<i>Pelea anisata</i>) [Mokihana]	Leaf steam distillate contained p-methoxypropenylbenzene (ca 40%) with lesser quantities of ME, limonene, methyl isoeugenol and estragole.	Scheuer 1955
<i>Melicope borbonica</i>	Leaf EO of this medicinal plant with antifungal activity contained ME (209 mg of 430 g powdered leaves).	Simonsen et al. 2004
<i>Murraya exotica</i> [Orange jasmine]	ME 0.1% of leaf EO, ME absent in flower EO.	Raina et al. 2006
<i>Pseudocdonia sinensis</i> [Chinese Quince]	0.4% and 0.1% of ME in fruit peel and fresh fruit EO, resp.	Mihara et al. 1987
<i>Vepris heterophylla</i>	ME at 0.3% of leaf EO from 1 of 2 localities in northern Cameroon.	Ngamo et al. 2007
<i>Vepris madagascariensis</i>	ME - 1 of 5 main components in leaf and stem oils.	Billet & Favre-Bonvin 1973
<i>Zieria smithii</i> [Sandfly Zieria]	85% ME in leaf EO.	Fletcher et al. 1975
Salicaceae – Willow family (Malpighiales)		
<i>Populus nigra</i> [Black poplar]	ME in fresh and dried buds 0.3 and 0.5%, and eugenol - 1.1 & 3.9%, resp.	Jerkovic & Mastelic 2003
Sapotaceae - Sapodilla family (Ericales)		
<i>Manilkara zapota</i> (<i>Achras sapota</i>) [Sapodilla, Ciku]	ME (0.5 %) in fruit EO which had 61 volatiles – 0.03 pg/kg of fruits.	MacLeod & de Troconis 1982
Sarraceniacae – Pitcher family (Ericales)		
<i>Sarracenia flava</i> [Yellow pitcherplant]	ME (0.3%) in EO of aerial parts.	Miles et al. 1975
Saururaceae – Lizard-tail family (Piperiales)		
<i>Anemopsis californica</i> [Yerba mansa]	ME (ca 6.9%) in rhizomes & dried roots; leaf EO contained 6.5-7.3 % ME; ME (59%) in New Mexico root EO; ME (55%) of rhizome & root EO.	Tutpalli et al. 1975; Medina et al. 2005 & 2008; Acharya & Chaubal 1968
<i>Saururus cernuus</i>	ME (< 2%) in EO of dried aerial parts.	Tutupalli et al. 1975
Scrophulariaceae – Figwort/Snapdragon family (Lamiales)		
<i>Bacopa axillaris</i>	Whole plant EO had camphor (30.6%) and ME (28.3%) as major components; ME (35.9%) and camphor (28.1%).	Zoghbi & Andrade 2006; Maia & Andrade 2009
<i>Limnophila geoffrayi</i> (<i>Limnophila racemosa</i>)	Aerial parts (flowers not included) contained ME at 0.33% (v/v) of EO.	Thongdon-A & Inprakhon 2009
Solanaceae – Nightshade/Potato family (Solanales)		
<i>Cyphomandra betacea</i> (<i>Solanum betaceum</i>) [Tamarillo, Tree tomato]	Fruit pulp volatiles contained <100 g/kg of ME.	Torrado et al. 1995

<i>Mandragora officinarum</i> [Mandrake, Hog apple Ground lemon]	ME (0.40%), eugenol (2.37%) and <i>E</i> -isoeugenol (1.63%) in fruit EO.	Fleisher & Fleisher 1994
Tamaricaceae – Tamarix family (Caryophyllales)		
<i>Tamarix boveana</i>	Aerial parts, leaf and stem EOs had 0.89%, 0.22% & tr ME, resp.	Saidana et al. 2008b
Theaceae – Tea family (Ericales)		
<i>Camellia sinensis</i> [Chinese tea]	ME (0.053 - 0.814 as ratio of peak area to that of internal standard) in 5 samples of tea EO.	Pripdeevech & Machan 2010
Thymelaeaceae – Mezereum family (Malvales)		
<i>Daphne genkwa</i>	ME (4.5%) in aerial parts EO.	Ueyama et al. 1990
Verbenaceae – Verbena family (Lamiales)		
<i>Aloysia triphylla</i> [Lemon verbena]	Dried leaves contained eugenol & ME at 0.5-0.6% & 0.3-1.2% of EO, resp.	Crabas et al. 2003
<i>Lippia alba</i> [Bushy lippia; Anise verbena]	ME small amounts.	Svendsen & Baerheim 1990
<i>Lippia glandulosa</i>	14 plant samples had eugenol 0.1-0.6% of EO but only 2 with tr ME.	Maia et al. 2005
Vitaceae – Grape family (Vitales)		
<i>Vitis rotundifolia</i> [Muscadines, Scuppernong berries]	ME in ripe berries from three CVs - Fry, Jumbo and Watergate.	Horvat & Senter 1984
Winteraceae - Winter's Bark Family (Canellales)		
<i>Drimys brasiliensis</i>	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 (Zingiberales)		
<i>Alpinia galanga</i> (Languas galang) [Greater galanga]	ME and α -copaene appeared as single peak (3.6%) of EO of fresh rhizomes; ME 0.9% of rhizome EO.	De Pooter et al. 1985; Pripdeevech et al. 2009
<i>Alpinia officinarum</i> [Galanga, galangal, galangale]	1.0% and 3.3% ME in EO of fresh and dried rhizome, resp; ME 3.0% and eugenol 0.5% of rhizome EO.	Tram Ngoc et al. 2001; Pripdeevech et al. 2009
<i>Alpinia speciosa</i> [Chinese Beauty, Atoumau, Variegated Dwarf]	ME in stem & leaves; only leaves from Japan, among 6 countries of origins, had ME, estragole & methyl cinnamate at 2.9, 4.6 & 24.1% of EO, resp.	Fujita & Yamashita 1973; Prudent et al. 1993
<i>Boesenbergia</i> sp. (species unknown)	Plant attracted the oriental fruit fly and volatile oil contained 17% ME.	Kittibarmuangsook 1980
<i>Curcuma angustifolia</i> (<i>Marantia arundinaceae</i>) [The narrow leaved Turmeric]	Rhizome EO from Central India had ME (10.5%).	Srivastava et al. 2006
<i>Elattaria cadamomum</i> [Cadamom]	ME and eugenol among the ten most abundant volatile components in seed EO; plant EO contained 0.1% ME.	Abo-Khatwa & Kubo 1987 c/f Kubo et al. 1991; De Vincenzi et al. 2000
<i>Etilingera cevuga</i> [Wax flower]	ME (47.4%) and <i>Z</i> - & <i>E</i> -methyl isoeugenol (18.8%) in rhizome EO	Lechat-Vahirua et al. 1993
<i>Etilingera linguiformis</i>	Rhizome oil contained methyl chavicol (49.9%) and ME (32.3%).	Bhuiyan et al. 2010
<i>Zingiber junceum</i>	ME (54.73%), α -pinene (10.49%) & <i>E</i> -methyl isoeugenol (8.68 %) found in rhizome oil.	Jarikasem et al. 2006 (poster)
<i>Zingiber officinale</i> [Ginger]	Rhizome EO from alcoholic extract contained tr to 0.5% ME.	Singh et al. 2008

* 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
Amoryllidaceae - Amaryllis/ Daffodil family (Asparagales)		
<i>Narcissus bugei</i>	<i>E</i> - β -Ocimene (54.7 - 64.4%) plus ME (0.2%) in floral EO.	Dobson et al. 1997
<i>Narcissus germanum</i> – a variety of <i>N. tazetta</i> x <i>N. poeticus</i> hybrid	Flower EO contains ME as a minor component.	van Dort et al. 1993
<i>Narcissus jonquilla</i> var <i>trevithian</i> (<i>N. trevithian</i>) [Trevithian narcissus]	Flowers contained ME as a minor component.	van Dort et al. 1993
<i>Narcissus poeticus</i> [Poet's Daffodil/Nargis]	ME a minor component of flower EO.	Ehret et al. 1989 c/f van Dort et al. 1993
Annonaceae – Custard apple family (Magnoliales)		
<i>Cananga odorata forma macrophylla</i> [Cananga]	Dried flower oil via controlled pressure drop method contained 0.4% ME & 0.5% eugenol, while via steam distillation contained 0.1% ME & 0.18% eugenol of EO (% = mass%).	Kristiawan et al. 2008
Apiaceae – Carrot family (Araliales)		
<i>Aegopodium podagraria</i> [Bishops Goutweed]	ME 0.22% of volatiles collected during flowering via Tenax GC sorbent.	Paramonov et al. 2000
<i>Cuminum cyminum</i> [Cumin]	ME (0.08%) & eugenol (0.79%) in floral EO.	Bettaieb et al. 2010
<i>Daucus carota</i> ssp. <i>carota</i> [Wild carrot]	Blooming umbels have tr quantities of ME and eugenol in EO	Staniszewska & Kula 2001
<i>Eryngium amethystinum</i> [calcatreppola ametistina]	ME (2.3%) and <i>E</i> -methyl isoeugenol (0.7%) in inflorescences and undetected in other plant parts.	Flamini et al. 2008
<i>Levisticum officinale</i>	Floral EO contains 0.1 - 0.2 % ME among 58 volatiles.	Bylaite et al. 1998
<i>Pimpinella affinis</i>	Inflorescence and seed EO contain 2.2% and 2.3% ME, resp, while seeds from 2 nd locality contain ME (9.7%).	Askari & Sefidkon 2006
<i>Portenschlagiella ramosissima</i>	ME at 0.3% of EO in flowering aerial parts	Sokovic et al. 2008
<i>Scandix iberica</i>	Flowers contain estragole (95.8% of EO) with 0.3% ME.	Kaya et al. 2007
<i>Seseli buchtormense</i>	ME in whole flowering tops EOs varied with altitude - 0.1 % at 300 m but in tr at 400 to 2030 m in Russian Altai (Siberia)	Tkachev et al. 2006
Araceae – Arum family (Arales)		
<i>Anthurium aporomum</i> .	ME (0.1 %) in floral fragrance.	Schwerdtfeger et al. 2002
<i>Colocasia esculenta</i> [Elephant Ears]	Flowers contain ME and eugenol, in floral spadix and bract. Photo showed >30 oriental fruit flies on visible side of a flower.	Sinchaisri & Areekul 1985
<i>Spathiphyllum cannaefolium</i> [Fruit fly lily]	Flower spike contains ME (20%), methyl chavicol, <i>p</i> -methoxybenzyl acetate, & benzyl acetate as major components.	Lewis et al. 1988
Areaceae – Palm family (Arecales)		
<i>Geonoma macrostachys</i> var <i>macrostachys</i>	ME varied 0.11-0.16% and 0.09-0.25% during staminate & pistillate phases, resp, & emitted ME & eugenol peaked at 11:15 - 13:00 hour.	Knudsen et al. 1999
<i>Geonoma polyandra</i>	ME detected in tr amount from two staminate inflorescences.	Knudsen et al. 2001
<i>Trachycarpus excelsa</i>	ME (tr amount) and eugenol (8.2%) in floral EO.	Kameoka & Wang 1980
<i>Trachycarpus fortunei</i> (<i>T. wagnerianus</i>) [Chusan/Windmill Palm]	Eugenol (32.2%) and ME (tr quantity) in flower EO.	Kameoka & Wang 1980
Asparagaceae - Agave-Century-plant family (Asparagales)		
<i>Dracaena fragrans</i> [Corn plant, Chinese money tree, or Cornstalk Dracaena]	Head-space analysis of flowers using two adsorbents, twister and tenax-TA showed ME at 0.015 and 0.002 %, resp.	Ishikawa & Tani 2007
<i>Polianthes tuberosa</i>	Floral absolute oil contained ca 20% <i>E</i> -isomethyleugenol, and ca 1.5% of ME and eugenol.	
Asteraceae - Aster family (Asterales)		
<i>Achillea conferta</i>	Top flowering aerial parts contained ME at 2.7% of EO.	Saeidnia et al. 2005
<i>Achillea crithmifolia</i>	Flower EO contained ME (0.08%).	Tzakou et al. 1993
<i>Achillea millefolium</i> [Yarrow, Common]	Flowers (white linguiform) from one of 14 different locations in Lithuania contained ME (0.15%) in floral EO.	Gudaityte & Venskutonis 2007
<i>Achillea umbellata</i>	Flower head ME 0.09% & eugenol 0.07% of EO; the chemicals not present in <i>A. lingulata</i> .	Kundakovic et al. 2007
<i>Artemisia alba</i> (<i>A. camphorata</i> .)	Inflorescences from northern Italy – ME (tr – 1.3%) & central Italy ME (0.2%), and those from central Italy a year later no ME.	Perfumi et al. 1999
<i>Solidago odora</i> [Sweet goldenrod]	Flowering tops EO of <i>f. odora</i> and <i>f. inodora</i> contained 5.8 and 4.4% ME, resp.	Tucker et al. 1999
<i>Tagetes erecta</i> [Aztec marigold]	ME (12.3%) and β -caryophyllene (15.2%) of flower EO; ME 0.7% of EO.	Gutierrez et al. 2010; Marotti et al. 2004
<i>Tagetes lucida</i> [Mexican tarragon]	Flowers and leaves contained ME at 0.1 & 3.6% of EO.	Marotti et al. 2004
<i>Tagetes minuta</i> [Wild marigold, South American Marigold]	ME in flowering shoots via hydrodistilled, steam-distilled and water-soluble oils was 0.6, 0.1 and 0.5-0.6 % of EO, resp.	Rajeswara Rao et al. 2006
<i>Tagetes patula</i> [French Marigold]	Flowers contained ME at 0.2% of EO but not detected in leaf EO.	Marotti et al. 2004
<i>Tanacetum chiliophyllum</i> var. <i>chiliophyllum</i>	Flowers contained ME at 0.2% of EO.	Baser et al. 2001c
Boraginaceae – Borage or Forget-me-not family (order = unplaced asterid I)		
<i>Borago officinalis</i> [Borage, Starflower]	Flower ME 2.9% of EO or 34.2 μ g/g fresh wt.	Mhamdi et al. 2009
Brassicaceae – Cabbage/Mustard family (Brassicales)		
<i>Matthiola longipetala</i> subspecies <i>livida</i>	Flowers contained ME and eugenol at 0.7% & 19.9% wt/wt of EO among 49 components.	Hammami et al. 2007
Campanulaceae - Bellflower family (Campanulales)		
<i>Siphocampylus giganteus</i>	ME second highest component in volatiles of two hummingbird-pollinated flowers, having relative amounts of 24% & 12%.	Knudsen et al. 2004

Caryophyllaceae – Pink family (Caryophyllales)		
<i>Dianthus arenarius</i>	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
<i>Dianthus monspessulanus</i>	ME (1.4%), elemicin (1.5%) emitted as part of floral volatiles.	Jürgens et al. 2003
<i>Dianthus superbus</i>	Emitted floral volatiles contain cis- β -ocimene (49.8%), ME (0.2%) and elemicin (0.2%).	Jürgens et al. 2003
<i>Dianthus sylvestris</i>	Floral volatiles emitted contain methyl benzoate (85.7%), eugenol (0.3%) and tr of ME.	Jürgens et al. 2003
<i>Silene latifolia</i> [White champion]	ME (0 - 0.9%) in single flower volatiles from a North American population but not detected in European populations.	Dotterl et al. 2005
Clusiaceae – Mangosteen family (Euphorbiales)		
<i>Clusia parviflora</i>	ME (3.5%) and 1,3,5-trimethoxy-benzene (0.5%) in fresh petal EO.	Nogueira et al. 2001
<i>Clusia renggerioides</i>	ME (2.0%), vanillin (1.1%) and eugenol (tr) in fresh petal EO.	Nogueira et al. 2001
<i>Kielmeyera rugosa</i>	ME (0.2%) found in bee pollinated flower EO but not in leaf and fruit EOs.	Andrade et al. 2007
Cycadaceae – Cycad family (Cycadales)		
<i>Cycas revolute</i>	Estragole (67.0 - 92.7%) with small amounts of anethole, methyl salicylate, ME & ethyl benzoate released from male & female cones.	Azuma & Kono 2006
Euphorbiaceae - Spurge family (Euphorbiales)		
<i>Croton micans</i>	ME (0.1%) in floral EO but not detected in leaf EO.	Compagnone et al. 2010
Fabaceae – Pea family (Fabales)		
<i>Acacia aroma</i> [Aromita]	Flowers contained ME and eugenol at 0.3 and 15.5% of EO.	Lamarque et al. 1998
<i>Acacia caven</i> var. <i>caven</i> [Roman Cassie]	Flowers contained traces of ME and eugenol at 11.2% of EO.	Lamarque et al. 1998
<i>Calliandra nerioides</i>	Flowers contain traces of ME and eugenol at 9.3% of EO.	Lamarque et al. 1998
<i>Cassia fistula</i> [Golden shower, Indian Laburnum]	An attractant of <i>Bactrocera dorsalis</i> in the blossom was identified as ME; flower EO contained 7.3% ME and tr of eugenol.	Kawano et al. 1968; Tzakou et al. 2007
<i>Ceratonia siliqua</i> [Carob tree]	Male whole flowers contained ME (2.8%) and female whole flowers 3.2 and 1.5 % in Galhosa and Mulata CVs.	Custodio et al. 2006
<i>Medicago marina</i> [Coastal medick, Sea medick]	EO of reproductive parts contained ME (20.4%) & eugenol (1.8%), and vegetative parts contained eugenol (4.9%) & ME (1.7%).	Flamini et al. 2003
<i>Trifolium repens</i> [White clover, Creeping clover]	Flower volatiles contained 8-11% ME, day emission 3 folds of night, and higher with increase temperature (10 - 20° C).	Jakobsen & Olsen 1994
<i>Vachellia farnesiana</i> (<i>Acacia farnesiana</i>) [Needle bush]	Cassie (floral distillate) contained ME.	Duke 1981
<i>Vicia faba</i> (<i>Faba sativa</i>) [Broad bean, Faba bean, Fava bean]	Headspace volatiles of cultivar Maris Bead flowers contained ME (0.29%), eugenol (0.66%), cinnamyl alcohol (0.77%), and methyl isoeugenol (0.02%).	Griffiths et al. 1999
Lamiaceae – Mint family (Lamiales)		
<i>Agastache foeniculum</i> [Anise hyssop]	ME in inflorescences & leaves increased from 28.6 to 41% in EO during 17 day storage; A putative hybrid of <i>A. rugosa</i> and <i>A. foeniculum</i> possessed ME (2.4%) in inflorescence EO.	Dimitriev et al. 1981; Wilson et al. 1992
<i>Ocimum basilicum</i>	ME 3-11% of inflorescence EO in two var.	Nudijati et al. 1996
<i>Ocimum gratissimum</i>	Floral EO contained ME (1.7%).	Sainsbury & Sofowora 1971
<i>O. gratissimum</i> x <i>O. viride</i>	Flower of this cross showed higher ME (3.16%) than that of parental species.	Khosla et al. 1989
<i>Ocimum sanctum</i> . (<i>Ocimum tenuiflorum</i>) [Holy basil; red basil]	ME contents in 5 var high in ME 64-77% and 2 var high in eugenol 1.7 - 2.3 % of inflorescence EO; ME in EO of leaf, stem and inflorescence 72.5%, 75.3%, 83.7%, resp.	Nudijati et al. 1996; Kothari et al. 2005
<i>Ocimum selloi</i> [Pepper basil]	Leaf and flower EOs in accession A had ME at 0.79 and 1.13%, resp. and in accession B, 65.5% and 66.2%, resp.	Martins et al. 1997
<i>Ocimum suave</i>	ME (66.18%) in flower oil.	http://www.emea.eu.int
<i>Rosemarinus officinalis</i>	Rosemary oil obtained from pale blue flowers contained < 0.01% ME.	
<i>Stachys lavandulifolia</i>	EO of flowering aerial parts contained 3.61% ME.	Sezik & Basaran 1985
Lauraceae – Laurel family (Laurales)		
<i>Laurus nobilis</i>	ME in headspace analyses of female flowers, flowering tops of female and male plants were 0.2, 1.6 & 3.6%, resp; ME(3.9%) in floral oil.	Flamini et al. 2002; Kovacevic et al. 2007
<i>Ocotea bofo</i>	EO of floral calyxes contained ME (0.08%) of 46 compounds.	Guerrini et al. 2006
Lecythidaceae – Lecythis family (Lecythidales)		
<i>Couropita guianensis</i> [Cannon ball tree]	Floral EO contains eugenol (2.9%) with traces of ME and <i>E</i> -methyl isoeugenol.	Knudsen & Mori 1996
<i>Gustavia longifolia</i>	Floral EO contains ME (7.9%), eugenol (0.1%), <i>E</i> -methyl isoeugenol (0.1%) & elemicin (1.3%).	Knudsen & Mori 1996
Liliaceae – Lily family (Lilliales)		
<i>Allium roseum</i> var. <i>odoratissimum</i> [Rosy garlic]	Fresh flowers contain ME and eugenol at 1.4 and 12.7 % of EO, resp.	Najjaa et al. 2007
<i>Hyacinthus orientalis</i>	Headspace volatiles of white flowers had ME (0.34 - 0.49%) among >70 constituents.	Brunke et al. 1994
Magnoliaceae – Magnolia family (Magnoliales)		
<i>Magnolia kobus</i>	Flowers from 1 of 32 localities studied emitted ME at 0.03 μ g/flower/hour.	Azuma et al. 2001
<i>Magnolia salisifolia</i> [Willow-leaved/ Anise magnolia]	1.8 kg of flower buds yielded 498 mg of ME.	Li et al. 2007
<i>Michelia alba</i>	Floral and leaf EO possessed 0.38% & 0.22% ME, resp.	Kameoka 1993
<i>Michelia champaka</i>	ME & methyl isoeugenol detected among many EO volatile components; champaka concrete contained 0.1% ME.	Zhu et al. 1982; Kaiser 1991
<i>Michelia longiflora</i>	Floral volatile oil contained linalool, ME, methyl- ethyl- acetic ester, & acetic acid.	

Malvaceae – Mallow family (Malvales)		
<i>Ochroma pyramidalis</i> [Balsa]	Bat-pollinated flowers contained 0.8% ME in floral volatiles.	Knudsen & Tollsten 1996
<i>Tilia cordata</i> [Linden]	Blossoms from 2 of 6 trees contained 0.6 and 0.1 % of EO, resp.	Nivinskienė et al. 2007
<i>Tilia platyphyllos</i> [Largeleaf Linden]	Inflorescences contained 2.43% eugenol and 1.27% ME.	Radulescu & Oprea 2008
Meliaceae – Mahogany family (Sapindales)		
<i>Carapa guianensis</i> [Caropa]	Flowers in one campus of Para, Brazil had eugenol (2.4%) & no ME, while flowers in another campus 2.9% eugenol and 0.1% ME.	Andrade et al. 2001
Morinaceae – Morinaceae family (Dipsacales)		
<i>Morina persica</i> [Prickly Whorlflower]	Fresh flowers had 32 components with ME and eugenol 0.36% and 0.27% of EO, resp.	Baser & Kurkcuoglu 1998
Myrtaceae – Myrtle family (Myrtales)		
<i>Myrtus communis</i> [Myrtle]	Flowers from Western and Central Albania had ME at 0.76 and 1.68% of EO, resp; ME (4.02% of EO) 1 of 7 major floral components in var <i>italica</i> .	Asllani 2000; Wannes et al. 2010
<i>Syzygium aromaticum</i> (<i>Eugenia caryophyllus</i>)	310 - 340 ppm of ME in flowers.	http://www.emea.eu.int
Oleaceae – Olive family (Lamiales)		
<i>Syringa vulgaris</i> [Lilac or Common lilac]	ME (tr) in floral EO; ME present in floral volatiles.	Wakayama et al. 1970; Lamparsky 1985 c/f Knudsen et al. 2006
Onagraceae – Evening Primrose family (Myrtales)		
<i>Clarkia breweri</i> [Fairy fans]	ME and isoME derived from eugenol and isoeugenol via the action of (<i>iso</i>)eugenol <i>O</i> -methyltransferase (<i>IEMT</i>); inbred line II contained veraldehyde (1.54 %), methyl isoeugenol (0.66%), ME (0.59%), & isoeugenol (0.16 %), but absent in inbred line I.	Wang et al. 1997; Raghuso & Pichersky 1995
Orchidaceae – Orchid family (Orchidales)		
<i>Angraecum bosseri</i> (<i>Angraecum sesquipedale</i> var <i>angustifolium</i>)	Traces of ME in orchid flower (Madagascar).	Kaiser 1993
<i>Bulbophyllum cheiri</i> [Fruit fly orchid]	ME (594 ppm) major component and four other phenylpropanoids (in much smaller quantities) in floral volatiles.	Tan et al. 2002; Nishida et al. 2004
<i>Bulbophyllum elevatopunctatum</i> [Raised dot Bulbophyllum]	ME 78.5 + 21.6 µg (mean + SD; n=10) per flower as major component in floral EO.	Tan & Nishida (unpublished)
<i>Bulbophyllum patens</i> [Ginger orchid]	ME - ca. 40 ng /flower, corresponding to a thousandth of zingerone (main floral volatile).	Tan & Nishida 2000
<i>Bulbophyllum vinaceum</i> [Wine red orchid]	ME – the 2 nd main component of eight floral phenylpropanoids detected.	Tan et al. 2006
<i>Cattleya araguaiensis</i>	Amazon region - ME and eugenol in tr amount.	Kaiser 1993
<i>Cattleya leopoldii</i>	ME (3%) in floral EO.	Kaiser 1993
<i>Epidendrum nocturnum</i>	Night-scented orchid, ME in minute quantity.	Kaiser 1993
<i>Gymnadenia conopsea</i>	Floral scent varied greatly, ME – 5.7%; Floral day and night emissions for ME 9.83% & 3.91% of volatiles and for eugenol 8.91% & 6.12%, resp.	Kaiser 1993; Huber et al. 2005
<i>Gymnadenia odoratissima</i>	Relative quantity of volatiles emitted during day and night for ME 0.07 & 0.18 and for eugenol 4.65 & 3.11, resp.	Huber et al. 2005
<i>Odontoglossum pulchellum</i>	“Rosy-floral” scent varied with volatiles - ME (1 - 20%) and hydroquinone dimethyl ether (10 – 60%).	Kaiser 1993
<i>Oncidium sarcodes</i>	Neo-tropics orchid – ME tr amount.	Kaiser 1993
<i>Pescatorea dayana</i>	ME (1.4% of peak area) and elemicin in tr.	Kaiser 1993
<i>Phalaenopsis violacea</i>	Eugenol and ME in tr amounts, and elemicin (26.7%) in the Malayan type. No ME detected in the Borneo type (currently <i>P. belina</i> Christenson).	Kaiser 1993
<i>Rangaeria amaniensis</i>	Highland orchid with tr quantity of ME.	Kaiser 1993
<i>Satyrium microrrhynchum</i>	Floral scent in 1 (Tam Cave) of 3 populations in South Africa, contained eugenol (0.14 - 0.55 %), ME (1.83 – 4.51%) & elemicin (2.01 - 8.53%).	Johnson et al. 2007
<i>Zygopetalum crinitum</i> [Hairy Zygopetalum]	Eugenol (2.6%), ME (3.1%) and chavicol (3.9%) of EO.	Kaiser 1993
<i>Zygopetalum mackayi</i> (<i>Z. mackayi</i>) [Caper bean]	ME a minor component in floral volatiles.	Williams & Whitten 1983
Paeoniaceae – Peony family (Saxifragales)		
<i>Paeonia lactiflora</i> (<i>P. albiflora</i>) [Chinese peony]	ME and eugenol present in low concentration (0.1-0.5%) of flower EO.	Kumar & Motto 1986
Pandanaceae – Screw-pine family (Pandanales)		
<i>Pandanus odoratissimus</i>	ME (0.1%) in volatile oil of fresh flowers.	Raina et al. 2004
Piperaceae – Pepper family (Piperales)		
<i>Piper betel</i> [Betel]	Flower EO had safrole as a major phenol, followed by hydroxychavicol, eugenol, ME, isoeugenol, flavone, and quercetin.	Chin & Sun 1990
Poaceae – Grass family (Poales)		
<i>Cymbopogon flexuosus</i>	ME and elemicin chemotypes had ME 32.6 –34.2% and 0.2-0.4 % of EO in inflorescence, resp, and no ME in citral and citronellol chemotypes	Nath et al. 2002
Putranjivaceae – Rosid family (Malpighiales)		
<i>Drypetes natalensis</i> [Natal drypetes]	Few minor phenylpropanoids and pollinated by cetonid beetles – ME in male (tr - 2.2%) & female flowers 0.3-0.9% .	Johnson et al. 2009
Ranunculaceae – Buttercup or crowfoot family (Ranunculales)		
<i>Pulsatilla rubra</i> [Pasque Flower]	Violet-purple flowers with traces of ME in anther volatiles, 1 of 2 among 12 spp.	Jurgens & Dotterl 2004
<i>Ranunculus plataniifolius</i> [Large white buttercup]	White open flowers with tr quantity of ME in anther volatiles, 1 of 2 among 12 spp in 6 genera in this family.	Jurgens & Dotterl 2004
Rhamnaceae – Buckhorn family (Elaeagnales)		
<i>Zizyphus mauritiana</i> [Indian jujube]	ME (0.4%) in floral faecal-like odor that attracted green dung beetles and many flies.	Alves et al. 2005

Rhizophoraceae – Mangrove family (Malpighiales)		
<i>Rhizophora stylosa</i>	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)		
<i>Prunus mume</i> [Japanese apricot]	ME present as minor component among 22 non-polar constituents of flowers.	Matsuda et al. 2003
<i>Rosa centifolia</i>	ME (1.4%) in EO.	Ohloff 1978
<i>Rosa chinensis</i> [China rose]	ME and isomethyl eugenol as minor floral components in var spontanea; ME at 0.65, 0.04 & 0.9 % of volatiles in CVs Diorama, Grand Mogul & Lady Hillingdon, resp, only 'Diorama' emitted ME (0.34% of volatiles).	Wu et al. 2003; Joichi et al. 2005
<i>Rosa damascena</i> [Damask Rose]	ME (1.4%) in EO; ME increased with time of fermentation (0-36 min.) 0 – 4.34% of EO.	Ohloff 1978; Baydar et al. 2008
<i>Rosa damascena semperflorens</i> cv. 'Quatre Saisons'	Free ME detected in petal volatiles, and detected volatiles emitted rhythmically, with maximum peaks coincided at 8–10 hour.	Picone et al. 2004
<i>Rosa hybrida</i>	Petals contained ME; ME (0.2%) detected only in floral EO of "Sandra" using C 18 (octadecyl silane) cartridge.	Lavid et al. 2002; Kim et al. 2000;
<i>Rosa Phoenicia</i>	Tr of ME and eugenol in petals fragrance.	Yomogida 1992
<i>Rosa rugosa</i>	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 & pollenkitt volatiles.	Wu et al. 1985; Dobson et al. 1987; Dobson & Bergstrom 2000
<i>Rosa setata</i> X <i>Rosa rugosa</i>	Floral fragrance contained 0.30% eugenol and 0.68% ME.	Chen et al. 1987a
Solanaceae - Nightshade/Potato family (Solanales)		
<i>Brunfelsia australis</i> [Paraguay jasmine]	ME tr. and 0.1% in young deep purple and mature white flowers, resp, with linalool and (E)-ocimene as major components.	Bertrand et al. 2006
Tamaricaceae – Tamarix family (Tamaricales)		
<i>Tamarix boveana</i>	ME (tr) and eugenol (0.83%) in floral EO.	Saidana et al. 2008b
Thymelaeaceae – Mezereum family (Malvales)		
<i>Daphne genkwa</i>	Flower EO contained 121 compounds - ME (4.55%) and eugenol (tr).	Ueyama et al. 1990
Valerianaceae - Valerian family (Dipsacales)		
<i>Valeriana tuberosa</i>	Inflorescence contained 0.47% and 0.45% of EO for eugenol and ME, resp, which were not found in other plant parts.	Fokialakis et al. 2002
Verbenaceae - Verbena/Vervain family (Lamiales)		
<i>Lippia alba</i> cv kavach [Bushy Matgrass/ Lippia]	Linalool in leaf (67.7%) & inflorescences (79.9%) with 0.1% ME & 0.5% eugenol of inflorescence EO, but absent in leaf EO.	Mishra et al. 2010
<i>Lippia origanoides</i> (<i>Lippia schomburgkiana</i>) [<i>Origanum dictamnus</i>]	Three chemotypes – only type A collected from 3 different sites in Columbia had ME 0.01- 0.19% in aerial parts EO.	Stashenko et al. 2010
Zingiberaceae – Ginger family (Zingiberales)		
<i>Hedychium coronarium</i> [White ginger lily]	ME tr amount in flower EO with E- & Z-methyl isoeugenol 0.45 & 0.06% of peak area.	Matsumoto et al. 1993

* quantitative data given if available.

** symbols and abbreviations as in Table I.