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# Medicinal VOCs in Plants Recommended for Prairie Strips and Pollinator Gardens as Prophylactic and Curative Support for Pollinating Insects: A Review

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## ABSTRACT

Plant VOCs are signaling compounds that attract pollinators, protect plants from stress, disease and predation, have allelopathic effects and play a role in plant growth and development. The purpose of this review was to evaluate pollinator plants for secondary metabolite VOCs such as monoterpenes and sesquiterpenes for their potential medicinal value to pollinating insects. To address disease pathogens impacting native pollinators and honeybees, plants with medicinal VOCs can be selected for prairie strips and pollinator gardens as agricultural best management practices. Eight flowering plants - bee balm, echinacea, catmint, prairie rose, lavender, thyme, oregano and red clover contain VOCs in their nectars and pollens such as caryophyllene, myrcene, germacrene, cymene, thymol, cineol, carvacrol, borneol, nonanal, linalool and terpineol that offer antimicrobial, antifungal, anti-inflammatory, antioxidant benefits and some are acaricides that may aid in controlling the *Varroa destructor* mite (=jacobsoni).


**Key words:** Plant VOCs, Pollinator gardens, Prairie strips, Terpenes.

A best management practice in rural and urban agriculture is to plant prairie strips or pollinator gardens which attract pollinators, help reduce soil erosion and aid in the biogeochemical cycling of nutrients and water (Harris and Iyer 2014, Liebman *et al.,* 2013). Prairie strips and pollinator gardens are planted with a variety of both annual plants (which establish fast and colonize quickly after disturbances) and perennial plants (which aid in long-term structure) resulting in a diversity of plants and insects that they attract. Prairie strips are dominated by native grasses and wildflowers (forb species) in relatively balanced proportion. A dominance of native plant species is recommended for both prairie strips and pollinator gardens since they draw native insect pollinators in addition to the honeybee which is more of a generalist in terms of foraging. Criteria for selection of plant species other than the plant's ability to draw pollinators may include seasonal bloom times, environmental/growth requirements (water, soil, sun, nutrients, *etc*.) and plant compatibility, but it would also be useful to select plants that can provide high quality food (*e.g*., specific amino acids and total protein content of pollen) and medicinal compounds that can aid in preventing and curing pathogenic diseases in pollinating insects.

The purpose of this review is to evaluate medicinal and nutritional properties of forb plants that are known to attract pollinators, to see if they have the potential to serve as prophylactic and curative support for pollinating insects, including honey bees that are suffering colony losses from myriad diseases. Most studies on plant VOCs pertain to their roles in herbivore defense or allelopathy. Floral nectars and pollen contain many plant secondary metabolites such as monoterpene and sesquiterpene, polyphenols and flavonoids that have medicinal properties such as antimicrobial, antioxidant and anti-inflammatory effects (Wiese *et al*., 2018; Ding *et al*., 2018 ; Rzepecka-Stojko 2015; De Cássia da Silveira e Sá *et al*., 2013; Gonzales *et al.,* 2012; Vladimir-Knežević *et al.* 2012, Park *et al*. 2011; Le Blanc *et al*., 2009; Baser 2008; Romeo *et al*., 2008). These medicinal properties help plants defend them self against disease, but the benefits may extend to organisms that feed on the plants.

The parasitic mite *Varroa destructor* (=jacobsoni) (Anderson and Trueman 2000) is presently the number one stressor to honeybees and greatest factor in overwintering colony declines in North America as it is a carrier of many diseases (USDA 2017). In Asia, *Tropilaelaps clareae* mites are also a significant threat to bees (Lancette 2017, Putatunda *et al*., 2001). Integrated pest management strategies for controlling mites include selection of mite-resistant bees, monitoring, chemical treatments, biological control (*e.g*., use of pseudoscorpions that feed on mites), interruption of the brood cycle and other physical approaches like the use of screened bottom boards, spacing out the hives, *etc*. (USDA 2017, Putatunda *et al*., 2001). Integrated

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pest management is the best approach but presently there is no approach with 100% efficacy. Common chemical treatments today include the use of formic acid, oxalic acid, essential oils and a couple of other commercial miticides. Sammataro *et al*. (2005) found that mites developed resistance to acaracides such as amitraz, coumaphos and fluvalinate. Commercial acaracides can get expensive and some have been shown to have negative effects on bees including death of the queen or worker bees, especially when over-dosed or when bees have other stressors (Johnson *et al.* 2013; Gregorc *et al.,* 2018).

Essential oils have been shown to be effective acaricides (Saad *et al.,* 2006; Bandoni *et al*., 2010; Sammataro *et al.,* 1998). US Patent US6932986B2 (Mishima *et al.,* 2002) describes a mixture of eucalyptus oil and rosemary oil as an effective acaricide. Lindberg *et al*. (2000) found that a vapor application of thymol, clove oil, methyl salicylate, or tau fluvalinate can be more effective than formic acid in mite control. Sabahi *et al.* (2017) found that oregano oil, which contains the varoacidal compound, carvacrol, was more effective than oxalic acid in mite treatment, but that it depended on the delivery system (using an electric vaporizer which at this time is unavailable to most beekeepers). The use of essential oil in concentrated form using a vaporizer in the hive has better efficacy than soaking the essential oil in cardboard. Capped honey that bees store will adsorb some of the VOCs from the oil, but the bees will still consume it. Since the delivery system affects the efficacy as a miticide, it can be expected that low concentrations of VOCs collected from natural plants will have an even lower efficacy than vaporized essential oil but may confer some efficacy in reducing mites in between more aggressive chemical treatments.

Thymol is a phenolic monoterpene that is an effective and selective acaricide - has high mite mortality and low bee toxicity (Gregorc *et al*., 2018). Other monoterpenes and terpenic alcohols that may be effective acaricides include borneol, geraniol and cineol (Saad *et al.,* 2006; Tiwari *et al.,* 2009). Wiese *et al.* (2018) found that thymol and other terpenes in *Thymus vulgaris* pollen and to a lesser extent nectar, also had antibiotic activity towards European foulbrood and other microbes.

Commercial bee feeds (nectar and pollen substitutes) contain a select number of essential oils because of their benefit to bee health and their ability to attract bees to the feed. For example, Honey-B-Healthy contains essential oils of lemongrass and spearmint that are known to attract bees. The product has shown efficacy in reducing reactive oxygen species in bees exposed to paraquat (Healthy bees LLC). Providing bees with healthy diets can aid bees in overcoming chemical toxicity from pesticides (Berrenbaum and Johnson 2015; Wheeler and Robinson 2014, Schmehl *et al*., 2014). Both pollen and nectar feeding during dearth periods can extend the honey supply in the hive and helps to combat diseases, thus supplemental feeding can be considered part of the integrated pest management strategy (Kumari and Kumar 2020).

## VOCs and plant-pollinator interactions

Plant volatiles are affected by environmental factors (Mahdavi *et al*., 2020; Graham *et al*., 2017). Mahdavi *et al*. (2020) reported that the VOC profile of thyme (*Thymus vulgaris*) changed in response to drought stress for some VOCs (namely, α-phellandrene, O-cymene, γ-terpinene and β-caryophyllene). Terpenoid levels may vary in different parts of plants and by growth phase of the plant (Begley *et al*., 2008). The VOC profile changes when insects damage plants (Tao *et al*., 2017). When plants are physically damaged from animal herbivory, they emit more VOCs which deter herbivores (Birkett *et al*., 2000). In some cases, pollinators may avoid plants that are damaged based on the change in VOC profile (Kessler and Halitschke, 2009; Mothershead and Marquis, 2000). However, relatively minor herbivore-damage to leaf tissue may increase pollen and nectar secondary metabolites that attract pollinating insects (Kessler and Halitchke 2009).

Presently it is unclear whether honey bees select plant nectar or pollen in order to self-medicate. Bees show selective responses to different terpenes but are less responsive to phenolic compounds (Wiese *et al*., 2018). Bumblebees responded to parasitic infection by increasing their intake of the alkaloid nicotine (Baracchi *et al*., 2015). Honey bees have been known to show a preference for neonicotinoid pesticides in their sugar water compared to sugar water not laced with the chemicals (Kessler *et al*., 2015), but nicotine itself was a slight deterrent (Kohler *et al*., 2011). Vaudo *et al*. (2016) found that bumble bees regulate their protein and lipid intake and make choices in food selection. Simone-Finstrom and Spivak (2012) showed that honey bees increased their collection of plant resins (for propolis) to combat fungal infection in the hive, however, propolis is a barrier strategy to keep insects out of the hive rather than a medicinal solution.

There are studies that indicate competition between honey bees and native insect pollinators, especially in landscapes with low plant diversity, between species (Herbertsson *et al*., 2016; Ropars *et al*., 2019) but there are also indications that what is good for honey bee colonies is also good for native pollinating insects when there is sufficient habitat provided for all (Evans *et al*., 2018). Bee-friendly habitat increased wild bee success and wild bee success correlated with honeybee success in a study by Evans *et al*. (2018). In more stressed urban environments, Ropars *et al*. (2019) advise urban beekeepers not to keep a high density of managed hives in urban areas so that native bees can also thrive. Increasing the floral abundance is expected to result in a higher per-flower visitation rate by pollinating insects (Cusser and Goodell 2013, Essenberg 2012). If the floral abundance is already high, the per-flower visitation rate may not correlate or may negatively correlate with floral abundance; the relationship is influenced by floral density in the surrounding environment and traits of both the plants and their pollinators (Essenberg 2012).

## VOCs in plants and their medicinal properties (emphasis on potential health benefits to bees)

In an earlier study on honey typing by VOC profiles, (Petz *et al*., 2019), freshly cut flower heads were extracted by solid phase microextraction (SPME) and qualitatively analyzed by GC/MS for VOCs. Bee balm, catnip, echinacea, prairie rose and lavender had a high number of VOCs and were attractive to pollinators, thus selected for review of medicinal properties associated with the VOCs found in the flower heads. Other plant candidates for pollinator gardens or prairie strips were searched in the literature for VOC data and their medicinal properties and the final data set includes eight flowering plants: bee balm, echinacea, catmint, prairie rose, lavender, thyme, oregano and red clover that produce over forty monoterpenes, sesquiterpenes and their (alcohol, aldehyde) derivatives, which have antioxidant, anti-inflammatory, antimicrobial/antibiotic, antifungal, antiviral properties and some are acaricidal which may help honey bees fight Varroa mites and diseases carried by them.

Table 1 shows these plants and VOC data and their medicinal properties. The source of VOC data and medicinal properties data are referenced below Table 1; NCBI database accessed between May 15 and June 11, 2020.

Borneol, carvacrol, cineole, p-cymene, linalool, thymol and methyl salycilate are acaricides which may aid in reducing mite infestations of honey bee colonies (reduce number of mites and their reproduction in the hives). Guitton *et al*. (2009) report some additional VOCs for lavender that are not in Table 1: linalyl acetate, lavendulyl acetate, lavandulol and bornyl acetate; these are more associated with *L.augustifolia* and not *L.xintermedia*. The lavender spp. in Petz *et al*. (2019) were not identified beyond the genus *Lavandula*. Discrepancies may also be a product of the method used for extraction and analysis of the VOCs as well as differences in the plants analyzed because production of VOCs changes with plant development. Guitton *et al*. (2009) also found that the distribution of VOCs varies by plant tissues. Whole flower heads with calyx were extracted in Petz *et al*. (2019) so it is more likely that the flowers extracted were not *L. augustifolia*.

When bees convert nectars to honey, terpenic compounds may be metabolized or oxidized and some may be lost by evaporation. Enough of the original VOC profile of nectar is retained by honey such that VOCs can be used for tracing floral origins of honey. The evaporation of nectar by bees in the hive releases some of the VOCs which may attract honey robbers to the hive such as wasps and ants or could have a deterrent effect depending on the specific VOCs. The release of VOCs may aid in controlling mites. It is not clear what concentration of the complex mixture of the above-listed naturally occurring acaricides would be efficacious.

Bees can inhale VOCs through spiracles and can take in VOCs by ingestion of honey and pollen. The VOC and phenolic (flavenoids and non-flavenoid types) profile of honey and pollen are what make bee products medicinal to humans. Certainly, a diversity of plants in any agricultural system attracts more pollinators, but more research needs to be done to determine the overall effect of plant VOCs on health and toxicity to bees and other pollinating insects. This review suggests that a diversity of plants in a pollinator garden or prairie strip offers a complex mixture of plant VOCs that have medicinal value. In the search for medicinal values, other benefits of pollinator-friendly plants include nutritional offerings such as amino acids and proteins, carbohydrates and lipids. The eight plants in Table 1 are recommended for medicinal VOCs and some additional recommendations and insights for prairie strips and pollinator gardens are discussed below.

### Asters

Echinacea is the only plant in the Asteraceae family listed in Table 1. Asters in general are recommended for prairie strips and a variety insures pollen and nectar during summer and early fall. Goldenrod (*Solidago spp.*) is one of the most important providers of pollen and nectar to bees in late summer into early fall when there is a dearth of other flowering plants. Goldenrod was not found to be rich in VOCs but provides much-needed pollen at end of season in North America. Goldenrod grows easily and reproduces through its roots, bulbs, stems and seeds. A cautionary note is that being weedy, it can be invasive. *S. nemoralis* is a good species to select for drought resistance and can grow in sandy soils, as a pioneer species in abandoned fields for prairie restoration, or for rock gardens. Prairie blazing star, *Liatris pycnostachya*, is a native perennial daisy of the north American prairie visited by native bees and honey bees as well as other pollinating insects. It pairs well with goldenrod.

### Clovers

There are about 300 species of clover. Clover is highly abundant in grasses of suburban and urban lawns, as well as farmland of former tall grass prairie habitat, parks, *etc*. In suburban and urban areas, choosing an apiary site near an abundance of white clover is beneficial as it is one of the largest contributors of nectar to honey bees in North America. Red clover (*Trifolium pratense*) is a short-lived perennial or biennial that is good for a cover crop, produces healthy pollen for bees and nectar for bumblebees, helps keep down weeds and grows over a wide range (Hardiness Zone 4 and warmer) of the US. Prairie clover (*Dalea spp.)* is a different genus but is in the same family (Fabaceae) of other clovers. *D. purpurea and D.candida*are recommended for prairie strips in dry to moderate soils; for more drier regions *D. enneandra* should be planted. Prairie clovers attract bees and butterflies, help reduce soil erosion and fix nitrogen.

### Sunflowers

*Helianthus augustifolius* is a perennial sunflower that produces pollen and nectar from mid to late summer which can be used in a prairie strip. *H. annuus* is the common annual sunflower which is a good garden variety. There are a variety of pollenless sunflowers that should be avoided.

**Table 1:** Monoterpenes, sesquiterpenes and terpene alcohols in pollinator plants.

| VOC[CAS] | Medicinal properties | Bee Balm | Echinacea | Catmint | Prairie Rose | Lavender | Thyme | Oregano | RedClover |
|---|---|---|---|---|---|---|---|---|---|
| benzene acetaldehyde [122-78-1] | antibiotic | | x | | | | | | |
| borneol [507-70-0] | acaricide | | | | | x | x | | |
| cadinene [483-76-1] | anti-inflamantibiotic | | x | | | | | | |
| calamenene [ 483-77-2] | immuno-active | | x | | | | | | |
| (+)-calarene [17334-55-3] | larvicidal to mosquitos | | x | | | | | | |
| camphene [79-92-5] | anti-inflamantioxidant | x | | | | x | x | | |
| camphor | anti-inflamantimicrobantifungal | | | | | x | x | | |
| (+)-2-carene [4497-92-1] | antimicrobantioxidan | x | | | x | | | | |
| 3-carene [13466-78-9] | antimicrobpest repellent | | | | | x | | | |
| caryo-phyllene [87-44-5] | ant irritant; induces apoptosisanti-inflam | | x | x | | x | x | x | x |
| **VOC[CAS]** | **Medicinal properties** | **Bee Balm** | **Echinacea** | **Catmint** | **Prairie Rose** | **Lavender** | **Thyme** | **Oregano** | **RedClover** |
| b-cedrene [546-28-1] | anti-inflaminsecticidalantifungal | | x | | | | | | |
| cineole (eucalyptol) [470-82-6] | acaricide; anti-inflamantimicrob | | | x | | x | x | | x |
| E_citral (geranial) [141-27-5] | antifungal anti-aflatoxin | | | | x | | | | |
| citronellal [106-23-0] | anti-microbial | | | | | x | | x | |
| a-cubebene [17699-14-8] | neuro-protective | | x | | | | x | | |
| p-cymene [99-87-6] | antioxidant antimicrob anti-inflamacaracide | x | x | | x | | x | x | |
| 4-carvo-menthenol (4-terpinenol) [562-74-3] | antimicrobmajor compd of tea tree oil) | | | | x | | | | |
| b and y-elemene [11029-06-4] | anti-inflamantitumor (induces apoptosis) | | x | | | | | | |
| eugenol [97-53-0] | antiseptic anti-inflam | x | | | x | | x | | |
| **VOC** | **Medicinal properties** | **Bee Balm** | **Echinacea** | **Catmint** | **Prairie Rose** | **Lavender** | **Thyme** | **Oregano** | **Red Clover** |
| farnesene[502-61-4] | Anti-inflam | | | | | x | | | x |
| geraniol[106-24-1] | anti-inflam antioxidant anti-microbial; antifungal. mosquito repellant; acaricide | | | | x | | | | |
| germacrene D [37839-63-7] | antimicrob | | x | | | x | x | | x |
| a- gurjunene [489-40-7] | anti-inflamantibiotic | | x | | x | | | | |
| hexene-1-ol [928-96-1] | Insect attractant | | | | x | | | | |
| cis-3-hexenyl acetate [3681-71-8] | attracts beneficial insects | | | | | | | | x |
| limonene [138-86-3 | anti-inflamantimicrobantiviral | | x | x | | x | | | x |
| linalool [78-70-6] | antiox; anti-inflamantimicrobacaricide | x | x | | | | x | x | x |
| **VOC[CAS]** | **Medicinal properties** | **Bee Balm** | **Echinacea** | **Catmint** | **Prairie Rose** | **Lavender** | **Thyme** | **Oregano** | **RedClover** |
| b-myrcene [123-35-3] | anti-inflam analgesic apoptotic | x | | x | | x | x | x | |
| nonanal [124-19-6] | acaracide antifungal | | x | | x | | | | x |

**Table 1 Continue...**

**Table 1: Continue...**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ocimene [13877-91-3] | antifungal anti-inflam | | x | | | x | x | | x |
| 1-octen-3-ol [3391-86-4] | Insect attractant or repellent | | | | | x | | | x |
| phellandrene [99-83-2] | Antimicrobanti-inflam | | x | | | x | x | | |
| a-pinene [80-56-8] | anti-inflamantimicrobantiviral ACE inhibitor | | x | | x | x | | | |
| b-pinene [127-91-3] | antimicrobantioxidant | | | x | | | x | | x |
| sabinene [3387-41-5] | antimicrob anti-inflamantioxidant | | | | x | | | | x |
| methyl/ethyl salicylate | Analgesicacaricide | | | | x | | | | |
| terpineol [98-55-5] | anticancer acaricide insecticidal | x | | | x | | | x | |
| **VOC [CAS]** | **Medicinal properties** | **Bee Balm** | **Echinacea** | **Catmint** | **Prairie Rose** | **Lavender** | **Thyme** | **Oregano** | **RedClover** |
| d- terpinene [99=85-4] | antifungal anti-inflamantiparasit antiviral | x | | | | x | x | x | |
| a-thujene [2867-05-2] | antibiotic | | | | | | x | | |
| a-thujone [546-80-5] | | | | | | x | | | |
| thymol [89-83-8] | anti-inflam antibiotic antifungal, acaricide | x | | x | | | x | x | |
| thymol methyl ether [1076-56-8] | antimicrob | x | x | | | | | | |
| ylangene[14912-44-8] | antiox | | x | | | | | | |

**Abbreviations:** anti-inflam (anti-inflammatory). Antimicrob (antimicrobial). Antiox (antioxidant).

**Table 1 Footnotes: Sources (data sets) for VOCs found in plants:**

Bee Balm (*Monarda didyma*): Petz *et al*. (2019); Echinacea *(E.sp):* Petz *et al*. (2019); Catmint (*Nepeta sp*): Petz *et al*. (2019); Prairie Rose (*Rosa sp*): Petz *et al*. (2019); Lavender (*L. angustifolia and L. intermedia*): Petz *et al*. (2019); Guitton *et al*. (2009); Romeo *et al*. (2008); Thyme (*T. vulgaris):* Wiese *et al*. (2018); Mahdavi *et al*. (2020); Vladimir-Knežević (2012); Oregano (*O. vulgare):* Leyva-López 2017; Mahdavi *et al*. (2020); Fani and Kohanteb (2017); Red Clover (*Trifoleum pretense):* Kigathi *et al*. (2009).

**Table 1 Footnotes: Sources for medicinal values of VOCs:**

De Cássia da Silveira e Sá *et al*. (2013); Gonzalez *et al*. (2012) for several compounds. cis-3-Hexen-1-ol: CID=5281167. NCBI (National Center for Biotechnology Information). PubChem Database. Benzene acetaldehyde: Pavillard and Wright (1957); Borneol: Zhong 2014, Sharifi-Rod *et al*. (2015); Cadinene: Gonzales *et al*. 2012, Ding *et al*. (2018); Calamenene: Ding *et al*. (2018); Calarene: Govindarajan *et al*. (2016); Camphene: Tiwari and Kakkar (2009); Romeo *et al*. (2008); Camphor: CID=2537. NCBI (National Center for Biotechnology Information). PubChem Database. 2-Carene: Romeo *et al*. 2008; Cherrat *et al*. (2014); 3-Carene: Calveiro *et al*.2006; Romeo *et al*. (2008); Carvacrol: Baser 2008; Weise *et al*. 2018; Lwande *et al*. (1999); Caryophyllene: Park *et al*. 2011; Martin *et al*. (1993); b-Cedrene: Jeong *et al*. (2014); Cineole: Cherrat *et al*. (2014); Romeo *et al*. (2008); Montanari *et al*. (2011); Citral: Phetsang *et al*. (2019); Citronella: Romeo *et al*. (2008); Cubebene: Sharifi-Rod *et al*. (2015); p-Cymene: Marchese *et al*. (2017); Lwande *et al*. (1999) 4-Carvo-menthenol (4-terpinenol) Flamini (2003); Elemene: Xie *et al*. (2020); Eugenol antiviral: Dai *et al*. (2013); Farnesene: Afoulous *et al*. (2013); Geraniol: Romeo *et al*. (2008) Germacrene: Montanari *et al*. (2011); Gurjunene: George *et al*. (2015); Saldanha *et al* (2019); Hexenyl acetate -James (2003); Limonene: Sharifi-Rod *et al*. (2015); Astani and Schnitlzer (2014); Limonene CID=22311. NCBI PubChem. Linalool: Romeo *et al*. (2008); Lwande *et al*. (1999); Flamini (2003); Methyl salicylate: Lindberg *et al*. (2000); Myrcene: Souza *et al*. (2003); Nonanal: Baumann and Weisberg (2010); Flamini (2003); Ocimene: Valente *et al*. (2013); 1-Octen-3-ol: Xu *et al*. (2015); 1-octen-3-ol, CID=18827. NCBI Pub Chem. a-Phellandrene: Zhang *et al*. (2017); a-Pinene: Park *et al*. (2011); Martin *et al*. (1993); Cherrat *et al*. (2014); Astani and Schnitlzer (2014); Sabinene: Valente *et al*. (2013) d- terpinene: Giweli *et al*. (2012); a-Thujene: Kalalinia *et al*. (2008); Thymol and thymol methyl ether: Vladimir-Knežević *et al*. 2012; Gregorc *et al*. (2018); Ylangene: Chen *et al*. (2012).

Giacomini *et al*. (2018) found that pollen from sunflower (*H.annuus*) fed to honey bees and bumblebees reduced pathogenic infections compared to diets of buckwheat pollen or no pollen. Sunflower pollen is low in protein and does not include all the amino acid requirement of bees and it offers fewer VOCs than other flowers, but it does contain dietary fatty acids, (Giacomini *et al*., 2018). Kostić *et al*. (2019) found that *H. annuus* had potent antioxidant activity due to its phenolic profile of polyphenols and flavonoids in pollen.

### Milkweed

Milkweed (*Asclepias sp*.) is the only food that monarch caterpillars eat, so milkweed is needed for the Monarch butterfly, however not all species of milkweed are used by monarchs. Prairie milkweed, *A. sullivantii*, is a long-lived perennial that is native to tallgrass prairie and will do best in moist prairies and meadows and is recommended for butterfly gardens. Butterfly weed (*A. tuberosa*) is not the favorite of the monarch but is satisfactory and attracts other butterflies. Common (*A. syriaca*), swamp (*A. incarnata*) and whorled (*A. verticillate*) varieties are recommended by Iowa State for prairie strips in addition to prairie milkweed and butterfly milkweed depending on soil moisture conditions (*e.g*., wet, mesic, dry).

### Herbs and mints

Oregano can be part of a pollinator garden or can be planted in an herb garden. Oregano and other species of the genus Origanum contain numerous terpenic compounds with anti-inflammatory and antimicrobial properties (Sökmen *et al*. 2004). Oregano is in the mint plant family, Lamiaceae. Mint plants are highly aromatic and thus there is more information available on VOCs/secondary plant metabolites of these plants. In Table 1, the mint plants in addition to oregano are bee balm, catnip, lavender and thyme. There are several species of mint plants in the genus Monarda (*e.g*., spotted bee balm and wild bergemot) and genus Pycnanthemum (mountain mints) that should be considered for prairie strips and herb/pollinator gardens.

### Gentians

Gentians are often rare and flower late summer into early fall when there are few flowers left blooming. Their flowers are blue, purple, or white. Genera include Gentiana, Gentianella and Gentianopsis. Fringed gentians (*Gentianopsis critina*) attract bees and bumble bees. Gentians are used in Chinese medicine, but they should have benefits to pollinators; the active compounds are not VOCs, but water-soluble glycosides and xanthones.

## CONCLUSION

The landscape that is the most natural and biodiverse will attract more native pollinators. The honeybee is a generalist forager, targeting plant species that are in great abundance and high floral density. They are well suited for pollinating large agricultural fields of monoculture, but it is not healthy for bees to have limited food sources. Native insect pollinators will not compete very well with honeybees in a monoculture, but they are better suited for diverse agricultural crop systems. Planting prairie strips and pollinator gardens that emphasize native plants can help populations of native pollinators as well as the honey bee in agricultural systems that lack plant diversity. Plants that are commonly found in pollinator gardens and prairie strips were searched for VOC data and the VOCs were searched for their potential health benefits (as prophylactic or curative support) to pollinating insects such as antimicrobial, anti-inflammatory, antifungal, antiviral and acaricidal properties. References to cancer and other human-related diseases were ignored or not emphasized. Most VOCs found were monoterpenes, sesquiterpenes and oxidation products of these (alcohols, ketones and aldehydes). Eight “super plants” (bee balm, echinacea, lavender, thyme, oregano, prairie rose, red clover, catmint) were identified that contained a variety of beneficial VOCs, but there are likely many other plants species that have not been sufficiently characterized for VOCs and their medicinal properties. The benefits of medicinal plant VOCs extend to other species and “stopping to smell the flowers” may be healthy for people, too.

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