New York State Integrated Pest Management Program | Cornell Cooperative Extension

Peppermint & Peppermint Oil Profile

Active Ingredient Eligible for Minimum Risk Pesticide Use

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Label Display Names: Peppermint; Peppermint oil

Active Components: Menthol, menthone, pulegone, others

CAS Registry #: 8006-90-4 (Peppermint oil); 2216-51-5 and 89-78-1 (Menthol)

U.S. EPA PC Code: 500740 (referenced, but not recognized in cross-search)

CA DPR Chem Code: 2058

Other Names: Brandy Mint; Lamb Mint; Oil of peppermint; *Mentha piperita* oil

Other Codes: EC 616-900-7; FEMA 2848; HT 3301.25

Summary: Peppermint (*Mentha piperita*) is a culinary and medicinal herb that is widely cultivated and used in various cuisines. Its essential oil is the primary source of menthol. Other active substances found in peppermint and its essential oil include menthone and pulegone. As a pesticide, the primary active ingredient, menthol, has biocidal properties and is effective at controlling mites, mosquito larvae, and various other pests. It also has repellent properties to insects, dogs, and cats. Peppermint oil is an effective antimicrobial. Because of its history as a flavoring agent, peppermint and peppermint are considered safe when used properly.

Pesticidal Uses: Insect repellent, insecticide, and acaricide; vertebrate animal repellent, including companion animals; antimicrobial disinfectant, bactericide, and fungicide; herbicide.

Formulations and Combinations: Combined with other essential oils, with vegetable oils, sodium lauryl sulfate. Peppermint can also be nanoemulsified with modified food starch (Liang et al. 2012).

Basic Manufacturers: Wrigley's; Seely Mint; Labeemint; Cascade Pacific Essential Oils; Camden-Grey; Foodchem International; Fuzhou Farwell; Jiangxi Baicao; Orchid Chemical Co.; Inan Tarim.

This document profiles an active ingredient currently eligible for exemption from pesticide registration when used in a Minimum Risk Pesticide in accordance with the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) section 25b. The profile was developed by the New York State Integrated Pest Management Program at Cornell University, for the New York State Department of Environmental Conservation. The authors are solely responsible for its content. The Overview Document contains more information on the scope of the profiles, the purpose of each section, and the methods used to prepare them. Mention of specific uses are for informational purposes only, and are not to be construed as recommendations. Brand name products are referred to for identification purposes only, and are not endorsements.

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Safety Overview: Peppermint and peppermint oil are widely consumed as common food and flavoring ingredients. However, overdoses of peppermint oil are possible and near-fatal situations have occurred due to menthol's anesthetic properties (HSDB 2015).

Background

Peppermint (*Mentha piperita*) is a perennial herb that is a hybrid of water mint (*Mentha aquatica*) and spearmint (*Mentha spicata*) (Tucker and Naczi 2007). It is cultivated widely in Asia, Europe and North America. Peppermint and its essential oil are used as flavoring agents in foods, liqueurs, and confectionaries. Fresh peppermint leaves are used as culinary herbs, while dried peppermint leaves are used in herbal teas. Peppermint's essential oil, dried leaves and flowering tops, as well as the fresh flowering plant are used medicinally as a carminative, antispasmodic and flavoring agent (Merck 2015). Besides food and medical uses, peppermint oil—a major source of menthol—is used in many personal care products such as soaps, toothpaste, mouthwashes, fragrances and hand lotions and even in tobacco products. (Hayes et al. 2007).

Peppermint oil is the fifth most produced essential oil in the world (Schmidt 2009), and the peppermint plant itself is presumed to be the most studied source of essential oils (Franz and Novak 2009). Essential oil yields and composition depend on a number of factors, including the cultivar, plant parts, maturity, soils, climate, temperature, day length, time of harvest, fertilization, irrigation, and extraction method (Lawrence 2007; Franz and Novak 2009; Khan and Abourashed 2010).

The United States, China and India lead the world as peppermint producing countries (Denny and Lawrence 2007); others are Morocco, Argentina, Bulgaria and Georgia (FAO 2015). Through most of the 19th century, US peppermint production and processing were centered in Wayne County, NY (Russell 1926). Most peppermint oil is produced by high pressure steam distillation (Schmidt 2009), a relatively simple process. Historically, fresh mint would be packed into a retort and steam passed through the chamber would be condensed. The oil would float on top of the water and be distilled by the different boiling points of water and oil (Russell 1926). Modern methods introduced higher pressures, a wider range of temperature control, vacuum distillation, and crystallization—resulting in greater yields, higher quality and a greater variety of products for specialty applications (Denny and Lawrence 2007).

Chemical and Physical Properties

Peppermint contains 1-3% essential oils (Merck 2015), which commercially yields 0.1–1.0%—usually 0.3–0.4%—of volatile oil that is mostly composed of menthol and menthone (Khan and Abourashed 2010). Related compounds menthyl acetate and menthofuran are also present in significant amounts. Other constituents of peppermint oil include limonene, pulegone, 1,8-cineole, piperitone, caryophyllene, viridiflorol, bisabolene, isomenthone, isomenthol, α- and ß-pinenes, neomenthol, ledol, d-trans-sabinene hydrate, and bicycloelemene, among others (Khan and Abourashed 2010). Local growing conditions cause variation in crop and product quality, and subsequently influences processing of peppermint oil to a suitable grade (Krupski and Fischer 1950).

The primary component of peppermint oil, menthol, is also known as hexahydrothymol, peppermint camphor, 3-p-menthanol, L-menthol, and 5-methyl-2-(l-methylethyl) cyclohexanol (Hayes et al. 2007). Menthol has also been widely studied for its medicinal and physiological properties. It is used as a local anesthetic and anti-tussive agent in cold and cough preparations, with delivery through steam vapor, or topically as an anti-tussive in chest rubs delivered in petroleum jellies (e.g. Vicks Vapo-rub®), or orally through throat lozenges. Menthol is thought to provide a local anesthetic action on the lungs and throat, suppressing the cough reflex (Gardiner 2000). Another biologically active constituent is pulegone, but its concentration varies according to the peppermint oil's origin, with some sources having pulegone levels as high as 4% (Nair 2001).

Peppermint oil may contain dimethyl sulfoxide (DMSO) (Burdock 2010), which is usually rectified by an additional distillation step to make the final oil food grade (Schmidt 2009; Başer and Demirci 2012). The chemical content of the oil is reflected in its physical characteristics. Most notably, viscosity and menthol content are positively correlated (Swift and Thornton 1943; Fischer et al. 1953).

The physical and chemical properties of peppermint derivatives are reported in Table 1. Values are for peppermint oil unless otherwise specified.

Table 1

Physical and Chemical Properties of Peppermint Derivatives

Property	Characteristic/Value	Source(s)
Molecular Formula (Menthol):	$C_{10}H_{20}O$	(Royal Society of Chemistry 2015)
Molecular Weight (Menthol):	156.265	(Royal Society of Chemistry 2015)
Percent Composition:	Menthol (29-60%), menthone (15-30%), methyl acetate (2-8.5%), menthofuran (1-7%), isomenthone (2-5.5%), limonene (1-4%), and germacrene D (0.5-3%)	(Hayes et al. 2007)
Physical state at 25°C/1 Atm.	Liquid	(Merck 2015)
Color	Colorless to pale yellow	(Merck 2015)
Odor	Strong, penetrating odor of peppermint	(Merck 2015)
Density/Specific Gravity	0.896-0.908	(Merck 2015)
Melting point (Menthol)	41 – 43° C	(Merck 2015)
Boiling point (Menthol)	212°C	(Merck 2015)
Solubility	Very slightly soluble in water; soluble in 70% alcohol. Insoluble in propylene glycol	(Merck 2015)
Vapor pressure	0.3 mm Hg at 25^0C	(EPI 2012)
pH	Not found	
Octonol/Water (K_{ow}) coefficient	19.94	(EPI 2012)
Viscosity	~380-700 sec at 30°C	(Swift and Thornton 1943)
Miscibility	Not found	
Flammability	Flammability Hazard Rating: 2	(Natural Sourcing 2008)
Storage stability	Fair	(US NLM 2016)
Corrosion characteristics	Not found	

Property	Characteristic/Value	Source(s)
Air half life	0.309 hrs	(EPI 2012)
Soil half life	4,320 hrs	(EPI 2012)
Water half life	8,640 hrs	(EPI 2012)
Persistence	4,490 hrs	(EPI 2012)

Human Health Information

The principal active ingredient in peppermint oil, menthol, has been widely studied for its effects on human health. Because of its use as a flavoring agent in cigarettes, a number of studies have looked at the acute, subchronic and chronic toxicity when combined with tobacco. Many such studies compare mentholated tobacco with unmentholated tobacco. Because of the confounding health effects of the exposure to tobacco and its toxic components, most of these studies were not considered for this profile. The constituent pulegone also shows some adverse human health effects.

Acute Toxicity

The acute toxicity of peppermint oil and menthol appears in Table 2. Values are for peppermint oil unless otherwise specified.

Table 2

Acute Toxicity of Peppermint Oil and Menthol

Study	Results	Source(s)
Acute oral toxicity	Rat: 2,426 mg/kg Mouse: 2,490 mg/kg	(Eickholt and Box 1965; HSDB 2015)
Acute dermal toxicity	Rabbit: >5,000 mg/kg	(Hayes et al. 2007)
Acute inhalation	Not found	
Acute eye irritation (Menthol)	Rabbit: Severe eye irritation	(US EPA 2004)
Acute dermal irritation (Menthol)	Mild irritant	(Hayes et al. 2007)
Skin sensitization (Menthol)	Negative	(Hayes et al. 2007)

More studies have been performed on the toxicity of menthol, which has been linked to atrial fibrillation, muscle pain, cooling or burning sensations, and eye injuries (HSDB 2015). Adult human subjects exposed to menthol at 0.5% mixed in light liquid petrolatum developed irritation on the nasal epithelium and mucous membranes (Hayes et al. 2007). Intraperitoneal toxicity of peppermint oil on rats was reported to be an LD_{50} of 819 mg/Kg. (Eickholt and Box 1965).

A small percentage of the population appears to be allergic to peppermint and/or to peppermint oil and its derivatives. Peppermint oil in lip balm has been linked to incidents of acute dermal toxicity in sensitive individuals (Tran et al. 2010). Another study conducted on human subjects found that menthol caused skin irritation, with the mean time of onset of sensation—including burning and cooling—being 2.59 minutes (Hayes et al. 2007).

There is also some epidemiological evidence of peppermint, peppermint oil, and menthol's ability to cause various health issues (Hayes et al. 2007). A 40-year-old woman who attempted suicide by drinking peppermint oil was comatose for 8 hours and unconscious for 24 hours, and the physicians who treated her found her vital signs in a near-fatal state (Nath et al. 2012). The dose ingested was not known. Injection of peppermint oil by an 18-year-old pregnant woman with a history of intravenous drug use—also a suspected suicide attempt—resulted in pulmonary edema and acute lung injury presumably due to the increase in pulmonary vascular permeability (Behrends 2005).

Peppermint allergies have been linked to ataxia, 'hot flashes', high blood pressure, shortness of breath, tremors, drowsiness, hyperextension of the extremities, metabolic acidosis, and unconsciousness (Woolf 1999). Menthol droplet ingestion was attributed as the cause of an 86-year-old man in India falling into a coma (Baibars et al. 2012). Skin eruptions were observed in one person who used mouthwashes that contained menthol and peppermint (Fleming and Forsyth 1998).

Sub-chronic Toxicity

The sub-chronic toxicity of peppermint oil and menthol appears in Table 3. Values are for peppermint oil unless otherwise specified.

Table 3

Sub-chronic Toxicity of Peppermint Oil and Menthol

Study	Results	Source(s)
Repeated Dose 28-day Oral Toxicity Study in Rodents	Rats: NOAEL = 10 mg/kg/day	(Thorup et al. 1983)
90 day oral toxicity in rodents	Rats: NOAEL = 40 mg/kg/day	(Spindler and Madsen 1992)
90 day oral toxicity in non-rodents	Not found	
90 Day dermal toxicity	Not found	
90 Day inhalation toxicity	Not found	
Reproduction/development toxicity screening test	Not found	
Combined repeated dose toxicity with reproduction/development toxicity screening test (Menthol)	Mice, rats, hamsters and rabbits: No teratogenic effects	(US EPA 2004)
Prenatal developmental toxicity study	Not found	
Reproduction and fertility effects	Not found	

Rats fed 100 mg/kg/day peppermint oil for 28 and 90 days developed spaces and cysts in the cerebellum (Spindler and Madsen 1992). No other adverse effects were observed and it was unclear what, if any, health problems were caused by those histopathological changes. An earlier study showed adverse histopathological effects in the form of lesions at doses as low as 10 mg/kg/day in a 28-day study (Thorup et al. 1983). The peppermint oil used in the earlier study had higher levels of pulegone and lower levels of menthol, possibly explaining the anomalous results of the shorter study having the lower adverse effect level. A 13-week inhalation study of menthol cigarettes had no adverse effects observed on mice inhaling tobacco with 5,000 ppm of menthol (Gaworski et al. 1997).

Pulegone is hepatotoxic (Sullivan et al. 1979). Peppermint oil and pulegone are also linked to neurotoxicity in 28-day sub-chronic feeding studies (Olsen and Thorup 1984). Peppermint tea has been implicated in kidney damage in rats (Akdogan et al. 2004). Rat spermatogenetic activity was reduced by peppermint tea consumed at doses of 20 g/L (Akdogan et al. 2004). Peppermint oil is sometimes used to induce menstruation, and exposure should be avoided during pregnancy (Gardiner 2000; NLM 2016).

Chronic Toxicity

The chronic toxicities of peppermint oil and some selected constituents appear in Table 4.

Table 4

Chronic Toxicity of Peppermint Oil and Selected Components

Study	Results	Source(s)
Chronic toxicity	Ames Test: Peppermint oil, menthol and Pulegone=Negative Menthone=Reactive	(Andersen and Jensen 1984; Nair 2001; Belsito et al. 2008)
Carcinogenicity	Mice: Peppermint oil=Negative	(Nair 2001)
Combined chronic toxicity & carcinogenicity	Hamster=Equivocal Human cells: Menthol=Negative	(Nair 2001; Belsito et al. 2008)

Peppermint, peppermint oil, and peppermint oil's major components are not classified as carcinogenic by the International Agency for Research on Cancer (IARC 2014); are not on the California Proposition 65 list of known carcinogens (Cal-EPA 1997); and do not appear on the Toxics Release Inventory (TRI) Basis of OSHA Carcinogens (US EPA 2015).

Most chronic toxicity tests found for peppermint, peppermint oil, and peppermint water extracts were negative. Peppermint's chemical isolates also tested negative in most cases, but in a few cases produced equivocal or even weakly positive results (Nair 2001). Peppermint oil was negative in the Ames test and a mouse lymphoma mutagenesis assay but gave equivocal results in a Chinese hamster fibroblast cell chromosome aberration assay (Nair 2001).

Human Health Incidents

The National Pesticide Information Center (NPIC) received 14 reports of human health incidents related to the use of peppermint or peppermint oil from April 1, 1996 to March 30, 2016 (NPIC 2016). Most involved formulated products with multiple active ingredients. Two involved only peppermint oil and other mint oils as ingredients. One was accidental inhalation and the other involved ingestion by a two-year-old infant who was asymptomatic. The outcomes were not reported.

Environmental Effects Information

Effects on Non-target Organisms

The effects of peppermint oil and its main active component, menthol, are summarized in Table 5.

Table 5
Effects of Peppermint Oil and Menthol on Non-target Organisms

Study	Results	Source(s)
Avian Oral, Tier I	Not found	
Non-target plant studies	Tomato (*Lycopersium esculantum*): MIC=900 µl/L^{-1} Radish (*Raphinus sativus*): MIC=1,800 µl/L^{-1}	(Mahdavikia and Saharkhiz 2015)
Non-target insect studies (Menthol)	Honey bees (*Apis mellifera*) LC_{50} = 5.3 µg/ml	(Ellis and Baxendale 1997)
Aquatic vertebrates (L-menthol)	*Pimephales promelas* EC_{50}(96 h) = 18.4 mg/l *Danio rerio*: LC_{50} (96 h) = 15.6 mg/l *Oryzias latipes*: LC_{50} (48 h) = 26 mg/l	(OECD 2003)
Aquatic invertebrates (L-menthol)	*Daphnia magna*: EC_{50} (24 h) = 37.7 mg/l EC_{50} (48 h) = 26.6 mg/l	(OECD 2003)

No results documenting the direct effects of peppermint oil alone on non-target organisms were found. Various studies of peppermint oil's main constituent, menthol, were available. While no avian toxicity studies were found for wildlife models, peppermint is used as a feed supplement for poultry. Peppermint fed to Japanese quails (*Coturnix japonica*) as a feed supplement at rates between 20 and 40 g/kg/week did not result in any significant difference in body weight gain, feed conversion ratio, or feed intake (Mehri et al. 2015).

Menthol is commonly applied to honey bees (*Apis mellifera*) for the control of tracheal mites (*Acarapis woodii*). Although it has a wide margin of safety between the effective dose for tracheal mites and bee mortality, menthol is one of the most toxic essential oil isolates to bees. Menthol was 18.9 times more toxic to mites than to honey bees at LC_{50} concentrations, but only 5.7 times more toxic at LC_{90} concentrations (Ellis and Baxendale 1997). Menthol's LC_{50} for tracheal mites was found to be 0.3 µg/ml, making the LC_{50} for honey bees 5.67 µg/ml. Despite its relatively high toxicity to bees, menthol had the widest margin of safety of all the acaricides tested in the study.

Two species of aphid predators—*Adalia bipunctata* (two-spotted ladybird beetle) and *Coccinella septempunctata* (seven-spotted ladybird beetle) were exposed to vapors of essential oils, including peppermint oil (Kimbaris et al. 2010). The LC_{50} after 24 h exposure to peppermint oil vapors at 21^0C for *A. bipunctata* was 0.62 ml/L and was 0.67 ml/L for *C. septempunctata*. Peppermint oil was one of the more toxic essential oils to the beneficial parasitoid *Cotesia glomerata,* but was still significantly less toxic than the insecticide dichlorvos, with an LD_{50} of 0.3 mg/paper (Yi et al. 2007).

Peppermint oil and peppermint water extract are phytotoxic to tomatoes (*Lycopersium esculantum*): and radishes (*Raphinus sativus*) (Mahdavikia and Saharkhiz 2015). Crop plants were more susceptible than weeds to peppermint oil and peppermint water extract damage, making it undesirable as a foliar treatment or selective herbicide.

NPIC received 12 reports of animal incidents related to the use of peppermint from April 1, 1996 to March 30, 2016 (NPIC 2016). Most involved non-fatal incidents with dogs and cats, although one cat fatality due to renal failure was reported. The formulation also had lemongrass oil and cinnamon oil as active ingredients.

The American Society for the Prevention of Cruelty to Animals, Animal Poison Control Center reported multiple flea product incidents between 2006 and 2008; 39 involved the exposure of cats and nine incidents involved dogs. These flea products contained peppermint oil and other ingredients are eligible to be EPA exempt from registration (Genovese et al. 2012). Three formulated products accounted for the incidents, and their symptoms included skin erythema, vomiting, diarrhea, lethargy, edema, ataxia, seizures, weakness, recumbent, tachycardia, agitation, anorexia, hyperactivity, hypersalivation, panting, retching, tremors, vocalization, and renal failure. The following three incidents were particularly poor outcomes: a 7-month-old kitten died with inappropriate use; a 3-year-old dog was euthanized 6 days after appropriate use; and a 13-year-old cat was euthanized 72 hours after appropriate use. All the formulations were sprays, shampoos or spot-on treatments and included peppermint oil as one of multiple active ingredients.

Environmental Fate, Ecological Exposure, and Environmental Expression

No studies on the leaching, photodegradation and biodegradability of peppermint and peppermint oil were found.

Environmental Incidents

NPIC received 29 reports of incidents involving the use of peppermint not related to human or animal exposure from April 1, 1996 to March 30, 2016 (NPIC 2016). Most involved spills or misapplications.

Efficacy

Peppermint and peppermint oil have been studied as insecticides, acaricides, antimicrobials, fungicides, and herbicides.

Insecticidal Activity

Peppermint oil can be used as a mosquito larvicide. When 3 ml/m^2 of peppermint oil was added to water, the mortality rate of the third instar larvae of *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus* was 85%, 90%, and 100%, respectively (Ansari et al. 2000).

Peppermint and three other essential oils were evaluated for their toxicity to third instar larvae of three mosquito species (*Anopheles stephensi*, *Culex quinquefasciatus*, and *Aedes aegypti*). Peppermint oil was toxic against *An. stephensi* and *Ae. Aegypti,* with LD_{50}s of 21.36 ppm and 26.19 ppm respectively (Pathak et al. 2000). However, in a comparison of 41 essential oils, peppermint performed relatively poorly, with no third instar larvae mortalities caused by a 50ppm solution within an hour, and 53.3% mortality in 24 hours. By comparison, 13 of the essential oils screened were able to achieve 100% mortality in 24 hours (Amer and Mehlhorn 2006).

A study on the larvicidal and adult repellency effects of peppermint oil against *Ae. aegypti*, LC_{50} and LC_{90} of peppermint oil were 111.9 and 295.19 ppm in 24 hrs for the fourth instar mosquito larvae. Human test subjects were protected from the adult bites for at least 150 min (S. Kumar et al., 2011). Of five essential oils screened, peppermint oil was found to be the most effective, deterring *Ae. aegypti* female mosquitos from ovipositing in cups under laboratory conditions, and suppressing egg hatch. No mosquito larvae hatched at concentrations of peppermint oil as low as 1% (Warikoo et al. 2011). Adult mosquitos

were repelled by peppermint oil applied to human skin. The percent protection and length of protection against *C. quinquefasciatus*, *Anopheles culicifacies*, and *Anopheles annularis* was 84.5% (6.7 h), 92.3% (9.6 h), and 100% (11.0 h), respectively. The authors concluded that the repellent action of peppermint oil was comparable to the commercially available repellent known as mylol oil, which is a mixture of dimethyl and dibutyl phthalates. (Ansari et al. 2000).

Terminix® ALLCLEAR® Sidekick, a blend of 5.3% peppermint oil and other active ingredients cinnamon oil, lemongrass oil, eugenol, and geranium oil reduced *Aedes albopictus* attacks by over 95% and *Culex pipiens* attacks by over 92% (Revay et al. 2013). The article did not identify whether the formulation was EPA registered or EPA exempt.

In another study, peppermint oil failed to repel *Ae. aegypti* at concentrations of 5% and 10% (Barnard 1999).

Houseflies (*Musca domestica*) are susceptible to the volatiles generated by peppermint oil with acetone on treated filter paper. One study reported the 24 hour contact LC_{50} concentration for housefly larvae was 3.39 µl/cm^2 and the 24 hour contact LC_{90} was 6.09 µl/cm^2. The 24 hour fumigation LC_{90} was reported to be 79.53 µl/L (P. Kumar et al. 2012).

The cecidomyiid gall midge *Camptomyia corticalis*, a dipteran pest of shiitake mushrooms, was treated with 49 essential oils and dichlorvos. Peppermint oil was more effective than the median essential oil, but not the most effective. The fumigant LC_{50} was estimated to be 0.70 mg/cm^3 and it achieved 100% mortality of the third instar of the cecidomyiid gall midge at a rate of 1.41 mg/cm^3 (Kim et al. 2012).

Human head lice (*Pediculus humanus capitis*) is resistant to the synthetic pyrethroid permethrin but was reduced by 93% using a combination of peppermint oil (5%) and eucalyptus oil (5%) (Audino et al. 2007). Addition of 1-dodecanol as an adjuvant gave 100% control, showing that peppermint oil can be part of an effective program to manage permethrin-resistant head lice. Five essential oils, including peppermint oil, were tested on the buffalo louse, (*Haematopinus tuberculatus*). The LC_{50} for peppermint oil after four minutes of exposure was 12.35% (Khater et al. 2009).

Tests on the chewing louse (*Bovicola (Werneckiella) ocellatus*), an external parasite of donkeys, exposed the pest to various levels of peppermint oil for 300 minutes. This resulted in a LC_{50} determined to be 1.24% (Talbert and Wall 2012).

Post-harvest pests can also be effectively managed by the use of peppermint oil. Among the insects studied were *Tribolium castaneum* (red flour beetle), *Callosobruchus maculatus* (pulse beetle), *Attagenus fasciatus* (black carpet beetle), *Rhyzopertha dominica* (false powderpost beetle), *Oryzaephilus surinamensis* (sawtoothed grain beetle), *Sitophilus oryzae* (rice weevil) and *Lasioderma serricorne* (cigarette beetle).

One study found that peppermint oil effectively reduced red flour beetle populations. The oil in the form of fumigant used against the first, second, third, and fifth instar larvae resulted in LC_{50} values of 0.76, 2.14, 11.88, and 20.4 ml/100 ml respectively (Misra and Kumar 1983). The authors determined that LC_{50} values for adults after 24-h and 48-h exposure were 3.04 and 3.21 ml/100 ml, respectively. A 90% kill rate was obtained for the emerging first instar larvae when they were exposed to 4.0 mL/100 ml, but the eggs were unaffected. Another study determined that the LD_{50} and a LD_{95} for *T. castaneum* exposed to volatiles from the essential oil of peppermint were 25.8 ml/l and 33.1 ml/l air respectively (Lee et al. 2002). *C. maculatus*

adult males are more susceptible to peppermint oil fumes than the females of *C. maculatus* (El Nagar et al. 2012). Peppermint oil was found to be ovicidal in the same study.

An assessment of the efficacy of 28 essential oils against *Rhyzopertha dominica*, *Oryzaephilus surinamensis*, *Tribolium castaneum*, and *Sitophilus oryzae* found that peppermint oil was one of 11 essential oils active against all four species (Shaaya et al. 1991). At concentrations of 15 µl/L of air, peppermint caused over 75% mortality of all four.

Peppermint oil volatiles produced the highest level of toxicity to the adults and larvae of the black carpet beetle (*Attagenus fasciatus*) and cigarette beetle (*Lasioderma serricorne*) compared with three other essential oils. These beetles feed on furs, hides, insect specimens stored in the museums and the wool articles and oil seeds. In tests using peppermint oil volatiles, black carpet beetle larvae and adults had an LD_{50} 1.09 and 1.67 ml/80 cm^3; for cigarette beetle larvae and adults the numbers were 1.28 and 1.80 ml/80 cm^3 respectively. The adults had malformed antennae and associated sensilla when exposed to peppermint oil vapors when they were third instar larvae (Bakr et al. 2010).

The variegated cutworm (*Peridoroma saucia*), a pest of vegetable crops, will also damage peppermint. Even though the variegated cutworm will feed on peppermint, some of the monoterpenes found in peppermint inhibit feeding. Larvae fed a diet with menthone and pulegone weighed less than the control because of feeding inhibition. Similarly, menthol caused molting abnormalities and inhibited pupation at doses similar to content in peppermint oil (0.05 – 0.2% wet weight). The microsomes of the midgut of sixth instar larvae of variegated cutworm were observed to metabolize the monoterpenes present in the peppermint oil (Harwood et al 1990). The metabolic activity explains how the variegated cutworm can develop tolerance to peppermint oil.

A comparison of the fumigant toxicity of 66 plant essential oils to *Plutella xylostella* (diamondback moth) larvae found peppermint oil to be one of the more effective active substances with an LD_{50} of 24.08 mg/filter paper (Yi et al. 2007).

A Japanese company manufactured a flea collar for dogs using a mixture of the essential oils eucalyptus, cedarwood, citronella, and peppermint, then added the mixture to ethylene-vinyl acetate polymer. The collar has shown some effectiveness in controlling dog fleas (Regnault-Roger 1997), but it may not be 25(b) exempt in the U.S., because eucalyptus oil is not an active ingredient eligible for exemption and the type of cedarwood oil was unspecified.

Laboratory assays were conducted to evaluate the repellency and contact toxicity of six essential oils to the Argentine ant (*Linepithema humile*) and the red imported fire ant. Both species crossed barriers treated with multiple rates of peppermint and other essential oils less frequently than paired control barriers (Wiltz et al. 2007). After 24 hours of exposure to peppermint oil, Argentine ant mortality was almost 90%. The results were confirmed in a study that found 1% peppermint oil to be an effective repellent of Argentine ants for a period of one week (Scocco et al. 2012).

In a lab study, eggs, nymphs and adults of greenhouse whitefly, *Trialeurodes vaporariorum,* were exposed to vapor treatments of peppermint oil. At 0.0023 ml/ml air, adult whiteflies had a 100% mortality rate; at a peppermint oil vapor concentration of 0.0093 ml/ml air, whitefly nymphs and eggs had 98 and 100% mortality, respectively (W. Choi et al. 2003). An experiment comparing the efficacy of 92 essential oils in the control of Sweetpotato whitefly (*Bemisia tabaci*) found peppermint oil to be one of the more effective, with an LC_{50} of 0.82 mL/cm^3 and 100% mortality at a rate of 2.4 mL/cm^3 (Kim et al. 2011).

Four species of aphids—*Aphis fabae* (black bean aphid), *Macrosiphoniella sanborni* (chrysanthemum aphid), *Acyrthosiphon pisum* (pea aphid) and *Myzus persicae* (green peach aphid)—were exposed to vapors of peppermint oil. The LC_{50} values of peppermint oil vapor for the fourspecies ranged between 0.46 and 0.99 ml/L after 24 h exposure at 21^{0}C (Kimbaris et al. 2010).

Peppermint oil repelled Japanese beetles (*Popilla japonica*), but it was never the most effective among the many essential oils screened, and results were inconsistent in different years (Youssef et al. 2009).
A patent also claims certain peppermint oil formulations to be effective in the control of three household pests: American cockroaches (*Periplanata Americana*), German cockroaches (*Blatella germanica*), and harvester ants (Pogonomyrmex barbatus) (Bessette and Enan 2003). Some of these formulations have been commercialized as 25(b) pesticides.

Acaricidal Activity

Tetranychus urticae (two-spotted spider mite) and its predator, *Phytoseilus persimilis*, were exposed to different concentrations of peppermint oil by placing them in plastic containers holding soaked filter paper. Placement was such that the mites were directly exposed to the volatiles. (Choi et al. 2004). The peppermint oil vapor killed almost 99% of the *T. urticae* adults at 0.014 ml/ml while only 0.0047 ml/ml air was required to kill 97% of the predatory mite (*P. persimilis*) adults and 84 % of eggs of *T. urticae*.

Another study exposed different groups of adult *T. urticae* as well as a predatory mite *Neoseilus californicus* to the vapor of peppermint oil. One group was acaricide-susceptible, and various strains resistant to the acaricides chlorfenapyr, fenpropathrin, pyridaben and abamectin were also exposed. In all groups of *T. urticae* the LC_{50} values of peppermint oil ranged from 22.8, 24.4, 23.5, 23.9 to 26.9 mg/cm^3 for the susceptible, chlorfenapyr-resistant, fenpropathrin-resistant, pyridaben-resistant, and abamectin-resistant strains of *T. urticae* adults, respectively. An LC_{50} of 28.6 mg/cm^3 was determined for *N. californicus* showing that the conventional acaricide-resistant *T. urticae* could be managed using peppermint oil volatiles. Predatory mites were slightly more tolerant to the volatiles than *T. urticae* (Han et al. 2010). A comparison study of the efficacy of 34 essential oils found that peppermint oil was one of five oils able to achieve 100% mortality of *T. urticae* at a rate of 10 µl/L at a temperature of 25°C (Lim et al. 2011).

Peppermint oil's main constituent, menthol, is used to control tracheal mites (*Acarapis woodii*) in honey bees (*Apis mellifera*). Menthol was found to have an LC_{50} of 0.3 µg/ml on tracheal mites, with both the greatest efficacy and largest margin of safety of any of the essential oil isolates tested (Ellis and Baxendale 1997).

Bactericidal, Fungicidal and Antiviral Activity

Peppermint oil inhibits a broad range of gram-negative and –positive bacteria, fungi, and yeasts (Shah and D'Mello 2004; Pauli and Schilcher 2009; Khan and Abourashed 2010). After the essential oil from *Eucalyptus globulus*, peppermint oil created the second largest area of exclusion for the fungal pathogen *Candida albicans* (Agarwal et al. 2008). Antimicrobial activity against *Listeria monocytogenes* and *Staphylococcus aureus* was not increased by nanoemulsification of peppermint oil, but the nanoemulsified formulation provided a period of antimicrobial activity for more than a day longer than the pure peppermint oil that was not nanoemulsified (Liang et al. 2012).

Peppermint oil also has reported antiviral properties (Alankar 2009). The active substance menthol has been found to be antiviral to influenza, herpes, Newcastle's virus and Vaccinia virus (Gardiner 2000).

Herbicidal Activity

The phytotoxic effects of peppermint oil and peppermint water extract were examined with the weeds jungle rice field (*Echinochloa colonum*), field bindweed (*Convulvolus arvensis*) and purslane (*Portolaca oleracea*). The minimum inhibitory concentration (MIC) for germination of seeds was 1,200 µl/L for the jungle rice and 1,800 µl/L for the field bindweed and purslane. The concentrations were higher than for tomatoes.

Vertebrate Repellency

Cardboard treated with a combination of peppermint and wintergreen oils with ink repelled various rats in field conditions compared with a no-treatment control and four other combinations of natural plant repellents in inks, including chili, geranium oil and bergamot oil (Kalandakanond-Thongsong et al. 2011).

Standards and Regulations

EPA Requirements

Peppermint and peppermint oil are exempt from the requirement of a tolerance and can be applied to food crops [40 CFR 180].

FDA Requirements

Essential oils, solvent-free oleoresins, and natural extractives, including distillates from peppermint are Generally Recognized As Safe (GRAS) by the FDA, when used in food [21 CFR 184.20].

Other Regulatory Requirements

Peppermint and peppermint oil are allowed by the USDA's National Organic Program (NOP) [7 CFR 205]. However, it is not clear whether the nanoemulsified versions would comply.

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