New York State Integrated Pest Management Program
Cornell Cooperative Extension

Geraniol Profile

Active Ingredient Eligible for Minimum Risk Pesticide Use

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Active Ingredient Name: Geraniol

Active Components: Geraniol

CAS Registry #: 106-24-1

U.S. EPA PC Code: 597501

CA DPR Chem Code: 309

Other Names: ß-Geraniol; Lemonol; Geranyl alcohol; trans-Geraniol; Geranial; (E)-Geraniol; trans-3,7-Dimethyl-2,6-octadien-1-ol; (E)-Nerol; nerol; Geraniol Extra; Vernol

Other Codes: BRN: 1722455 & 1722456; ChemSpider: 13849989; FEMA—2507; RTECS—RG5830000; EC—233-377-1; EINECS : 203-339-4, 203-377-1; 203-378-7

Summary: Geraniol, a naturally-occurring terpenoid found in food plants, is often used as a fragrance or ingredient in cosmetics. When used as a pesticide, it is primarily a mosquito and tick repellent, or used against mites. Most studies show geraniol poses little risk to the environment or human health, although a portion of the population suffers from sub-lethal allergies upon dermal or inhalation exposure.

Pesticidal Uses: As a pesticide, geraniol is used as a mosquito and tick repellent and as an insecticide for other target pests (including mites). It has antimicrobial and fungicidal applications as well.

Formulations and Combinations: Often formulated with other essential oils, including citronellol, farnesol, nerolidol, eugenol, thymol, lemongrass oil, cinnamon oil and cedarwood oil. May be formulated with sodium lauryl sulfate, glycerin, isopropyl myristate, ethyl lactate, cinnemaldehyde, 2-phenylethyl propionate, potassium sorbate and mineral oil. A patent is pending for a product encapsulated in glucan from yeast cell walls (Franklin and Ostroff 2014). Some of these substances are not eligible for 25(b) exemption, so pesticide products containing them and geraniol must be registered by the EPA.

Basic Manufacturers: Millenium Specialty Chemicals; BASF; BBA-Innova; DRT (France); International Flavors & Fragrances, Inc., Penta Manufacturers, Inc; Shaanxi Kingsci Biotechnology Co., Ltd.; Arora Aromatics; Simagchem Corp.; Symrise, AG.

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.

Safety Overview: EPA determined geraniol to be a pesticide active ingredient of minimum risk because exposures resulting from applications of registered pesticide products at labeled rates would be unlikely to result in human health and environmental impacts. Acute and chronic risks were determined to be low. Sub-chronic risks of allergenicity are observed in sensitive individuals. Non-registered pesticides may be applied at higher concentrations and rates than registered pesticides. Geraniol poses moderate to low risk to non-target species. The EPA waived most data and registration requirements for geraniol and other flower-derived essential oils because of their natural occurrence, safe use as fragrances and flavoring agents, and low exposure (US EPA 1993).

Background

Geraniol is a naturally occurring essential oil. Significant amounts are found in roses (*Rosa* spp.), Palmarosa (*Cymbopogon martini*) (Merck 2015), and geraniums (*Pelargonum* spp.*),* from which it was first isolated by fractional distillation (Jacobsen 1871). Geraniol is present in grapes, basil, lemon balm, lemons, oranges, cilantro, blueberry, carrots, ginger and cardamom (Duke 1992; Khan and Abourashed 2010), and citronella (*Cymbopogon nadrus*). *Monarda fistulosa* (bee balm) oil contains over 90% geraniol (Baser and Buchbauer 2009).

Geraniol can be synthesized from various sources. The first synthesis was reported in 1966, via reduction of *trans*-methyl geranate and purification with calcium chloride (Burrell et al. 1966). It can be derived from geranyl pyrophosphate by simple hydrolysis (Sell 2009). The leading manufacturers of geraniol synthesize it from α-pinene (Sell 2000).

When administered orally, geraniol produced several identifiable metabolites: 8-hydroxygeraniol via 8-carboxygeraniol to 3,7-dimethyl-2,6-octenedioic acid (Hildebrandt's acid), or geranic acid and 3-hydroxy-citronelic acid (Jäger 2009).

Geraniol is primarily used as a mosquito and tick repellent on skin and clothing. Other target arthropods include ants, bed bugs, beetles, cockroaches, crickets, earwigs, fleas, flies, gnats, small flying moths, lovebugs, millipedes, pill bugs, red flour beetles, rice weevils, scorpions, silverfish, spiders, spittle bugs, stink bugs, termites, various Lepidopterae, and other crawling and flying insects; various nematodes; arachnids, including ticks, mites, spiders and scorpions. Geraniol is used against bacteria, including *E. coli, Salmonella* spp. and *Listeria* spp.; and fungi, including *Aspergillus* spp., *Botrytis cinerea, Monilinea fructicola*. Efficacy for these target organisms is cited below.

Field uses of geraniol as a pesticide include a wide range of food crops such as grapes, strawberries, nuts, hops, cucurbits, stone fruit, and pome fruit. Geraniol is an active ingredient in EPA registered pesticide products labeled for use on ornamentals and nursery stock (Brandt Co. 2009), and is used in food handling and preparation areas, in residences and commercial establishments (FMC Corp. 2011).

Chemical and Physical Properties

The molecular structure of geraniol is displayed in Figure 1.

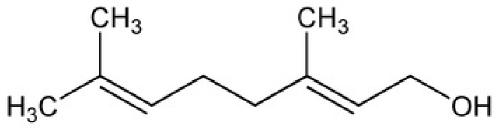

Figure 1: Geraniol molecular structure

The physical and chemical properties of geraniol are summarized in Table 1.

Table 1

Physical and Chemical Properties of Geraniol

Property	Characteristic/Value	Source
Molecular Formula:	$C_{10}H_{18}O$	(Merck 2015)
Molecular Weight:	154.25	(Merck 2015)
Percent Composition:	C 77.87%, H 11.76%, O 10.37%	(Merck 2015)
Physical state at 25°C/1 Atm.	Oily liquid	(Merck 2015)
Color	Colorless to pale yellow	(Royal Society of Chemistry 2014)
Odor	(Merck 2015)	(Merck 2015)
Density/Specific Gravity	0.8894 g/mL at 20 °C	(HSDB 2015)
Melting point	-15 °C	(HSDB 2015)
Boiling point	229-230°C	(Merck 2015)
Solubility	Solubility in water: 100 mg/L at 25° C. (Practically insoluble). Soluble in acetone, ether, alcohol, fixed oils, mineral oil. Insoluble in glycerin.	(HSDB 2015)
Vapor pressure	~0.159 mm Hg (20 °C)	(EPI 2012)
pH	NA	
Octanol/Water (K_{ow}) coefficient	2,060 (log K_{ow} = 3.56)	(EPI 2012)
Viscosity	6.75-8.21 mPa s (dynamic) at 20°C	(Renessenz 2014)
Miscibility	Miscible in acetone and ether.	(Merck 2015)
Flammability	Flash point – 108°C	(Sigma-Aldrich 2015)
Storage stability	Stable and non-reactive under normal conditions.	(Renessenz 2014)
Corrosion characteristics	No corrosive effect on metal.	(BASF 2014)
Air half life	0.261 hr	(EPI 2012))
Soil half life	720 hrs (30 days)	(EPI 2012)
Water half life	13.61 hrs (model river); 252.6 hrs (10.53 days) (model lake)	(EPI 2012)
Persistence	442 hrs (18.4 days)	(EPI 2012)

Human Health Information

Geraniol is an ingredient in many food and cosmetic products, and as such, there are many studies on its safety. Occupational exposure to this substance may occur through inhalation and dermal contact at workplaces where geraniol is produced or used. The general population may be exposed by ingestion of food, and inhalation or dermal contact with consumer products containing geraniol (US NLM 2014). Because geranyl acetate (CAS #105-87-3) readily hydrolyzes into geraniol, the US EPA accepted the toxicology data for the two to be equivalent (Jones 2002).

The National Pesticide Information Center reported 23 incidents involving geraniol as an active ingredient between April 1, 1996 and March 30, 2016 (NPIC 2016). Most incidents involved dermal or respiratory effects such as irritation and skin discoloration.

Acute Toxicity

The US EPA waived many of the human health and related animal model toxicity tests required for pesticide registration for geraniol along with other flower oils. The Agency's justification for the waiver is the low concentration of the active ingredient in registered pesticide products, low use volume, and rapid degradation in the environment by normal biological, physical and/or chemical processes that can be reasonably expected where it is applied (Matthews 2012). Because geraniol is an active ingredient in registered pesticides, some EPA-reviewed acute toxicity studies are available and are summarized in Table 2.

Table 2

Acute Toxicity of Geraniol

Study	Results	Source
Background	Not found	
Acute oral toxicity	Mouse LD_{50}: 3,600 mg/kg	(Jenner et al. 1964; US EPA 2007)
Acute dermal toxicity	Rabbit LD_{50}: >5,000 mg/kg	(Opdyke 1974)
Acute inhalation	Mouse ED_{25}: 570 µg/L	(FFHPVC 2004)
Acute eye irritation	Rabbit Draize: 5% Cleared by Day 4, 12.5% cleared by Day 7; 100% not cleared by Day 7	(Lapczynski et al. 2008)
Acute dermal irritation	Guinea pig: Described as not irritating	(HSDB 2015)
Skin sensitization	Not found	

The Draize test showed that geraniol cleared from the eyes naturally at lower concentrations of 5% and 12.5% in 4-7 days, but at a 100% dosage, eye irritation in rabbits persisted for more than a week (Lapczynski et al. 2008).

Geraniol residue studies were conducted for the registration of Biomite®. The EPA estimated that the potential exposure of the US population to geraniol in this EPA registered product applied as an acaricide to food crops was 0.000997 mg/kg/day, which was 0.20% of the World Health Organization's (WHO) Acceptable Daily Intake of 0.5 mg/kg/day. Non-nursing infant exposure at the highest possible consumption was estimated to be 0.0066 mg/kg/day, or 1.3% of the WHO's ADI (Jones 2002).

Sub-chronic Toxicity

Results of various sub-chronic toxicity studies are summarized in Table 3.

Table 3

Sub-chronic Toxicity of Geraniol

Study	Results	Source
Repeated Dose 28-day Oral Toxicity Study in Rodents		Not found
90-day oral toxicity in rodents	Rats: No adverse effects observed at the highest dose (10,000 ppm) Study extended to 112 Days.	(FFHPVC 2004)
90-day oral toxicity in non-rodents	Not found	
90 Day dermal toxicity	Not found	
90 Day inhalation toxicity	Rat maternal NOAEL:60 mg/kg	(FFHPVC 2000)
Reproduction/development toxicity screening test	Not found	
Combined repeated dose toxicity with reproduction/development toxicity screening test	Not found	
Prenatal developmental toxicity study	Maternal LOAEL = 125 mg/kg-bw/day Maternal NOAEL = NE	(FFHPVC 2004)
Reproduction and fertility effects	Maternal LOAEL = 0.423 mg/L/day NOAEL (maternal toxicity) = 0.152 mg/L/dayLOAEL (developmental toxicity) > 0.423 mg/L/dayNOAEL (developmental toxicity) = 0.423 mg/L/day	(FFHPVC 2004)

Rats treated with sublethal oral doses of geraniol showed clinical signs of depression, wet fur and coma (Jenner et al. 1964; Lapczynski et al. 2008). Inhalation studies on mice showed that the test group experienced minor moderate respiratory depression (FFHPVC 2000).

Because of its widespread use as a cosmetic and fragrance ingredient, many studies have been conducted on geraniol's dermal impacts. Many of the studies were conducted by or for the Research Institute for Fragrance Materials (RIFM), and a many of the results are presented in Lapczynski et al. (2008).

Geraniol was found to be a severe dermal irritant in people subjected to a 48 hour patch study with acetone (Lapczynski et al. 2008). Subjects who wore closed patches of 100% geraniol for four hours were also observed to have irritation reactions (York et al. 1996; Basketter et al. 2004).

Chronic Toxicity

Chronic toxicity and carcinogenicity of geraniol is summarized in Table 4.

Table 4

Chronic Toxicity of Geraniol

Study	Results	Source
Chronic toxicity	Negative	(US NLM 2014)
Carcinogenicity	Negative	(FFHPVC 2004)
Combined chronic toxicity & carcinogenicity	Negative	(FFHPVC 2004)

IARC does not list geraniol as a human carcinogen (IARC 2017). Geraniol tested negative as a mutagen using the Ames test (Eder et al. 1980). It is not listed as a carcinogen or teratogen under California Prop. 65 (Cal-EPA 2016). In fact geraniol has been shown to have anti-carcinogenic properties (Buchbauer 2009; Duncan et al. 2004; Polo and de Bravo 2006; Vinothkumar and Manoharan 2011).

The US EPA concluded that geraniol was not mutagenic (US EPA 2007) because multiple strains of *Salmonella typhimurium* did not mutate after exposure to geraniol at six concentrations up to 500 µg/plate, with and without metabolic activation system. Geraniol induced neither sister chromatid exchanges nor chromosomal aberrations in genotoxicity assays (JECFA 2004).

Environmental Effects Information

Between April 1, 1996 and March 30, 2016, there were 24 reported pesticide incidents involving geraniol, but they did not involve human or animal exposure (NPIC 2016). Several of these involved cleanup or disposal of multiple pesticide products. Others incidents reported prior to 2006 had no narrative description.

Effects on Non-target Organisms

Effects of geraniol on non-target organisms are summarized in Table 5.

Table 5

Effects of Geraniol on Non-target Organisms

Study	Results	Source
Avian Oral, Tier I	Northern bobwhite quail: >10,000 mg/kg bw/d	(Gwynn 2014)
Non-target plant studies	Aquatic plant growth: 72-h EC_{50} = 5.93 mg/LAquatic plant biomass: 72-h EC_{50} = 3.32 mg/L	(FFHPVC 2004)
Non-target insect studies	Not Found	
Aquatic vertebrates	Zebrafish (*Brachydanio rerio*): 96-h LC_{50} = 14.0 mg/L	(FFHPVC 2004)
Aquatic invertebrates	*Daphnia magna:* 48-h EC_{50} = 7.75 mg/L	(FFHPVC 2004)

While LC_{50} values for honey bees (*Apis mellifera*) were not found, various studies that used geraniol to treat bee parasites and pathogens reported low or no toxicity to the bees treated. These studies are summarized in the efficacy section below.

Environmental Fate, Ecological Exposure, and Environmental Expression

Table 6

Environmental Fate, Ecological Exposure, and Environmental Expression

Study	Results	Source
Leaching series	Not found	
Photodegradation in water	Not found	
Photodegradation in air	Half-life: 0.71 hrs	(FFHPVC 2004)
Photodegradation in soil	Not found	
Ready biodegradability	Readily biodegradable	(FFHPVC 2004)

Geraniol is extremely volatile and biodegrades readily in air, soil and water, as well as through microbial activity. In many cases, natural levels of geraniol will be present in the environment at comparable or higher levels than what are applied, and it is not expected to persist (Gwynn 2014). Geraniol does not absorb light at wavelengths >290 nm and therefore is not expected to be susceptible to direct photolysis by sunlight (US NLM 2014).

Efficacy

Geraniol disrupts cell walls, membranes, or organelles of microorganisms (Gwynn 2014). Insects can also be repelled or inhibited by geraniol and other essential oils binding with the General Odorant Binding Proteins (GOPBs) in the insects' antennae or other olfactory sensory organs (Regnault-Roger 2005). Geraniol demonstrates GOPB binding properties in tobacco hornworm (*Manduca sexta*) and the polyphemus moth (*Antheraea polyphemus*) (Feng and Prestwich 1997). At low doses, geraniol induces an increase in spontaneous neuro-electrical activity; high doses cause a decrease (Regnault-Roger et al. 2012).

Insecticidal and Acaricidal Activity

Common uses of commercial geraniol insecticides are as mosquito and tick repellents for humans, and mosquito repellency is the most studied. Compared with linalool or citronella, geraniol delivered in candles and diffusers was shown to be a significantly greater mosquito repellent in both indoor and outdoor experiments (Muller et al. 2009). Geraniol demonstrated a duration of protection from *Aedes* mosquitoes of 2-3 hours (King 1967).

After camphor, geraniol was the second most widely cited plant-based chemical component in a search of the patent literature of essential oil mosquito repellents (Pohlit et al. 2011). In a review of the literature, one author listed geraniol among the most effective essential oil repellents for malarial, filarial, and yellow fever vector insects (Maia and Moore 2011). Geraniol had significantly more repellent activity against mosquitoes than citronella or linalool in both indoor and outdoor settings (Muller et al. 2009). The formulated product, MosquitoSafe (EPA registration status unknown)—with 25% geraniol, 74% mineral oil and 1% aloe vera—repelled *Aedes albopictus* for 2.8 hours (Xue et al. 2007). However, in another study, geraniol blended with citronella oil and lemongrass oil did not provide significant protection from *Aedes albopictus* and *Culex pipiens* mosquitos (Revay et al. 2013).

In a study performed by the manufacturer, TT-4228, a plant-based repellent composed of 5 % geraniol was compared to 15% DEET in laboratory two-choice bioassays against the lone star tick (*Amblyomma americanum*), American dog tick (*Dermacentor variabilis*), black-legged tick (*Ixodes scapularis*), and brown dog tick (*Rhipicephalus sanguineus*). No significant differences between the two repellents were observed (Bissinger et al. 2014). Geraniol was also compared to DEET in field trials against wild populations of ticks in North Carolina. Significantly fewer ticks were collected from socks worn by human volunteers and impregnated with a 5% geraniol formulation (90% reduction), compared to socks treated with 15% DEET formulation (70% reduction) and no-treatment controls 2.5 or 3.5 h after treatment (Bissinger et al. 2014). The authors concluded geraniol was more effective than DEET in the experiment.

Geraniol demonstrated nematicidal properties for the model nematode, *Caenorhabditis elegans*, in laboratory plate assays (Kumaran et al. 2003). Field tests validating efficacy in the soil were not found.

Formosan termites (*Coptotermes formosanus*) exposed to as little as 0.2 µL/g of geraniol had a 100% mortality rate (Cornelius et al. 1997). Blocks of Douglas fir treated with geraniol had no termite tunneling and significantly greater termite mortality than the no treatment control.

Mites were attracted by low concentrations (0.001 µL) of geraniol, uninfluenced by a medium concentration (0.01 µL), and repelled by high concentrations (0.1 µL) (Bowen-Walker et al.1997). Along with farnesol, geraniol is a component of mite female sex pheromones, which can be used to prematurely attract the male and disrupt the mating cycle (Regev and Cone 1975). Geraniol was shown to be moderately toxic (LC_{50} = 219.69 mg/l) to the two-spotted spider mite (*Tetranychus urticae*) (Badawy et al. 2010). Experiments show that geraniol can have a synergistic effect to lower the toxicity of other acaricides used to control populations of the two-spotted spider mite, thereby lessening the effectiveness of the acaricides, such as bifenthrin, chlorfenapyr, pyridaben, and tebufenpyrad (Van Pottelberge et al. 2008).

Geraniol was relatively ineffective as a fumigant against adult houseflies (*Musca domestica*) with an LC_{50} >1,750 µg/cm3 and adult red flour beetles (*Tribolium castaneum*) with an LC_{50} >889 µg/cm^3. However, as an ovicide, geraniol had a 99% inhibition of housefly hatches (Rice and Coats 1994).

Antimicrobial and Fungicidal Activity

In one study, Geraniol showed potent antibacterial activity against *Salmonella typhimurium* and its rifampicin-resistant (Rif^R) strain grown on fish (Kim et al. 1995). The study showed a 3% concentration killed 99% the bacteria in the media, making it second to carvacrol, which was 100% effective at a 3% concentration. In screening essential oils for efficacy against *Escherichia coli, Listeria innocua* and *Salmonella enteritidis*, researchers found geraniol to be one of the top three essential oils, along with lemongrass oil and cinnamon oil (Raybaudi-Massilia et al. 2006). At a concentration of 3 µL/ml, geraniol inhibited the growth of all three microorganisms to <10 CFU/ml. In particular, geraniol reduced the populations of *E. coli* O157:H7 strain in apple juice (Friedman et al. 2004). The BA_{50} for geraniol was 0.089% suspension in apple juice for 5 minutes, 0.027% for 30 minutes and 0.025% for 60 minutes with ascorbic acid; and 0.11% for 5 minutes, 0.057% for 30 minutes and 0.026% for 60 minutes without ascorbic acid.

In experiments conducted on various *Aspergillus* species, geraniol was identified as the most potent antifungal agent in the essential oil of lemongrass (Misra et al. 1988). The Minimum Inhibitory Concentration (MIC) of lemongrass oil was found to be 3,000 ppm, 2,000 ppm and 900 ppm for *A. flavus, A. fumigatus,* and *A. parasiticus,* respectively. Geraniol was found to have a slightly higher MIC than the essential oil.

When compared with other essential oils, geraniol was moderately toxic to four plant pathogenic fungi, *Rhizoctonia solani* (EC_{50} = 357.0 mg/l), *Fusarium oxysporum* (EC_{50} = 275.9 mg/l), *Penecillium digitatum* (EC_{50} = 73.9 mg/l), and *Aspergillus niger* (EC_{50} = 38.0 mg/l) (Marei 2012). Of the 14 monoterpenes screened in the study, geraniol showed the greatest efficacy against *A. niger*. However, geraniol was less effective than other essential oils in the study, particularly limonene and thymol. Geraniol was shown to be a contact growth inhibitor for *Botrytis cinerea* and *Monolinea fructicola,* with higher inhibition found against *M. fructicola* (Tsao and Zhou 2000). Again, geraniol was less effective than thymol and carvacrol. Geraniol showed a 46% inhibition at a concentration of 100 µg/mL for *B. cinerea*, compared to 100% for thymol and carvacrol at the same concentration. The inhibition of *M. fructicola* was 18% at 100 µg/mL, where thymol and carvacrol again had 100% inhibition at that concentration. The vapors of 5 µl of citral or 10 µl of geraniol per culture dish prevented vegetative growth of the fungus *Ascosphaera apis*, which causes chalkbrood in honey bees (Gochnauer et al. 1979).

Standards and Regulations

EPA Requirements

Geraniol is explicitly exempt from the requirement of a tolerance [40 CFR 180.1251] and can be used on food and feed.

FDA Requirements

Geraniol is Generally Recognized As Safe (GRAS) as a food additive used as a synthetic flavoring agent and adjuvant [21 CFR 182.60].

Other Regulatory Requirements

Non-synthetic sources are allowed for organic production under the USDA's National Organic Program [7 CFR 205.105].

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