New York State Integrated Pest Management Program | Cornell Cooperative Extension

Cloves & Clove Oil Profile

Active Ingredient Eligible for Minimum Risk Pesticide Use

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Active Ingredient Name: Cloves and clove oil

Active Components: Eugenol, eugenyl acetate, ß-carophyllene methyl eugenol

CAS Registry #: 8000-34-8

U.S. EPA PC Code: 220700 (oil of cloves) & 128895 (crushed cloves)

CA DPR Chem Code: 5018 & 2333

Other Names: Oil of cloves; Clove bud oil; Eugenia oil, minyak cengkeh (Indonesian)

Other Codes: EINECS 616-772-2; FEMA 2327 (cloves), 2323 (clove bud oil), 2325 (clove leaf oil), 2328 (clove stem oil)

Summary: Clove oil is the essential oil of the clove plant, and may be derived from flower buds, leaves and stems. The principal biologically active component is eugenol. Clove oil may be used as an insecticide, fungicide or herbicide. Because it is a common ingredient in food, the EPA considers risks to human health to be minimal.

Pesticidal Uses: Insecticide, acaricide, insect attractant, bait lure, and herbicide. It is used as a direct contact insecticide to kill crawling, flying and stinging insects and arachnids (both indoors and outdoors); as an attractant/lure for Japanese beetles in traps; to kill stored-grain pests; to repel dogs and cats from gardens; and as a post-emergent herbicide.

Formulations and Combinations: Other essential oils, cottonseed oil, sesame oil, 2-phenethyl propionate, octanoic acid, and sodium lauryl sulfate.

Basic Manufacturers: Harga, Indaroma, Indesso, Takasago; Kautilya Commodities; Biolandes; Divehi, Gramme, Fuzhou Farwell.

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: The EPA concluded that clove oil products used as pesticides according to the given label directions would not cause any significant harm to humans and the environment.

Background

Cloves and clove oil are derived from the tropical evergreen, *Syzygium aromaticum*, native to Southeast Asia. Phenotypically similar species also known as cloves are *Eugenia caryophyllata* and *Caryophyllus aromaticus,* although there is a difference of opinion among taxonomists as to whether these are distinct species or synonyms for the same species*.* The tree is cultivated in tropical regions worldwide. Indonesia is the world's largest producer of cloves, followed by Madagascar, Tanzania and Sri Lanka (FAO 2015). Madagascar has relatively limited clove oil production capacity compared to Indonesia. Indonesia was the largest exporter of clove oil to the US, accounting for 70% of US imports in 2013 (ITC 2014). The remainder was supplied by Madagascar, Singapore, France and the UK, with the last three relying mainly or entirely on imported raw cloves as the feedstock.

The dried flower buds are referred to as 'cloves' when used as a spice. The essential oil can be produced from these buds, or from other constituents of the plant. The buds are approximately 15-21% volatile oil (Merck 2015), with extraction yields averaging 15-18% (Khan and Abourashed 2010). The remainder consists of carbohydrates (61%), lipids (20%) and proteins (6%) (Merck 2015; Khan and Abourashed 2010). Other constituents present in clove buds include glucosides of sterols, including sitosterol, stigmasterol, and campesterol; crategolic acid, methyl ester, oleanolic acid, quercetin, eugeniin, kaempferol, and rhamnetin (Khan and Abourashed 2010). The chemical compositions of clove oils will vary due to the differences in plant growing conditions, genetic traits, plant parts used and the extraction methods (Alma et al. 2007).

Bud and leaf oil are generally extracted by water distillation, and stem oil is extracted by steam distillation. The stems yield 4-6% and the leaves yield 2-3% volatile oils (Khan and Abourashed 2010). The primary active constituent in clove oil is the terpenoid eugenol, which is covered in a separate 25(b) profile. Clove oil consists of 60-90% eugenol, 2-27% eugenyl acetate, 5-12% β-caryophyllene, and minor constituents such as methyl amyl ketone, methyl salicylate, and benzaldehyde (Bhuiyan et al. 2010; Khan and Abourashed 2010; Bhuiyan 2012; Merck 2015). Clove stem oil usually contains 90–95% and clove leaf oil 82–88% eugenol. Stem and leaf oil may have traces of naphthalene (Burdock 2010; Khan and Abourashed 2010).

As a pesticide, cloves and clove oil are mainly used as insecticides and fungicides, applied in cropping systems, and for post-harvest protection and in food storage areas. Target arthropod pests include aphids, armyworms, beetles, cutworms, mites, weevils, flies, wasps, and hornets. Diseases treated include *Botrytis* (Khan and Abourashed 2010).

Clove oil is also used in medicine, dentistry, perfumery, food industry and recently used as fish anesthesia.

Chemical and Physical Properties

The physical and chemical properties of cloves and clove oil appear in Table 1. Values are for clove oil unless otherwise specified. Values for eugenol are reported in that 25(b) profile.

Table 1

Physical and Chemical Properties of Cloves and Clove Oil

Property	Characteristic / Value	Source(s)
Molecular Formula:	N/A	
Molecular Weight:	N/A	
Percent Composition (clove bud oil):	Eugenol (60-90%), Eugenyl acetate (2-27%), β-caryophyllene (5-12%)	(Merck 2015; Khan and Abourashed 2010)
Physical state at 25°C / 1 Atm.	Liquid	(Merck 2015)
Color	Colorless to pale yellow; darker with age	(Merck 2015)
Odor	Not found	
Density / Specific Gravity	1.038-1.060 at 25°C	(Merck 2015)
Melting point	Not found	
Boiling point	251°C (484°F)	(Sigma-Aldrich 2015)
Solubility	Insoluble in water; soluble in 2 vols 70% alcohol.	(Merck 2015)
Vapor pressure	4.91×10^{-6} mm Hg	(EPI 2012)
pH	Not found	
Octonol/Water coefficient	Log K_{ow} = 0.99	(EPI 2012)
Viscosity	Not found	
Miscibility	Not found	
Flammability	Flash point: 151°C (239°F)	(Sigma-Aldrich 2015)
Storage stability	Not found	
Corrosion characteristics	Not found	
Air half life	0.01 hr	(EPI 2012)
Soil half life	21.5 hr	(EPI 2012)
Water half life	78.4 hr	(EPI 2012)
Persistence	709 hr	(EPI 2012)

Clove oil is a powerful agent against oxidation, with inhibition of peroxidation and hydroxylation equal to or greater than the commonly used synthetic antioxidants butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), as well as isolated eugenol and quercetin (Jirovetz et al. 2006). This is a possible explanation of its action as a fungal inhibitor.

Human Health Information

Acute Toxicity

The acute toxicity of cloves and clove oil appears in Table 2.

Table 2

Acute Toxicity of Cloves and Clove Oil

Study	Results	Source(s)
Acute oral toxicity	Rat: Leaf oil 1,370mg/kg Stem oil 2,020mg/kg Bud oil 2,650mg/kg Leaf and flower 3,598mg/kg	(Opdyke 1975; Opdyke 1978; Shalaby et al. 2011)
Acute dermal toxicity	Rabbit: Leaf oil 1,200mg/kg Stem oil >5,000mg/kg Bud oil >5,000mg/kg	(Opdyke 1975; Opdyke 1978)
Acute inhalation	Not found	
Acute eye irritation	Not found	
Acute dermal irritation	Mice: Not irritating; Rabbit: Moderately irritating	(Opdyke 1975)
Skin sensitization	Not found	

In closed-patch tests on human skin, clove bud oil applied at a rate of 20% in Vaseline or ointment caused primary irritation or erythema on two out of 25 human subjects. However, 2% or 5% clove bud oil did not cause any reactions in human subjects (Opdyke 1975).

A 7-month-old child developed central nervous system depression, urinary abnormalities and a large anion-gap acidosis after the accidental oral administration of clove oil (Lane et al. 1991). The patient recovered with supportive care and gastric lavage.

Sub-chronic Toxicity

The sub-chronic toxicity of clove oil appears in Table 3.

Table 3

Sub-chronic Toxicity of Clove Oil

Study	Results	Source(s)
Repeated Dose 28-day Oral Toxicity Study in Rodents	Rats fed 10% of the LD_{50}: Liver inflammation and kidney damage.	(Shalaby et al. 2011)
90 day oral toxicity in rodents	Not found	
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	Not found	
Prenatal developmental toxicity study	Rats, mice, hamsters and rabbits: No difference in abnormalities between the treatment and control groups	(FDRL 1973)
Reproduction and fertility effects	Not found	

An *in vitro* study of six male partners of infertile couples found clove oil and eugenol to be spermicidal (Buch et al. 1988). Inhalation of clove smoke in cigarettes is linked to respiratory problems including pulmonary edema and asthma (AMA Council on Scientific Affairs 1988). The American Medical Association concluded in its review that cloves in cigarettes created additional hazards to the health problems associated with tobacco. Rats fed clove oil at approximately 360 mg/kg for one month were found to have liver inflammation and renal corpuscular tubules that were convoluted and hemorrhaging in the interstices of the kidneys (Shalaby et al. 2011).

Chronic Toxicity

Chronic toxicity studies of clove and clove oil were not found. However, there is a considerable literature on clove and clove oil active constituents, in particular the main active constituent, eugenol.

Cloves and clove oil are not classified as carcinogens by the International Agency for Research on Cancer (IARC) (IARC 2014). Clove and clove oil do not appear on the Toxics Release Inventory (TRI) Basis of OSHA Carcinogens (US EPA Toxics Release Inventory Program 2015), nor on the California Proposition 65 List (Cal-EPA 2015).

Clove oil is highly cytotoxic to human fibroblasts and endothelial cells at concentrations as low as 0.03%, a level that is found in consumer products such as flavoring agents, fragrances and herbal medicines. The cytotoxic effect is attributed to eugenol (Prashar et al. 2006).

Human Health Incidents

The National Pesticide Information Center (NPIC) received 19 reports of human health incidents related to the use of clove and clove oil from April 1, 1996 to March 30, 2016 (NPIC 2016). Most involved formulated products with multiple active ingredients.

Environmental Effects Information

Effects on Non-target Organisms

The effects of clove oil on non-target organisms are summarized in Table 4.

Table 4

Effects of Clove Oil on Non-target Organisms

Study	Results	Source(s)
Avian Oral, Tier I	Not found	
Non-target plant studies	Not found	
Non-target insect studies	Honeybee (Apis mellifera): LT_{50} = 11,200ppm	(Ebert et al. 2007)
Aquatic vertebrates	Rainbow trout (Oncorhynchus mykiss) LC_{50} @10 min = 81.1 mg / L @30 min = 65.0 mg / L @24 hr = 61.5 mg / L Carp (Cyprinus carpio) LC_{50} @96 hr:74.3 mg/L Zebrafish (Danio rerio) LC_{50} @96 hr: 18.2 mg/L Guppy (Poecilia reticulate) LC_{50} @96 hr: 21.7 mg/L	(Velíšek 2005b; Velíšek 2005a; Doleželová et al. 2011)
Aquatic invertebrates	(Gammarus minus) EC_{50} >14.7 10 µl / ml	(Venarsky and Wilhelm 2006)

Clove oil has been tested extensively as a fish anaesthetic and is considered relatively safe for fish when used for that purpose. Clove oil is a potent anaesthetic for common carp, with the safest and most effective dose being at the concentrations of 30-50 mg/L. No mortalities were recorded in ten-minute exposures at doses up to 200 mg/L (Hajek et al. 2006). However, longer periods of exposure resulted in significant carp mortalities (Velíšek et al. 2005). Results for rainbow trout, zebrafish and guppy are also reported in Table 4. Nile tilapia (*Oreochromis niloticus*) anesthetized with clove oil prior to transportation suffered a significantly higher mortality rate than the no treatment control (Simões et al. 2011). No mortality was observed with *Gammarus acherondytes*, a federally endangered cave amphipod at an exposure of 80 mg /L used in the field (Venarsky and Wilhelm 2006).

When screened as a possible control for varroa mites (*Varroa jacobsonii*), clove oil resulted in no deaths to honey bees (*Apis mellifera*) at the most effective dose against the mites of 1 mg/cage over 48 hours (Lindberg 2000). A review of the literature cited a doctoral dissertation where honeybee mortality of 50% was reported at a dose of 15 mL per colony (Hoppe 1990; Imdorf et al. 1999). Clove oil concentrated at 98% eugenol reduced the growth of corals in a concentration dependent manner (Boyer et al. 2009).

The American Society for the Prevention of Cruelty to Animals' Animal Poison Control Center reported 39 incidents between 2006 and 2008 that involved the exposure of cats, and nine incidents involving the exposure of dogs, to flea products that contained clove oil and other active ingredients that are eligible to be EPA exempt from registration (Genovese et al. 2012). Three formulated products accounted for all incidents. 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 that was euthanized 6 days after appropriate use, and a 13-year-old cat that was euthanized 72 hours after appropriate use. All the formulations included clove oil as one of multiple active ingredients. These were sprays, shampoos and spot-on treatments.

Environmental Fate, Ecological Exposure, and Environmental Expression

The leaching, photodegradation and biodegradability of cloves and clove oil are summarized in Table 5. NPIC received 31 reports of incidents related to the use of clove and clove oil that were not specified as human or animal exposures from April 1, 1996 to March 30, 2016 (NPIC 2016). Not all incidents had detailed information, but most appeared to be spills or odor complaints.

Table 5

Environmental Fate, Ecological Exposure, and Environmental Expression

Study	Results	Source(s)
Leaching series	Not found	
Photodegradation in water	Not found	
Photodegradation in air	1.975 hr	(EFSA 2012)
Photodegradation in soil	Not found	
Ready biodegradability	Not found	

Environmental Incidents

NPIC received 12 reports of animal incidents related to the use of clove and clove oil from April 1, 1996 to March 30, 2016 (NPIC 2016).

Efficacy

No EPA reviewed efficacy claims for cloves and clove oil were found.

Bactericidal and Fungicidal Activity

Clove oil is effective against a broad range of acid-fast, gram-positive and -negative bacteria, as well as against yeasts and fungi (Pauli and Schilcher 2009; Khan and Abourashed 2010). Various aflatoxin producing fungi are susceptible to clove oil (Hussain et al. 2012).

Insecticidal Activity

The insecticidal properties of clove oil and its derivatives have been studied since the 1940s (West 1944). Clove oil toxicity varies among different insects because of different insect susceptibilities, variability in the concentration of eugenol and other active substances in the clove oil, and feeding behaviors. Susceptible arthropods include mites, termites and mosquitoes.

A set of experiments involving 38 essential oils found that clove oil gave the longest duration of 100%

repellency (2–4 hr.) against three species of mosquitoes: *Aedes aegypti*, *Culex quinquefasciatus*, and *Anopheles dirus* (Trongtokit et al. 2005). Clove oil (50%) combined with geranium oil (50%) or with thyme oil (50%) prevented biting by *Anopheles albimanus* mosquitoes for 1¼ to 2½ hours (Barnard 1999).

Bed Bug Patrol, a 25(b) exempt product consisting of clove oil (0.3%) combined with the other active ingredients 1% peppermint oil and 1.3% sodium lauryl sulfate was one of two products formulated with essential oils that resulted in an over 90% mortality of bed bugs (*Cimex lectularius*) (Singh et al. 2014).

Commercially available Rescue® traps with two known stink bug pheromone attractants were used to test the potential repellency of essential oils to the brown marmorated stink bug (*Halyomorpha halys*). Traps treated with 14 mg/day of clove oil repelled over 95% of the insects (Zhang et al. 2014). The same study noted that lemongrass oil, spearmint oil and ylang-ylang oil were as effective as clove oil as repellents.

Clove oil reduced oviposition and adult emergence of the cowpea weevil (*Callosobruchus maculatus*) on a variety of seeds. Efficacy varied by seed type, and oviposition was reduced by roughly 70% on bambaranut seeds (Ajayi and Lale 2001). Common bean (*Phaseolus vulgaris*) treated with clove oil grew less and resulted in increased mortality of the bean weevil, (*Acanthoscelides obtectus*), a storage pest—when compared to untreated plants. Applications of clove oil at 43.6 μL/kg beans resulted in a 50% mortality of bean weevil (Viteri Jumbo et al. 2014).

Clove oil is generally more effective when delivered orally than as a contact insecticide. The noctuid caterpillars (*Trichoplusia ni* and *Pseudaletia unipuncta*) did not appear to be susceptible to clove oil when compared with other essential oils. The EC_{50} values for reduced growth of the two species of caterpillars were 400 ppm and 6,900 ppm, respectively. The contact LC_{50} values were 63,000 and 54,000 ppm for contact sprays of *T. ni* and *P. unipuncta* respectively; the oral LC_{50} values were 3,700 and 4,900 ppm for feeding (Akhtar et al. 2008).

Clove bud oil killed 100% of Formosan termites (*C. formosanus*) in 2 days at 50 μg/cm^2 (2 kg/ha) (Zhu et al. 2001). Clove oil produced 100% mortality in Japanese termites (*Reticulitermes speratus*) at 0.5 μL/L of air (Park and Shin 2005).

Mixtures of clove, geranium, and lemongrass essential oils blocked the attraction of vespid wasps to baited traps (Zhang et al. 2013).

Clove oil can be effective against soft-bodied insects. Pear psyllid (*Cacopsylla chinensis*) treated with clove oil had a contact LD_{50} of 0.730 μg/adult and 1.795 μg/nymph (Tian et al. 2015). An experiment that compared the efficacy of 92 essential oils for the control of sweet potato whitefly (*Bemisia tabaci*) found clove oil to be one of the more effective, with an LC_{50} of 0.22 mL/cm^3 for clove bud oil, 0.26 mL/cm^3 for clove leaf oil and 100% mortality at a rate of 2.4 mL/cm^3 for the oil from both species (Kim et al. 2011).

Experiments in Korea showed that clove oil is effective as an acaricide as well. A formulation of 20% clove oil, 40% cottonseed oil and 10% garlic oil (GC-Mite) was the most effective of 12 natural treatments for two spotted spider mite (*Tetranychus urticae*) with nearly 100% mortality after 21 days (Cloyd et al. 2009). In a test with adults of two species of dust mites, *Dermatophagoides farinae* and *D. pteronyssinus* adults, the clove oil resulted in 100% mortality at 12.7 μg/cm^2 against both species (Kim et al. 2003). The copra mite (*Tyrophagus putrescentiae*) was also 100% susceptible to clove bud oil at a dose of 12.7 μg/cm^2 (Kim et al. 2003). Rabbits infested with mange mites (*Psoroptes cuniculi*) were topically treated with *E. carophylllata* oil both *in vitro* and *in vivo,* and significantly reduced infestations at applications rates lower than for pyrethrins (Fichi et al. 2007). At a rate of 2.5% *E. caryophyllata* oil, rabbits had no mange lesions after 14 days.

Nematicidal Activity

Greenhouse trials showed that clove oil drenches had inconsistent results in reducing southern root knot nematode (*Meloidogyne incognita*) populations before transplant of cucumber (*Cucumis sativus*), muskmelon (*Cucumis melo*), pepper (*Capsicum annuum*), and tomato (*Solanum lycopersicum*) seedlings (Meyer et al. 2008).

Herbicidal Activity

Clove oil exhibits phytotoxicity, which means it has herbicidal activity that can also make it undesirable as a foliar insecticide or fungicide for some plants at certain growth stages (Bainard et al. 2006; Boyd and Brennan 2006; Cloyd et al. 2009; Meyer et al. 2008). Clove oil produced severe leaf injury to dandelion (*Taraxacum officinale*) at a 2% concentration (Tworkoski 2002). The same study found that a concentration of 8% was sufficient to induce plant injury in common lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemesiifolia*) and johnsongrass (*Sorghum halepense*). Further studies would be needed to determine if injuries were sufficient for control. The study determined that of all the constituents of clove oil, eugenol was the most biologically active.

Another study compared 2.5% clove leaf oil and 1.5% eugenol with a distilled water control. The clove leaf oil and eugenol were formulated with 2% Tween 20 and the remaining ingredients were not reported. Researchers found that clove oil significantly reduced seedling growth and disrupted leaf membranes of common lambsquarters (*Chenopodium album*) and redroot pigweed (*Amaranthus retroflexus*) (Bainard et al. 2006). The mode of action appeared to be the removal of leaf epicuticular wax by the essential oil.

Clove oil is applied post-emergent, non-selective, and broad-spectrum. Care should be taken during applications to direct the herbicide to the weeds only (Patton and Weisenberger 2012). Cucumber seedlings treated with 2% clove oil at the first true leaf stage showed phytotoxicity within one hour of treatment under both dark and light conditions (Park et al. 2011). Clove oil's disruption of cell membranes took place under both dark and light conditions. Broccoli (*Brassica oleracea* var. *italica*) also suffered leaf tissue damage when exposed to clove oil (Stoklosa et al. 2012). In contrast to the cucumber study, broccoli and lambsquarters had increased tissue damage brought about by exposure to light, leading the authors to conclude that efficacy may be a function of timing and weather conditions.

However, field use has yielded inconsistent and disappointing results. Matran 2, a 45% clove oil based herbicide, when applied at 40% rate, controlled 100% of purslane (*Portulaca oleracea*). At 80% rate, it controlled 99% of burning nettle (*Urtica urens*) with a spray volume of 281 L/ha. With a higher spray volume (468 L/ha), a lower rate of Matran 2 provided similar rate of weed control. Common rye was relatively unaffected at all volumes and doses, with 2.5% control at the highest dose of 468 L a.i./Ha at an 80% dose. (Boyd and Brennan 2006). The article did not state whether the formulation was registered or exempt. Vidalia onions (*Allium cepa*) sprayed with Matratec, a 50% clove oil herbicide exempt from registration and various adjuvants resulted in minimal improvement in weed control, and no increase in yield—at great expense (Johnson and Davis 2014).

Because of the relatively high application rate, clove oil-based 25(b) exempt herbicides such as Matran® 2 and Burnout II® EC are often not seen as cost-effective herbicides, even in high value vegetable systems (Dayan, et al. 2009). At the lowest recommended rate, clove-based herbicides were estimated to cost about $600/ha (~$243/A) (Brainard et al. 2013).

Standards and Regulations

EPA Requirements

Cloves and clove oil are exempt from the requirement of a food tolerance [40 CFR 180.1164(d)]. They can be used on food and feed crops.

FDA Requirements

Cloves and their derivatives, including clove oil, are considered common food ingredients and are Generally Recognized As Safe (GRAS) [21 CFR 184.1257] by the FDA for food uses. However, clove oil and its constituents are not approved as an animal drug, and the FDA has voiced concerns about its use as a fish anesthetic (FDA CVM 2007).

Other Regulatory Requirements

Occupational Health and Safety Administration (OSHA) considers clove oil a potential skin and eye irritant under 29 CFR 1910 (Sigma-Aldrich 2015).

Cloves and clove oil are allowed by the USDA's National Organic Program (NOP) [7 CFR 205.105].

The European Union has approved clove oil to be used for the control of *Gloeosporium* spp. and *Penicillium* spp. in apples and pears (EC SANCO 2008).

Clove oil herbicides that are 25b exempt are permitted for use in K-12 schools and day care facilities in New York (Kao-Kniffin 2011).

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