New York State Integrated Pest Management Program
Cornell Cooperative Extension

Cinnamon & Cinnamon Oil Profile

Active Ingredient Eligible for Minimum Risk Pesticide Use

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Label Display Names: Cinnamon, Cinnamon OIl

Active Components: Cinnamaldehyde (Cinnamic aldehyde); camphor, coumarin, eugenol, linalool

CAS Registry #: 8015-91-6 (Cinnamon oil)

U.S. EPA PC Code: 129066

CA DPR Chem Code: 3607 (Cinnamon), 5577 (Cinnamon Oil)

Other Names: Cassia, Cinnamal, Burmese cinnamon, Ceylon cinnamon, Chinese cinnamon, Korintje, Sri Lankan cinnamon

Other Codes:

FEMA: 2286 (trans-Cinnamaldehyde), 2291 (Cinnammon bark oil), 2292 (Cinnamon leaf oil)
EINECS: 283-479-0 (Cinnamon bark oil), 203-213-9 (Cinnamaldehyde)
RTECS: GD6475000 (Cinnamon bark oil)
Beilstein: 2-07-00-00273 (Cinnamaldehyde)

Summary: Cinnamon and cinnamon oil are spices derived from tropical plants with a long and well-established use in food and fragrances. The main biologically active substances in cinnamon are cinnamaldehyde and eugenol, although others also appear to have significant activity. As a pesticide, cinnamon's main mode of action with insects appears to be as a repellent, although it has biocidal action at higher doses. Phytotoxic effects of cinnamon make it a possible herbicide, but also limit its practical foliar application to crops. Cinnamon and its essential oils are antimicrobial in nature and are effective at inhibiting the growth of bacteria and fungi. While cinnamon and cinnamon oils may cause skin irritation, the EPA allows their use as active ingredients in pesticide products that are exempt from registration. The EPA considers them exempt from the requirement of a tolerance on the various food crops to which they are applied.

Pesticidal Uses: Insecticide and acaricide. Repellent of cockroaches, mosquitoes, dogs and cats. Nematicide for plant parasitic nematodes. Fungicide used for disease control in edible mushrooms, with target pathogens including *Verticillium* spp., *Sclerotinia* spp. and *Rhizoctonia* spp. Water disinfectant. Herbicide.

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.

Formulations and Combinations: Formulated with other essential oils. Used in combination with garlic oil and its components (diallyl disulfide) as a fungicide and nematicide. Used in combination with clove oil and its components (eugenol) as an herbicide.

Basic Manufacturers: Penta Manufacturing; Treatt; Cassia Co-op; Baurs; EOAS, Pvt. Ltd; D.D. da Silva.

Safety Overview: The EPA reviewed the safety of cinnamon-based pesticides prior to the establishment of the 25(b) exempt list and concluded that food grade cinnamon products posed no harm and supported a waiver of data required for registration of biopesticides (McClintock 1991). Cinnamon and cinnamon oil are known skin irritants.

Background

The genus *Cinnamomum* has over 300 reported species with estimates of over 400 species extant (Ravindran et al. 2004). Cinnamon is primarily cultivated for the aromatic bark widely used in cooking and in traditional medicine. The EPA considers any cinnamon obtained from the bark of a *Cinnamommum* species widely distributed as a common food to be eligible for use as an active ingredient in pesticide products that are exempt from registration (Burnett 2017). Most spice sold as 'cinnamon' on the world market and in the US comes from Chinese cinnamon or cassia (*Cinnamomum cassia*). Cassia accounts for over 90% of what is traded as cinnamon (Madan and Kannan 2004). Indonesia, China, Madagascar, Seychelles, and Vietnam are the largest suppliers of cassia (Coppen 1995). The aromatic bark of the true cinnamon tree (*Cinnamomum verum*)—also known as Ceylon or Sri Lankan cinnamon (*C. zeylanicum*)—is the next most common source. Sri Lanka is the only significant commercial source of true cinnamon. In the United States, the common name cinnamon applies also to Indonesian cinnamon or korintji (*C. burmanii*) (Khan and Abourashed 2010) and Saigon cinnamon (*C. loureirii*) (Merck 2015).

The bark is composed of approximately 4% volatile oils, which can be extracted by steam distillation (Dayananda et al. 2004; Merck 2015). Cinnamon oil can also be distilled from the leaves and twigs, but consists of between 80 and 88% eugenol, which is also the main constituent of clove oil. The root bark oil of *C. zeylanicum* has approximately 4-5% cinnamaldehyde and eugenol, and about 60% camphor (Wijesekera et al.1974). Sometimes cinnamon oleoresins are produced by extraction with a solvent, such as hexane (Dayananda et al. 2004). It is possible to produce cinnamon oil by use of supercritical fluid extraction, but that technique is rarely used because of the high cost and insignificant quality advantage.

Cinnamon oil in an exempt product can only be from the species covered in the listed CAS number for this ingredient (CAS No. 8015-91-6) (Burnett 2017). The specification can be narrowly construed as only cinnamon bark oil from *C. zeylanicum,* but the CAS recognizes other terms, including leaf oil and essential oils from *Cinnamomum* species (ACS 2017). For the purposes of this profile, where a species is not reported, cinnamon oil is used as a generic term that presumably meets the standard of identity given by the EPA. Studies that involve essential oils from *C. zeylanicum, C. verum,* and *C. cassia* are also included.

A number of other *Cinnamonum* species derivatives could potentially be used as sources for essential oils (Coppen 1995). The two most significant of these are the camphor tree (*C. camphora*), which is the main commercial source of camphor essential oil, and Taiwanese indigenous cinnamon (*C. osmophloeum*), which is used for culinary, medicinal and pest control purposes in that country. *C. osmophloeum* has higher levels of the *trans*-isomer of cinnamaldehyde (Hussain et al. 1986), which is significantly more reactive than the *cis*-isomer (Klibanov and Giannousis 1982). For the purpose of this review, camphor and Taiwanese indigenous cinnamon oils are considered outside the scope of cinnamon oil. A number of other species are used for food consumed locally, but are not traded in significant quantities (Coppen 1995). Many of these species are used for local or regional cuisines, and in folk medicine (Shylaja et al. 2004). Therapeutic uses include as a carminative, antiseptic, and astringent (Merck 2015).

Chemical and Physical Properties

The chief chemical component of cinnamon oil is cinnamaldehyde—also known as cinnamic aldehyde—which comprises between 60-90% of cinnamon oil (Dayananda et al 2003). Other constituents include cinnamyl acetate, cinnamyl alcohol, cuminaldehyde, eugenol, linalool, and pinene. *C. cassia* has a higher average concentration of cinnamaldehyde when compared to *C. zeylanicum* (Dao 2004). Coumarin is generally present in *C. cassia* and absent in *C. zeylanicum,* and is sometimes used as an indicator to distinguish the two species (Senanayake and Wijesekera 2004).

The chemical and physical properties of cinnamon and cinnamon oil are reported in Table 1. Values are for cinnamon oil from *C. cassia*, unless otherwise noted.

Table 1

Physical and Chemical Properties of Cinnamon, Cinnamon Oil and Cinnamaldehyde

Property	Characteristic/Value	Source
Molecular Formula:	C_9H_8O (Cinnamaldehyde)	(Merck 2015)
Molecular Weight:	132.159 (Cinnamaldehyde)	(Merck 2015)
Percent Composition:	Cinnamon bark oil: Cinnemaldehyde (75-90%); linalool, eugenol, cinnamyl acetate; cinnamic acid; cinnamon alcohol; various other terpenoids	(Khan and Abourashed 2010)
Physical state at 25°C/1 Atm.	Liquid (oil) Solid (powder)	(Merck 2015)
Color	Yellow/amber/dark brown/clear	(Merck 2015; Royal Society of Chemistry 2014)
Odor	Distinct cinnamon spice aroma (cinnamon bark oil); cinnamon-clove odor (cinnamon leaf oil)	(Burdock 2010; Merck 2015)
Density/Specific Gravity	1.010-1.030	(Merck 2015)
Melting point	-7.5°C (Cinnamaldehyde)	(Royal Society of Chemistry 2014)
Boiling point	253°C (Cinnamaldehyde)	(Royal Society of Chemistry 2014)
Solubility	Soluble at 10% in ethyl alcohol 96%; soluble in most vegetable oils and glacial acetic acid. Soluble in propylene glycol. Slightly soluble in water. Insoluble in glycerin, mineral oil.	(Food Chemicals Codex Committee 2011; Merck 2015; Royal Society of Chemistry 2014)
Vapor pressure	0.13 hPa	(Royal Society of Chemistry 2014)
Acid Value	NA (varies)	
Octonol/Water (K_{ow}) coefficient	1.90 (Cinnamaldehyde)	(US NLM 2014)
Viscosity	Poise: 0.041, ±0.001	(Siddiqui and Ahmad 2013)

Property	Characteristic/Value	Source
Miscibility	Miscible in chloroform, ether, oils and alcohols; not miscible in water	(US NLM 2014; Merck 2015)
Flammability	Flash point: 88°C open cup	(US NLM 2014)
Storage stability	Stable. Combustible. Incompatible with strong oxidizing agents, strong bases.	((US NLM 2014)
Corrosion characteristics	Cinnamon plant extracts act as a corrosion inhibitor in steel.	(Fouda et al. 2014)
Air half life	5.13 hr (Cinnamaldehyde)	(Royal Society of Chemistry 2014)
Soil half life	720 hrs (Cinnamaldehyde)	(Royal Society of Chemistry 2014)
Water half life	360 hrs (Cinnamaldehyde)	(Royal Society of Chemistry 2014)
Persistence	Not found	

Human Health Information

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) concluded that cinnamaldehyde and other cinnamon derivatives did not pose food safety concerns at the current estimated levels of intake (JECFA 2001). Prior to determining cinnamon and cinnamon oil were eligible for exemption as minimum risk active ingredients, the EPA waived requirements for acute toxicity testing of cinnamon and cinnamon oil because of their safe uses in food (McClintock 1991; Mendelsohn 1992). There is limited data available for the acute and chronic toxicity of cinnamon and cinnamon oil. The acute, subacute and chronic toxicities for the primary ingredient of cinnamon oil, cinnamaldehyde, are reported in Tables 2, 3, and 4. Where isomers are distinguished, the values for *trans*-cinnamaldehyde are reported, because it is the more biologically active form. Cinnamon and cinnamon oil toxicity provide a margin of safety by comparison with their biologically active constituents given long-established historic patterns of intake of cinnamon as food (Adams et al. 2004). Cinnamon values are also reported here when they are available.

Acute Toxicity

The acute toxicity values for cinnamon, cinnamon oil, or cinnamaldehyde are reported in Table 2. Because of the data waivers and its common use as a food ingredient, there are numerous data gaps for cinnamon. Where possible, cinnamon bark oil rather than cinnamon leaf oil is reported.

Table 2

Acute Toxicity of Cinnamon and Cinnamaldehyde

Study	Results	Source
Acute oral toxicity	Cinnamaldehyde: 2,200 mg/kg (guinea pig) 2,250-3,350 mg/kg (rat) Cinnamon: 2,800 mg/kg (rat)	(Jenner et al. 1964; US NLM 2014)
Acute dermal toxicity	Cinnamaldehyde: >1,200 mg/kg (rat) Cinnamaldehyde: >1,000 mg/kg (rabbit)	(US EPA 2015)
Acute inhalation	Not found	
Acute eye irritation	Not found	
Acute dermal irritation	Cinnamaldehyde: 320 mg/kg (rabbit)	(Adams et al. 2004)
Skin sensitization	Not found	

Recorded cases of cinnamon poisoning are rare. A seven year old child was reported to develop severe gastrointestinal, central nervous system, and cardiovascular manifestations after intentionally ingesting 60 mL of cinnamon oil (Pilapil 1989). There have been reports of children intentionally consuming doses of cinnamon oil for the purpose of intoxication (Schwartz 1990).

Sub-chronic Toxicity

No sub-chronic data was found for cinnamon or cinnamon oil. Results of oral, dermal, and inhalation toxicity studies for cinnamaldehyde in rodents and non-rodents are reported in Table 3 when available.

Table 3

Sub-chronic Toxicity of Cinnamaldehyde

Study	Results	Source
Repeated Dose 28-day Oral Toxicity Study in Rodents	2,620 mg/kg/day (mice) 940 mg/kg/day (rats)	(Hébert, Yuan, and Dieter 1994)
90 day oral toxicity in rodents	NOEL: 625 mg/kg bw (rats)	(Adams et al. 2004)
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	2,620 mg/kg/day (mice)	(Hébert, Yuan, and Dieter 1994)
Prenatal developmental toxicity study	Not found	
Reproduction and fertility effects	Negative	(Shah et al. 1998)

Cinnamon and cinnamon oil are known skin irritants. Numerous cases of contact dermatitis from exposure to cinnamon oil and cinnamaldehyde have been reported over the years (Leifer 1951; Drake and Maibach 1976; Gosselin et al. 1976; Ackermann et al. 2009; Isaac-Renton et al. 2015; Connolly et al. 2017). Cinnamon bark oil and cinnamon leaf oil were found to inhibit skin sensitization caused by concentrated cinnamaldehyde in human subjects (Opdyke 1976).

Laboratory animals fed cinnamaldehyde by gavage had 100% mortality within three weeks at exposure levels of 940 mg/kg/day for rats and 2,620 mg/kg/day for mice (Hébert et al. 1994). Animals in the same study fed cinnamaldehyde by microencapsulations had no deaths. Mice that orally consumed *C. zeylanicum* extract had significantly lower sperm counts and sperm motility than the control, with no statistically significant difference in health for female mice (Shah et al. 1998).

Chronic Toxicity

Chronic toxicity data for cinnamon and cinnamon oil was not found. Results of studies using cinnamaldehyde are reported in Table 4.

Table 4

Chronic Toxicity of Cinnamaldehyde

Study	Results	Source
Chronic toxicity	Negative	(Bickers et al. 2005; US NLM 2014)
Carcinogenicity	Negative	(Bickers et al. 2005; US NLM 2014)
Combined chronic toxicity & carcinogenicity	Negative	(Bickers et al. 2005; US NLM 2014)

A comprehensive review of the chronic toxicology literature of cinnamaldehyde and other substances found in cinnamon showed negative results for most tests, but positive for mutagenicity in some results (Bickers et al. 2005). Cinnamon, cinnamon oil and cinnamaldehyde are not identified as carcinogens by IARC, NTP, ACGIH, or OSHA.

Cinnamaldehyde demonstrated anti-mutagenic properties in *E. coli* bacteria exposed to mutagenic methylated compounds (Ohta et al. 1983). Rats exposed to urethane, a carcinogen, without cinnamaldehyde had higher rates of lung tumors and lesions than rats exposed to both urethane and cinnamaldehyde (Imai et al. 2002). Cinnamon oil with cinnamaldehyde levels greater than 90% demonstrated cytotoxic effects against human leukemia cells, effectively slowing their reproduction (Huang et al. 2006).

Another biologically active component of cinnamon is coumarin. Cinnamon is believed to be the main potential source of human exposure to coumarin. While coumarin has been linked to hepatotoxicity and elevated levels of both liver cancer in rats and mice, and lung cancer in mice, natural sources of dietary coumarin, including cinnamon, are not believed to be a significant cancer risk (Lake 1999).

Human Health Incidents

Between April 1, 1996 and March 30, 2016, the National Pesticide Information Center (NPIC) had 11 reported human health incidents involving cinnamon oil as an active ingredient (NPIC 2016). All incidents involved formulations with multiple active ingredients, including some EPA-registered products.

Environmental Effects Information

Effects on Non-target Organisms

Most tests of cinnamaldehyde on non-target organisms were waived (US EPA Office of Pesticides and Toxic Substances 2011). Data found for the effects on non-target species is summarized in Table 5.

Table 5

Effects of Cinnamon oil on Non-target Organisms

Study	Results/Notes	Sources/Notes
Avian Oral, Tier I	Not found	
Non-target plant studies	Not found	
Non-target insect studies	Bees: >400 mg/kg (non-toxic at highest dose)	(Calderone, Wilson, and Spivak 1997)
Aquatic vertebrates	Not found	
Aquatic invertebrates	Not found	

Cinnamon oil can have phytotoxic properties when applied directly to growing plants, and therefore might be effective as an herbicide (Tworkoski 2002). A formulated product composed of cinnamon oil, rosemary oil and cottonseed oil was found to be phytotoxic to Coleus (*Solenostemon scutellarioides*) when tested as an insecticide (Cloyd et al. 2009). The same study also found that a formulated product with the active ingredients cinnamon, clove oil, rosemary, and garlic extract had the highest phytotoxicity of all the essential oil products tested on Transvaal daisy (*Gerbera jamesonii*). Because the formulations in this study contained multiple ingredients, it is unclear whether cinnamon oil itself caused or contributed to the observed phytotoxicity.

Studies that looked at the efficacy of cinnamon oil on Varroa mites (*Varroa jacobsoni*), a parasite of honey bees (*Apis mellifera*), also tested bee toxicity. One study showed that 10% doses of both generic and Ceylonese cinnamon oils caused nearly 99% bee mortality (Kraus et al. 1994). A study looking at the efficacy of cinnamon oil against the honey bee disease American foulbrood (*Paenibacillus larvae*) estimated the effective dose of 50 μg/ml was 'virtually non-toxic' to bees (Gende et al. 2009), and the minimum inhibitory concentration (MIC) for the spore-forming bacterial disease of bees was within a security index for the bees by a factor of approximately eight or nine. In other words, the lethal dose to bees was eight or nine times greater than the effective dose for American foulbrood treatment.

Between 2006 and 2008, The American Society for the Prevention of Cruelty to Animals' Animal Poison Control Center reported 48 incidents involving three formulated flea products that contained cinnamon oil and other active ingredients the EPA considers exempt from registration (Genovese et al. 2012). 39 reports involved exposure of cats, and nine involved dogs. Symptoms included skin erythema, vomiting, diarrhea, lethargy, edema, ataxia, seizures, weakness, recumbent tachycardia, agitation, anorexia, hyperactivity, hypersalivation, panting, retching, tremors, vocalization, and renal failure. Three incidents had 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 of sprays, shampoos and spot-on treatments included cinnamon oil as one of multiple active ingredients.

NPIC reported five incidents between April 1, 1996 and March 30, 2016 involving animals where cinnamon oil was an active ingredient (NPIC 2016). All involved formulations that had other ingredients in addition to cinnamon oil.

Environmental Fate, Ecological Exposure, and Environmental Expression

There is almost no information on the environmental fate, ecological exposure, and environmental expression of cinnamon, cinnamon oil, and its main active constituents. The biosynthesis and degradation pathways of cinnamon and cassia have been studied extensively in the laboratory (Senanayake and Wijesekera 2004).

Environmental Incidents

NPIC had 25 incidents reported between April 1, 1996 and March 30, 2016 for cinnamon oil that did not involve animal or human health (NPIC 2016). Most of these involved other active ingredients, including some EPA registered formulations. Reported incidents included abandoned pesticides, spills and inquiries prior to use.

Efficacy

Insecticidal activity

Cinnamon oil acts as a repellent to certain species of mosquitos, and is used as an ingredient in various mosquito repellents—often in combination with other essential oils. One study found that a repellent formulated with 10.5% cinnamon oil, along with eugenol, geranium oil, peppermint and lemongrass oil repelled the mosquito species *Aedes albopictus* and *Culex pipiens* at a rate not significantly different from a repellent having metafluthrin as the active ingredient (Revay et al. 2013). The article did not identify whether the formulation was EPA registered or exempt, and it was not possible to attribute efficacy to any one essential oil.

Efficacy data for German cockroaches (*Blatella germanica*) was submitted to EPA in 1991 and 1992, (Culleen 1993). The data was sufficient for products with cinnamon as an active ingredient to make a label claim that it controlled that public health pest (Bays et al. 1992). Note that products making specific public health claims on the label do not qualify as a 25(b) pesticide [40 CFR 152.25(f)(3)(ii)]. No such products were found in the EPA database as of 2017 (US EPA 2017).

Cinnamon and cinnamon oils have demonstrated efficacy against various storage pests. Cinnamon oils from *C. verum* and *C. cassia*, as well as their active constituents, were tested for their toxicity to the rice weevil (*Sitophilus oryzae*) (Lee et al. 2008). Both types of oils demonstrated toxicity to *S. oryzae* adults, with LC_{50} ranging from 0.016 to 0.10 mg/cm^2. The researchers found that allyl cinnamate levels had greater influence on mortality than cinnamaldehyde, and that the mode of action was through exposure to the volatilized aldehydes. *C. verum* was rated as one of the most active substances against the bean weevil (*Acanthoscelides obtectus*) when compared with other essential oils (Regnault-Roger et al.2005). Cinnamon oil inhibited the reproduction of the flour beetle (*Tribolium castaneum*), the maize weevil (*Sitophilus zea-mais)*, and the lesser grain borer (*Rhyzopertha dominica*) at a concentration of 0.1–0.2% mixed with wheat or wheat flour (Vijayan and Thampuran 2004). Common bean, (*Phaseolus vulgaris*) treated with cinnamon oil decreased the growth and resulted in increased mortality of the storage pest, the bean weevil, (*Acanthoscelides obtectus*). Applications of cinnamon oil resulted in an LD_{50} = 46.8 µL/kg beans (Viteri Jumbo et al. 2014).

Out of 49 essential oils screened against the larvae of the cecidomyiid gall midge (*Camptomyia corticalis*), a pest of shiitake mushrooms, cinnamon oils had 100% mortality at doses of 1.05 mg/cm^3 for 24 h (Kim et al. 2012). Cinnamon oil from *C. cassia* had an LC_{50} of 0.61 mg/cm^3 and cinnamon bark oil had an LC_{50} of 0.77 mg/cm^3. However, none of the essential oils was as effective as the organophosphate insecticide dichlorvos.

A 25(b)-exempt commercial blend of 0.10% cinnamon oil, 0.10% rosemary oil and 1.5% cottonseed oil (Pharm Solutions Flower Pharm) achieved over 90% mortality of citrus mealybug (*Planococcus citri*) at the ready-to-use label rate (Cloyd et al. 2009). However, the treatment also resulted in significant damage to the test plants. A 25(b)-exempt commercial formulation composed of 0.30% cinnamon, 0.40% rosemary, 0.30% clove oil and 0.30% garlic extract (Dr. Earth Fruit & Vegetable Insect Spray) was relatively ineffective against western flower thrips (*Frankliniella occidentalis*), sweetpotato whitefly (*Bemisia tabaci*), and green peach aphid (*Myzus persicae*) (Cloyd et al. 2009). For both formulations, it was not possible to attribute efficacy to any single ingredient.

Acaricidal Activity

The essential oil of *Cinnamomum zeylanicum* leaves demonstrated acaricidal activity on *Psoroptes cuniculi*, a mange mite that is hosted by rabbits. Concentrations of 0.31% and higher resulted in 100% mortality of the mites in Italy (Fichi et al. 2007). In another study, the American house dust mite (*Dermatophagoides farina*), and the European house dust mite (*Dermatophagoides pteronyssinus*) in Korea were exposed to contact and vapor of cinnamon oils in open and closed containers. Hexane-, methanol- and chloroform-soluble fractions of cinnamon oil from *C. cassia* resulted in 100% mortality to both species at a dose of 509.6 mg/m^2 (Kim et al. 2008). The test compounds were more effective in closed containers rather than in open containers, indicating that the mode of action is likely in the vapor phase. Cinnamaldehyde and benzaldehyde salicylaldehyde were determined to be the most effective constituents of the oils in this study.

The ethereal components of a 10% concentration of cinnamon oil in cage studies are effective as a control of the bee parasite, *Varroa jacobsonii.* However, a concentration of 10% is also fatal to bees (Kraus et al.1994). Feeding cinnamon oil and other essential oils in sugar may be more effective in controlling Varroa mites than by volatilization of cinnamon oil's aromatic (Sammataro et al. 2009).

A 25(b)-exempt formulation combination of cinnamon, rosemary, clove oil and garlic extract (Dr. Earth Fruit & Vegetable Spray) was the least effective of ten commercial products against the two-spotted spider mite (*Tetranychus urticae*) (Cloyd et al. 2009). However, the product was significantly more effective than the no-treatment control with about an 80% mortality after 7 days, compared with nearly zero for the water and untreated controls.

Nematicidal Activity

Cinnamon oil formulated with the synergist diallyl disulfide, a biologically active component of garlic oil, was shown to be an effective nematicide. Against root-knot nematode (*Meloidogyne incognita*), greenhouse-raised cucumbers grown in soil treated with cinnamon oil and allyl disulfide applied at 300 ppm cinnamaldehyde AI/pot had a galling index of 5, compared with 9 for the no-treatment control (on a scale from 0-9) (Belkind et al. 2012). While garlic oil is eligible for use as an active ingredient in 25(b)-exempt pesticide products, the concentrated extracts allyl disulfide and diallyl disulfide are not on the list of inert ingredients permitted in such products [40 CFR 152.25(f), Table 2].

Anti-microbial Activity

An extensive literature review documented that a variety of applications and exposures of cinnamon oil from *C. cassia* was effective against a large number of yeasts, fungi, and gram-positive and gram-negative bacteria (Pauli and Schilcher 2009). Among the organisms inhibited by Ceylon cinnamon bark oil were *Campylobacter jejeuni, Candida albicans, E. coli* O157:H7, *Staphylococcus aureus,* and *Shigella* spp.

A comparison of the antimicrobial activity of 51 different essential oils showed cinnamon oil, used with or without a dispersing agent, was effective against yeasts and a range of both gram-positive and gram-negative bacteria. Of several essential oils tested at concentrations of 500 µg/ml, cinnamon oil was the most effective against *Pseudomonas aeruginosa* with an 85.8% reduction in growth and *Torulopsis utilis,* with a 100% reduction in growth (Hili et al.1997). Thyme and palmarosa oils also resulted in 100% reduction in growth of *T. utilis.*

The bark and leaf oils of *C. zeylanicum* demonstrate antimicrobial activity against various plant and food-borne pathogens. Cinnamon oil combined with salt (sodium chloride) at the non-phytotoxic level of 5 µl/g corn in combination with 10 µl/g NaCl solution (5%) effectively inhibited the infection, growth and aflatoxin production by *Aspergillus flavus* and *A. glaucus* grown on corn (*Zea mays*) (Chatterjee 1989). However, cinnamon oil applied alone was effective at reducing mycotoxins below the limit of detection only at the phytotoxic level of 20 µl/g. Another study found that, of 11 different essential oils tested, *C. zeylanicum* provided the most effective control on *A. flavus* and without phytotoxicity to *Zea mays* (Montes-Belmont and Carvajal 1998). Bark oil was shown to be effective at inhibiting growth of *Aspergillus flavus, Aspergillus ochraceus, Aspergillus terreus, Penicillium citrinum,* and *Penicillium viridicatum,* with the leaf oil effective against all the same organisms except for *A. ochraceu* (Singh et al. 2007). When tested against food-borne pathogen bacteria, cinnamon oil was found to be very effective with a lowest minimum inhibitory concentration (MIC) of 1.25% (v/v) against *Bacillus* sp., *Listeria monocytogenes, E. coli* and *Klebsiella* sp. (Gupta et al. 2008).

Cinnamon oil was shown to be as effective against American foulbrood—an apiary pathogenic bacteria—as the antibiotic oxytetracycline-HCl on honey bees (Gende et al. 2009).

Cinnamon oil is an effective disinfectant of the bacteria that is the main causative agent of Legionaires' Disease and Pontiac Fever, *Legionella pneumophila* (Chang et al. 2008a; Chang et al. 2008b)

Herbicidal Activity

Cinnamon oil can be used with clove oil for herbicidal purposes (Hsu et al.2012). The formulation was rendered more effective by the addition of an oxidizing agent (hydrogen peroxide) and a surfactant made of casein and egg. Cinnamon oil at concentrations of 1-2% injured dandelion (*Taraxacum officianale*) (Tworkoski 2002). Cinnamon oil along with clove oil caused the greatest damage to johnsongrass (*Sorghum halepense*). Concentrations of 5% resulted in visible plant injury, while 10% concentrations became phytotoxic. The study concluded that eugenol was the most effective phytotoxic constituent in both cinnamon and clove.

Standards and Regulations

EPA Requirements

Cinnamon and cinnamon oil are exempt from the requirement of a tolerance [40 CFR 180].

FDA Requirements

The essential oils, solvent-free oleoresins, and natural extractives—including distillates—of cinnamon are Generally Recognized As Safe by the FDA [21 CFR 180.20]. The FDA regulation explicitly lists *C. cassia, C. burmanni, C. loureirii,* and *C. zeylanicum* as GRAS sources of cinnamon. The Flavor and Extract Manufacturer's Association looked at 55 derivatives of cinnamyl, all found in various forms of cinnamon and cinnamon oil to support a reaffirmation with the FDA that these flavoring agents were all Generally Recognized As Safe (Adams et al. 2004).

Cinnamon oil and cinnamon tincture are permitted for use as an Over-the-Counter digestive aid (US FDA 2010). However, based on the evidence currently available, the FDA said there are inadequate data to establish general recognition of safety and effectiveness for the specific use [21 CFR 310.545(a)(8)(ii)].

Other Regulatory Requirements

Cinnamon and cinnamon oil are allowed by the USDA's National Organic Program (NOP) [7 CFR 205].

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