New York State Integrated Pest Management Program | Cornell Cooperative Extension

# 2-Phenethyl Propionate Profile

## Active Ingredient Eligible for Minimum Risk Pesticide Use

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**Label Display Name**: 2-Phenethyl Propionate

**Active Components:** 2-Phenethyl Propionate

**CAS Registry #:** 122-70-3

**U.S. EPA PC Code:** 102601

**CA DPR Chem Code:** 2094

**Other Names:** 2 methyl-4-phenylbutanoate, phenethyl propanoate, phenethyl propanate, propanoic acid, Benzyl carbinyl propionate, Phenyl ethyl propionate, 2-phenylethyl ester, Propionic acid, 2-phenethyl alcohol ester; PEP, Japanese Beetle bait

**Other Codes:** BRN: 2097455, Caswell: 655D; EINECS: 204-567-7; ENT: 18544; FEMA No. 2867; NSC 404457

**Summary:** 2-phenethyl propionate (PeP) is as an insect attractant that is applied in traps where the substance does not come into direct contact with food or humans. It is usually formulated with other attractants. Although it is approved for use as a food additive, PeP is not exempt from the requirement of a tolerance. Because no food tolerance is established, it cannot be applied directly to food crops.

**Pesticidal Uses:** PeP is used primarily as a Japanese beetle lure, but also works as an attractant for other pests, including various beetles and bed bugs.

**Formulations and Combinations:** Formulated with various essential oils, such as geraniol, eugenol, rosemary oil, thymol, and peppermint oil. Dusts are formulated with sodium carbonate, sodium bicarbonate. Some formulations combine PeP with other ingredients (e.g. pyrethrins and various pheromones) that do not qualify for exemption from registration as minimum risk pesticides.

**Basic Manufacturers:** Alfa Aesar; Elan Chemicals; International Flavors and Fragrances; Penta Manufacturing.

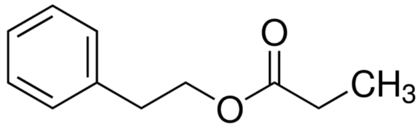
**Safety Overview:** Because of its non-toxic mode of action, prevalent use in traps that limit human and other non-target organism exposure, and lack of incidents that solely involve PeP, the EPA concluded that the risks it poses are at or near zero (Rexrode 2011).

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.

## Background

Phenethyl propionate (PeP) is an ester of phenethyl alcohol and propionic acid, and is found in various plants and plant products including guava (*Psidium guajava*), peanuts (*Arachis hypogea*), apple cider, beer, rum, apple brandy, and various cheeses (Burdock 1997). PeP can be synthesized by esterification through condensation of phenyl alcohol and propionic acid (Burdock 2010). It is used as a fragrance and food flavoring, as well as an insecticide.

## Chemical and Physical Properties




*Source: Sigma-Aldrich, 2014.*

**Table 1**

**Physical and Chemical Properties of 2-Phenethyl Propionate**

| Property | Characteristic/Value | Source |
|---|---|---|
| Molecular Formula: | $C_{11}H_{14}O_2$ | (Royal Society of Chemistry 2015) |
| Molecular Weight: | 178.22766 g/mol | (US National Library of Medicine 2015) |
| Percent Composition: | Food grade: 98% $C_{11}H_{14}O_2$ | (Food Chemicals Codex Committee 2011) |
| Physical state at 25°C/1 Atm. | Liquid | (Lewis 2001) |
| Color | Colorless | (Lewis 2001) |
| Odor | Flower fruit odor | (Lewis 2001) |
| Density/Specific Gravity | 1.02 at 25/25 deg C | (Lewis 2001) |
| Melting point | <25°C | (US National Library of Medicine 2015) |
| Boiling point | 298.3±9.0 °C at 760 mmHg | (Royal Society of Chemistry 2015) |
| Solubility | Water solubility at 25°C: 136 mg/L (estimated) | (EPI 2012) |
| Vapor pressure | 0.051 mmHg at 25°C | (US National Library of Medicine 2015) |
| pH | 5.7-6.2 | (Gonzalez 2011) |
| Octonol/Water ($K_{ow}$) coefficient | Log $K_{OW}$ = 3.06 (estimated) | (Gonzalez 2011) |
| Viscosity | Not found | |
| Miscibility | Miscible with alcohols and ether | (Lewis 2001) |
| Flammability | Flash Point: >200 °F (closed cup) | (Matthews 2011) |
| Storage stability | Stable, incompatible with strong oxidizing agents | (Sigma Aldrich 2014) |
| Corrosion characteristics | Not found | |
| Air half life | 31 hrs | (EPI 2012) |
| Soil half life | 360 hrs | (EPI 2012) |
| Water half life | 720 hrs | (EPI 2012) |
| Persistence | 471 hrs | (EPI 2012) |

## Human Health Information

PeP is not found to be inherently toxic to humans (Environment Canada DSL 2015).

### Acute Toxicity

**Table 2**

**Acute Toxicity of 2-Phenethyl Propionate**

| Study | Results | Source |
|---|---|---|
| Acute oral toxicity | $LD_{50}$ Rat: 4,500mg/kg (3,590-5,640 mg/kg) in males; 4,400 mg/kg (4,780 – 4,050 mg/kg) in females; 4,000mg/kg | (Lewis 2004; Rexrode 2011) |
| Acute dermal toxicity | $LD_{50}$ Rabbit: >2,000-5,000 mg/kg | (Lewis 2004; Rexrode 2011) |
| Acute inhalation | Not found | |
| Acute eye irritation | (Rabbit) minimal irritation, cleared by 72 hrs. | (Rexrode 2011) |
| Acute dermal irritation | (Rabbit) mild at 72 hrs, minimally irritating | (Rexrode 2011) |
| Skin sensitization | (Guinea pig) Non-sensitizer | (Rexrode 2011) |

The acute toxicity studies for PeP show that it is relatively non-toxic. Some of the irritation studies show it to be mildly irritating. The EPA plans to address the data gap on acute inhalation (McDavit 2010).

### Sub-chronic Toxicity

No sub-chronic toxicity studies were found for PeP. The EPA waived 90-day oral toxicity in rodents. PeP is not used on food, and non-food uses are unlikely to result in oral exposure to humans (Rexrode 2011; Gonzalez 2011). The EPA identified data gaps for 90-day dermal toxicity, 90-day inhalation toxicity, and prenatal developmental toxicity (Gonzalez 2011; Matthews 2011). PeP has not been screened for endocrine disruption, but the EPA plans to require it to be screened for its estrogen, androgen, and thyroid effects at the Tier 1 level (Matthews 2011).

### Chronic Toxicity

No chronic toxicity studies for PeP were found. The International Agency for Research on Cancer does not include PeP on its list of known carcinogens (IARC 2014). Carcinogenicity was not identified as data gaps for registration review (Matthews 2011) but PeP's mutagenicity is a data gap that the agency intends to fill (McDavit 2010)

### Human Health Incidents

The EPA records 421 incidents involving PeP as a pesticide active ingredient. These reports did not distinguish between registered and exempt products, and were compiled from all of EPA's incident databases and sources between January 1, 1992 and October 2, 2009 (Gonzalez 2011; Matthews 2011). Of those, 312 were classified as minor human incidents, mostly reported as respiratory irritation, dermal irritation, vomiting, hives and rashes. Other reported symptoms included dizziness, fevers, chest pain, and seizures. One additional human incident described 'unknown' symptoms. All reported incidents involved formulations that had at least one additional active ingredient, usually a pheromone or an essential oil such as eugenol, geraniol, thyme oil, and/or nuranone (Matthews 2011). Thus, it was not possible to attribute the incident solely to PeP. One of the databases used by EPA, the National Pesticide Information Center (NPIC), had 18 human health incidents reported between April 1, 1996 and March 30, 2016 (NPIC 2016).

Reports included both registered and exempt pesticide products. Consistent with the registration review report, all had other active ingredients listed in addition to PeP. Three of the incidents were in New York.

## Environmental Effects Information

### Effects on Non-target Organisms

The EPA has granted waivers to manufacturers of registered pesticides for testing PeP on aquatic invertebrate toxicity, freshwater fish acute toxicity, avian acute oral toxicity, avian dietary toxicity, and terrestrial plant toxicity (Rexrode 2011). Since PeP is generally used as either an insect attractant in traps, or in spray formulations used in cracks or crevices around buildings, there is generally very low non-target organism exposure. This low non-target exposure combined with PeP's non-toxic mode of action makes it unlikely to be an ecological risk (McDavit 2010).

The effects of PeP on non-target organisms, when available, are reported in Table 3.

**Table 3**

**Effects of 2-Phenethyl Propionate on Non-target Organisms**

| Study | Results | Source |
|---|---|---|
| Avian Oral, Tier I | Not found | |
| Non-target plant studies | Not found | |
| Non-target insect studies | Not found | |
| Aquatic vertebrates | Not inherently toxic to aquatic organisms | (Environment Canada DSL 2015) |
| Aquatic invertebrates | Molluscs (*Biomphalaria alexandrina*) Snail $LC_{50}$: 296.27 ug/L | (Radwan and El-Zemity 2007) |

Between 2006 and 2008, the American Society for the Prevention of Cruelty to Animals' Animal Poison Control Center reported 38 incidents involving the exposure of cats, and eight incidents involving the exposure of dogs, to spray and spot-on flea products containing PeP and other active ingredients eligible for EPA exemption from registration (Genovese et al. 2012). Two 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, and vocalization. One 7-week old kitten died from inappropriate use of the product.

### Environmental Fate, Ecological Exposure, and Environmental Expression

PeP biodegrades rapidly and is considered readily biodegradable (EPI 2012). Environment Canada does not consider the substance to be bio-accumulative or persistent in the environment (Environment Canada 2015).

### Environmental Incidents

To estimate risk, the EPA considered a worst case scenario-use of PeP trapping: placement of the maximum 8 traps per acre would mean about 6 gallons per acre of active ingredient (Matthews 2011). The amount of active ingredient that would be released if all 8 traps were opened and consumed by non-target mammals would be 3,080 mg/A, which is less than the 4,000 mg/kg no adverse effect level for female rats (Table 2). The EPA concluded that such a scenario was highly unlikely (Matthews 2011), and that release of the active ingredient from traps was not likely to present any risk nor have an effect on threatened or endangered species (Matthews 2011).

EPA's registration review of PeP found that 108 incidents involved PeP exposure to domestic animals during the time period of January 1, 1992 through October 2, 2009 (Gonzalez 2011; Matthews 2011). As with human incidents, these involved both registered products and minimum risk products. All were formulations with multiple active ingredients. Eight incidents were reported to NPIC between April 1, 1996 and March 30, 2016 (NPIC 2016).

## Efficacy

### Insecticidal Activity

Much of the efficacy data was obtained with experimental formulations prior to PeP's eligibility for use as an active ingredient in minimum risk pesticides. PeP is an effective lure for the Japanese beetle (*Popillia japonica*), particularly when combined with eugenol (McGovern et al. 1973). Preliminary screening of PeP and other phenethyl and phenylpropyl esters found that PeP was by far the most effective attractant of the Japanese beetle, and its attraction was enhanced by the presence of eugenol (McGovern et al. 1970). Subsequent laboratory and field trials explored formulations and techniques to optimize attraction and increase capture of adult beetles (McGovern et al.1973; Ladd et al. 1974; Ladd et al. 1975; Ladd et al. 1976). The addition of geraniol further enhanced the attraction (Ladd and McGovern 1980). Combining PeP and essential oils with the Japanese beetle pheromone, Japonilure (5-(dec-1-enyl)oxacyclopentan-2-one) increased attractiveness by a factor greater than 3, capturing males at a rate comparable to traps with virgin females (Klein et al. 1981; Ladd et al. 1981). The pheromone is considered a biopesticide, but is not eligible for use in a minimum risk pesticide.

A similar approach has been shown effective with other beetles, particularly those in the scarab family. The closely related Chinese scarab, *Popillia quadriguttata*, a pest of turf, soybean (*Glycine max*), corn (*Zea mays*), and horticultural crops, was trapped at a rate comparable to the results found with Japanese beetles (Chen et al. 2013). The white-spotted flower chafer (*Protaetia brevitarsis*), a scarab beetle that is a significant pest in corn, was also trapped using the Japanese beetle bait at a rate of 36.4%, though not as effectively as *P. quadriguttata* (Chen and Li 2011).

A mixture of PeP, essential oils, and pheromones showed promising results against the garden chafer (*Phyllopertha horticola*), a significant pest of horticultural crops in Europe (Ruther and Tolasch 2004; Ruther 2004; Ruther and Mayer 2005). The mixtures with geraniol (27%), eugenol (11.5%), and the pheromone (Z)-3-hexen-1-ol (50%) captured over 1,000 *P. horticola* in each of three different dispensers over a three-week period, but PPE alone captured 715 in that same period (Ruther and Mayer 2005). A series of experiments on the scarab pest *Maladera matrida* in organic peanut fields compared the attractiveness of Attack Japanese beetle lure (Ringer Corp.) with its components. The lure was effective, with eugenol alone having superior attraction to PeP or Japonilure (Ben-Yakir et al. 1995).

The attractiveness of PeP does not seem as strong to other orders of insects as it does to Coleoptera. The dipteran pest, spotted-wing drosophila (*Drosophila suzukii*), was exposed to a number of alcohols, acids, acetates, and esters. While PeP showed attractive properties, vinegar, various acetates and the ester phenethyl butyrate were stronger attractants (Kleiber et al. 2014).

Some minimum risk products with PeP make bed bug control claims. These include Bed Bug Fix (NuSafe), Stop Bugging Me (Rocasuba), and Rest Assured (ES&P Global). All of these formulations include other active ingredients that are also eligible for use in minimum risk pesticides in addition to PeP. Bed Bug Fix is formulated with 2% PeP, along with geraniol and cedar oil. Rest Assured contains 2% PeP and also includes geraniol and sodium lauryl sulfate. Stop Bugging Me is made with cinnamon oil, eugenol, geraniol, sodium lauryl sulfate and 2% PeP. Researchers compared these three formulations with the active ingredients imidacloprid (a neonicotinoid ) and ß-cyfluthrin (a synthetic pyrethroid) in the EPA-registered pesticide Temprid SC (Bayer). When applied to the point of run off, the three pesticides that included PeP had significantly lower bed bug mortality than Temprid SC – in general about 50% mortality as opposed to 100% (Singh et al. 2014).

PeP is also used in acaricide formulations along with various essential oils. A combination of PeP and eugenol was effective at killing the European dust mite (*Dermatophagoides pteronycsinus*) and the American dust mite (*Dermatophagoides farina*), achieving 100% mortality in 15 minutes for every formulation (Bessette 2005).

## Standards and Regulations

### EPA Requirements

EPA lists PeP as a minimum risk active ingredient [40 CFR 152.25(f)], but it is not currently approved as an inert ingredient in minimum risk pesticides. PeP was first registered as a pesticide by EPA in 1983 (McDavit 2010). Because of its non-toxic mode of action and established use as a food ingredient, EPA classified it as a biopesticide and waived a number of data requirements. There are no tolerance exemptions for PeP (Gonzalez 2011), therefore it cannot be applied directly to food crops (US EPA 2015). EPA published a notification in the Federal Register regarding the review of 2-phenethyl propionate's registration status [75 FR 60117] which they expected to complete by September 2016 (McDavit 2010). However, it was still listed as "under review" as of December 5, 2017 (US EPA 2017).

### FDA Requirements

There is no tolerance for PeP as a pesticide in food and therefore PeP is allowed for non-food uses only (US EPA 2015).

### Other Regulatory Requirements

Synthetic sources of PeP are prohibited under the National Organic Program (NOP) [7 CFR 205.105(a)]. Non-synthetic sources are allowed [7 CFR 205.602].

## Literature Cited

Ben-Yakir, D, A Bazar, and M Chen. 1995. "Attraction of *Maladera matrida* (Coleoptera, Scarabaeidae) to Eugenol and Other Lures." *Journal of Economic Entomology* 88 (2):415–20.

Bessette, Steven M. 2005. Method for controlling house dust mites with a composition comprising phenylethyl propionate. US Patent Office 6,887,889, issued May 2005.

Burdock, George A. 1997. *Encyclopedia of Food and Color Additives*. CRC Press.

———. 2010. *Fenaroli's Handbook of Flavor Ingredients*. Boca Raton, FL: CRC press.

Chen, Ri-zhao, Michael G. Klein, Cheng-fa Sheng, Yu Li, and Qi-yun Li. 2013. "Male and Female *Popillia quadriguttata* (Fabricius) and *Protaetia brevitarsis* (Lewis) (Coleoptera: Scarabaeidae) Response to Japanese Beetle Floral and Pheromone Lures." *Journal of Asia-Pacific Entomology* 16 (4):479–84. https://doi.org/10.1016/j.aspen.2013.08.001.

Chen, Ri-zhao, and Yu Li. 2011. "A Novel Plant Volatile Attractant Scheme to Protect Corn in China from the White-Spotted Flower Chafer (Coleoptera: Scarabaeidae: Cetoniinae)." *Journal of Pest Science* 84 (3):327–35. https://doi.org/10.1007/s10340-011-0353-6.

Environment Canada. 2015. "Domestic Substances List Categorization Database." Database Search Engine. Search Engine for the Results of DSL Categorization. 2015. http://www.ec.gc.ca/lcpe-cepa/eng/subs_list/DSL/DSLsearch.cfm.

EPI. 2012. "Estimation Programs Interface (EPI) Suite (V4.11)." Washington, DC: US EPA Office of Pesticides and Toxic Substances.

Food Chemicals Codex Committee. 2011. *Food Chemicals Codex*. Rockville, MD: US Pharmacoepial Convention.

Genovese, Allison G, Mary Kay McLean, and Safdar A Khan. 2012. "Adverse Reactions from Essential Oil-Containing Natural Flea Products Exempted from Environmental Protection Agency Regulations in Dogs and Cats." *Journal of Veterinary Emergency and Critical Care* 22 (4):470–475. https://doi.org/10.1111/j.1476-4431.2012.00780.x.

Gonzalez, Angela L. 2011. "Chemistry and Toxicology Scoping Document for the Registration Review of 2-Phenethyl Propionate." EPA-HQ-OPP-2010-0714-0004. US EPA Office of Chemical Safety and Pollution Prevention. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2010-0714-0004.

IARC. 2014. "Agents Classified by the IARC Monographs." 2014. http://monographs.iarc.fr/ENG/Classification/.

Kleiber, Joseph R., C. Rikard Unelius, Jana C. Lee, David Maxwell Suckling, Michael C. Qian, and Denny J. Bruck. 2014. "Attractiveness of Fermentation and Related Products to Spotted Wing Drosophila (Diptera: Drosophilidae)." *ENVIRONMENTAL ENTOMOLOGY* 43 (2):439–47. https://doi.org/10.1603/EN13224.

Klein, MG, JH Tumlinson, TL Ladd, and RE Doolittle. 1981. "Japanese Beetle (Coleoptera, Scarabaeidae) – Response to Synthetic Sex Attractant plus Phenethyl Propionate-Eugenol." *Journal of Chemical Ecology* 7 (1):1–7. https://doi.org/10.1007/BF00988630.

Ladd, TL, CR Buriff, M Beroza, and TP McGovern. 1975. "Japanese Beetles: Attractancy of Mixtures of Lures Containing Phenethyl Propionate and Eugenol." *Journal of Economic Entomology* 68 (6):819–820.

Ladd, TL, MG Klein, KO Lawrence, and M Beroza. 1974. "Japanese Beetles – Duration of Attractancy in Field of Phenethyl Propionate plus Eugenol." *Journal of Economic Entomology* 67 (1):139–40.

Ladd, TL, MG Klein, and JH Tumlinson. 1981. "Phenethyl Propionate + Eugenol + Geraniol (3-7-3) and Japonilure – a Highly Effective Joint Lure for Japanese Beetles (Coleoptera, Scarabaeaidae)." *Journal of Economic Entomology* 74 (6):665–67.

Ladd, TL, and TP McGovern. 1980. "Japanese Beetle (Coleoptera, Scarabaeide) – a Superior Attractant, Phenethyl Propionate + Eugenol + Geraniol, 3-7-3." *Journal of Economic Entomology* 73 (5):689–91.

Ladd, TL, TP McGovern, M Beroza, CR Buriff, and MG Klein. 1976. "Japanese Beetles – (Coleoptera Scarabaeidae) Attractancy of Phenethyl Propionate and Eugenol (3-7) and Synthetic Eugenol." *Journal of Economic Entomology* 69 (4):468–70.

Lewis, RJ Sr. 2001. *Hawley's Condensed Chemical Dictionary*. 14th ed. New York: Wiley.

———. 2004. *Sax's Dangerous Properties of Industrial Materials*. 11th ed. New York: Wiley.

Matthews, Keith A. 2011. "2-Phenethyl Propionate Final Workplan." EPA-HQ-OPP-2010-0714-0003. US EPA Office of Chemical Safety and Pollution Prevention. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2010-0714-0003.

McDavit, WM. 2010. "2-Phenethyl Propionate Draft Workplan." EPA-HQ-OPP-2010-0714-0002. US EPA Office of Chemical Safety and Pollution Prevention. http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OPP-2010-0714-0003.

McGovern, TP, M Beroza, and TL Ladd. 1973. Phenethyl propionate and eugenol, a potent attractant for the Japanese beetle (*Popillia japonica* Newman). US Patent Office 3,761,584, issued September 1973.

McGovern, TP, M Beroza, TL Ladd, JC Inganci, and JP Jurimas. 1970. "Phenethyl Propionate, a Potent New Attractant for Japanese Beetles." *Journal of Economic Entomology* 63 (6):1727–1729.

McGovern, TP, TL Ladd, M Beroza, Sarmient, MG Klein, and KO Lawrence. 1973. "Attraction of Japanese Beetles *Coleoptera Scarabaeidae* by Chemicals Related to Phenethyl Propionate (plus Eugenol) and Effect of Selected Additives." *Journal of Economic Entomology* 66 (5):1103–5.

NPIC. 2016. "NPIC Special Report: 25(b) Incidents." Corvallis, OR: National Pesticide Informatiom Center.

Radwan, MA and SR El-Zemity. 2007. "Naturally occurring compounds for control of harmful snails." *Pakistan Journal of Zoology* 39 (5): 339-344.

Rexrode, Michael. 2011. "Ecotoxicity Scoping Document for the Registration Review of 2-Phenethyl Propionate." EPA-HQ-OPP-2010-0714-0005. US EPA Office of Chemical Safety and Pollution Prevention. file:///C:/Users/Administrator/Downloads/EPA-HQ-OPP-2010-0714-0005.pdf.

Royal Society of Chemistry. 2015. "Chemspider." 2015. http://www.chemspider.com/.

Ruther, J. 2004. "Male-Biassed Response of Garden Chafer, *Phyllopertha horticola* L., to Leaf Alcohol and Attraction of Both Sexes to Floral Plant Volatiles." *Chemoecology* 14 (3–4):187–92. https://doi.org/10.1007/s00049-004-0271-7.

Ruther, J, and CJ Mayer. 2005. "Response of Garden Chafer, *Phyllopertha horticola*, to Plant Volatiles: From Screening to Application." *Entomologia Experimentalis et Applicata* 115 (1):51–59. https://doi.org/10.1111/j.1570-7458.2005.00264.x.

Ruther, J, and T Tolasch. 2004. "Attraction of Garden Chafer, *Phyllopertha horticola*, to Floral Japanese Beetle Lure." *Journal of Applied Entomology* 128 (2):158–60. https://doi.org/10.1111/j.1439-0418.2004.00832.x.

Sigma-Aldrich, Inc. 2014. "2-Phenylethyl propionate Safety Data Sheet." St. Louis, MO: Sigma-Aldrich, Inc.

Singh, Narinderpal, Changlu Wang, and Richard Cooper. 2014. "Potential of Essential Oil-Based Pesticides and Detergents for Bed Bug Control." *Journal of Economic Entomology* 107 (6):2163–2170.

US EPA. 2015. "Active Ingredients Eligible for Minimum Risk Pesticide Products." Washington, DC: US EPA Office of Chemical Safety and Pollution Prevention. https://www.epa.gov/sites/production/files/2015-12/documents/minrisk-active-ingredients-tolerances-2015-12-15.pdf.

———. 2017. "Pesticide Chemical Search." 2017. https://iaspub.epa.gov/apex/pesticides/f?p=chemical-search:1.

US National Library of Medicine. 2015. "Hazardous Substances Data Bank (HSDB)." 2015. http://toxnet.nlm.nih.gov/newtoxnet/hsdb.htm.