United States Department of Agriculture
Agricultural Marketing Service | National Organic Program
Document Cover Sheet
https://www.ams.usda.gov/rules-regulations/organic/petitioned-substances

Document Type:

☐ **National List Petition or Petition Update**

A petition is a request to amend the USDA National Organic Program's National List of Allowed and Prohibited Substances (National List).

Any person may submit a petition to have a substance evaluated by the National Organic Standards Board (7 CFR 205.607(a)).

Guidelines for submitting a petition are available in the NOP Handbook as NOP 3011, National List Petition Guidelines.

Petitions are posted for the public on the NOP website for Petitioned Substances.

☒ **Technical Report**

A technical report is developed in response to a petition to amend the National List. Reports are also developed to assist in the review of substances that are already on the National List.

Technical reports are completed by third-party contractors and are available to the public on the NOP website for Petitioned Substances.

Contractor names and dates completed are available in the report.

Sucrose Octanoate Esters

Crops and Livestock

Identification

Chemical Names:
sucrose octanoate esters

Other Name:
sucrose octanoate; alpha-D-glucopyranosyl - beta-D-fructofuranosyl ocanoate; sucrose caprylate; mono-, di-, and triesters of sucrose octanoate

Trade Names:
Organishield Sucrose Octanoate (40%); Organishield Sucrose Octanoate Manufacturing Use Product

CAS Numbers:
42922-74-7 (monooctanoate)
58064-47-4 (dioctanoate)

Other Codes:
OPP Chemical Code: 035300
EC/EINESC Number 256-002-9 (monooctanoate)
EC/EINECS Number 261-088-6 (dioctanoate)
UNII: 7MUS7RP47D (monooctanoate)
UNII: J75MK4RJET (dioctanoate)

Summary

This limited scope technical report provides information to the National Organic Standards Board (NOSB) to support the sunset review of sucrose octanoate esters, listed at:

- 7 CFR 205.601(e)(10) in crop production as an insecticide (including acaricides or mite control) in accordance with approved labeling (per the substance's annotation).
- § 205.603(b)(10) in organic livestock, as a topical treatment, external parasiticide or local anesthetic as applicable, in accordance with approved labeling (per the substance's annotation).

Sucrose octanoate esters (SOEs) were petitioned in 2004 for addition to the National List of Allowed and Prohibited Substances (hereafter referred to as the "National List") at § 205.601 for use as an insecticide in organic crop production and at § 205.603 for use as an external parasiticide for organic livestock. The NOSB recommended their addition to the National List in 2005 (NOSB, 2005). The National Organic Program (NOP) implemented the recommendation in 2007, when it added SOEs to § 205.601(e) and § 205.603(b). Both listings state: "Sucrose octanoate esters (CAS #s 42922-74-7; 58064-47-4)—in accordance with approved labeling" (72 FR 69569, December 10, 2007).

SOEs were renewed on the National List through the sunset review process in 2010 and 2015 (NOSB, 2010a, 2010b, 2015, 2015). In 2018, the NOSB recommended removing SOEs from the National List due to low reported use (NOSB, 2018), but the NOP renewed the listings in 2022 (87 FR 10930, February 28, 2022). AMS renewed the listing due to the following factors:

1. Lack of approved alternatives: Most public comments favored keeping SOEs, emphasizing that their removal would negatively impact organic farmers and beekeepers. Commenters highlighted that SOEs are a key ingredient in OrganiShield, a widely used product in Integrated Pest Management (IPM) systems. They further stressed that no other available product offers the same combination of safety, efficacy, and organic compliance for crop and livestock production, reinforcing the need to maintain SOEs on the list.
2. Environmentally friendly pesticide: The use of sucrose octanoate esters benefits crop-friendly insects such as pollinators, biodegrades rapidly after use, and does not negatively impact the environment.
3. Change in market situation: Since the NOSB's 2018 recommendation, products have been registered with the EPA.

As sucrose octanoate esters are listed at § 205.601 and § 205.603, synthetic forms are allowed.

Focus Questions

Focus Question #1: Information needed on whether natural sources of raw materials are used in manufacturing SOEs.

Sucrose octanoate esters (SOEs) are a class of compounds manufactured from sucrose and octanoic acid (Puterka et al., 2003). Producers use SOEs as biopesticides to control soft-bodied insects such as mites, aphids, whiteflies, etc.

(Buta et al., 1993; Cantrell et al., 2012; J. S. Hu et al., 2010; McKenzie et al., 2005; Puterka et al., 2003).[1] SOEs are chemical analogs of the naturally occurring sugar ester isolates of *Nicotiana* plant species, and mimic their pest control properties (Severson et al., 1984, 1985). SOEs are synthesized commercially, and the patented process (Farone & Serfass, 1998) uses materials such as alcohol, several catalysts, and solvents, in addition to sucrose and octanoic acid (Desai & Gruning, 1999; Huang et al., 2010; Song et al., 2006).

The steps involved in the synthesis of SOEs are detailed below, along with information on the sources of raw materials.

Step 1: Esterification of fatty acid

The first step in the synthesis of sucrose octanoate esters is to react octanoic acid (a C8 fatty acid) with methanol or ethanol in the presence of a sulfuric acid catalyst to form fatty acid ester (methyl octanoate or ethyl octanoate) and water (Castanheiro, 2021; PubChem, n.d.) (see *Equation 1*).

$$C_8H_{16}O_2 + CH_3OH \rightarrow C_9H_{18}O_2 + H_2O$$

(octanoic acid) + (methanol) → (methyl octanoate) + (water)

Catalyst not shown

Equation 1

Octanoic acid sources

Octanoic acid, also known as caprylic acid, is a naturally occurring fatty acid present in plants and some animal materials (PubChem, n.d.). We were unable to find recent statistics on the sources and production volume of octanoic acid. However, commercially available octanoic acid is produced from at least two different processes:

- oxidation of octanol (Krems Chem, n.d.; PubChem, n.d.; Riemenschneider, 2000)
- extraction from natural oils (Acme-Hardesty, n.d.; Burdock & Fenaroli, 2010; PubChem, n.d.)

Researchers have also developed microbial fermentation techniques to produce octanoic acid (Deng et al., 2020; P. Liu et al., 2013; Wernig et al., 2021; Yan & Pfleger, 2020). It is unclear whether these are used commercially, but it is possible. Use of microbes provides a scalable, controllable, and efficient method to produce octanoic acid as described in the studies cited above. Although scientifically feasible, using microbes to commercially produce octanoic acid has its challenges. For example, octanoic acid is an antimicrobial at higher concentration and inhibits microbial growth. Thus, it shuts down its own production process after reaching a concentration that is inhibitory to the strain producing it. Optimizing microbial strains to balance production efficiency and tolerance is crucial for industrial applications.

Industrial production of octanoic acid often relies on the oxidation of octanol, an eight-carbon alcohol. The oxidation process converts the alcohol into the corresponding carboxylic acid (Ishida et al., 2012). The reaction proceeds through the activation of molecular oxygen in the alcohol, transforming the hydroxyl group (-OH) to a carboxylic acid group (-COOH) in the presence of catalysts such as gold or ruthenium (Ishida et al., 2012). This constitutes a chemical change. Using NOP 5033-1 *Guidance: Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016), we would classify octanoic acid produced from this method as synthetic.

Octanoic acid can also be isolated from coconut oil, palm oil, or milk fats. The extraction process typically involves several methods, including solvent extraction (Zhang et al., 2018), distillation (Zhang et al., 2018), and supercritical fluid extraction (Wrona et al., 2017). We found one reference that also mentioned isolating octanoic acid using saponification (PubChem, n.d.). Additionally, microbial fermentation techniques, particularly using engineered strains of *Saccharomyces cerevisiae* and *Escherichia coli*, have been explored as alternative methods for octanoic acid production, offering potential for biosynthesis (Deng et al., 2020; Y. Hu et al., 2019; Yan & Pfleger, 2020).

Solvent extraction

In solvent extraction, organic solvents, like ethanol or methanol, are utilized to dissolve the fatty acids, separating them from the raw material. The process usually follows these steps (Zhang et al., 2018):

1. The solvent penetrates the solid matrix.
2. The fatty acids are dissolved.
3. The solutes diffuse out of the raw plant material or oil.
4. The extracted solutes are collected.

[1] In agricultural settings, soft-bodied insects are often pests. They tend to be sucking insects which not only damage crops through feeding, but also by transmitting diseases. However, soft bodied insects also have beneficial ecological functions. For example, aphids are a major food source for small birds and arthropod predators (Loxdale et al., 2020). Aphids also form complex relationships with ants, where ants feed on honeydew produced by aphids (Tegelaar et al., 2012).

Distillation
In the distillation method, octanoic acid is separated from the raw material based on its boiling point (Zhang et al., 2018).

Supercritical fluid extraction
Supercritical fluid extraction (SFE) employs supercritical carbon dioxide as a solvent to efficiently extract non-polar compounds, including octanoic acid. SFE is advantageous because (P. Liu et al., 2013; Wrona et al., 2017; Zhang et al., 2018):

- it allows temperature sensitive compounds to be extracted without thermal degradation.
- it produces a high yield with a lower environmental impact compared to traditional solvents.

Provided that synthetic solvents used to extract octanoic acid from plant oils are removed, the resulting material could be classified as nonsynthetic according to NOP 5033-1 *Guidance*: *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016).

Saponification
Saponification typically relies on heat and the use of alkaline substances to break apart triglycerides found in oils. Triglycerides are composed of fatty acids connected to each other via a glycerol bridge. Saponification chemically separates the fatty acids from the glycerol. While we did not find a specific manufacturing process that describes in detail the production of octanoic acids in this manner, PubChem (n.d.) does include a note saying that some octanoic acid is produced via saponification. Saponification is a synthetic process.

Microbial fermentation
Microbial fermentation is another process for obtaining octanoic acid, using bacteria or yeasts like *Saccharomyces cerevisiae*. These organisms can produce octanoic acid as a secondary metabolite when cultivated in bioreactors under specific conditions (Y. Hu et al., 2019; Yan & Pfleger, 2020). However, microorganisms used in this process are genetically engineered in some cases to withstand the toxicity of specific fatty acids that cause membrane damage (Chen et al., 2018).

Thus, depending on the method employed for octanoic acid preparation, the material can be classified as synthetic or nonsynthetic per the NOP 5033-1 Guidance *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016).

Ethanol and methanol sources
Ethanol is obtained from the fermentation of sugars from corn or sugarcane, or via the hydration of ethylene (Bai et al., 2008; Bedia et al., 2011; Hidzir et al., 2014). The former can be a nonsynthetic process, while the latter is synthetic. Methanol is synthesized via the catalytic hydrogenation of carbon dioxide (P. Liu et al., 2010), which is also a synthetic process.

<u>Step 2: Neutralization and separation of the catalyst</u>
The sulfuric acid catalyst used in the reaction of octanoic acid and methanol (or ethanol) is neutralized by a metal carbonate (*e.g.,* sodium carbonate or potassium carbonate), forming metal sulfate (*e.g.,* sodium sulfate). The octanoate ester is separated from these byproducts using physical methods such as filtration or decantation (Pavia, 1995).

Catalyst and neutralizer sources
Sulfuric acid is created from synthetic chemical processes involving the catalytic oxidation of sulfur dioxide (Katada et al., 2003; NIH, n.d.). Sodium carbonate is obtained from salt (sodium chloride) and limestone (calcium carbonate) via the Solvay process (Steinhauser, 2008). It can also be produced through the trona process, and rarely via solution mining of nahcolite, as described in the 2025 *Sodium Bicarbonate* technical report (in draft at the time of writing). Potassium carbonate is primarily made by the carbonation reaction between potassium hydroxide and carbon dioxide (NIH, n.d.).

<u>Step 3: Second esterification with sugar</u>
The recovered fatty acid ester is reacted with sucrose that is dissolved in dimethyl sulfoxide (Li et al., 2008), in the presence of a metal carbonate catalyst to produce the sucrose ester (Chortyk et al., 1996).

Sucrose sources

The sucrose (a sugar) commonly used in this step is obtained from natural sources such as sugar cane and sugar beets.

A generalized sugar cane manufacturing process is as follows (Babu & Adeyeye, 2024; OMRI, 2024):

1. The plant's stalks are harvested and crushed in a mill to extract the juice.
2. Lime in the form of calcium hydroxide is added to neutralize the natural acidity of the juice and cause impurities to precipitate. In some manufacturing processes, other clarifying agents, including carbon dioxide, may also be used.
3. The clarified juice is decanted to separate it from the precipitated impurities and lime residues.
4. The solution is then evaporated to yield concentrated syrup.
5. Sugar crystals are added to initiate the crystallization process.
6. The syrup is boiled under vacuum to complete the crystallization, then cooled and centrifuged to separate the crystallized sugar from the molasses.

Similarly, sugar beet roots are harvested and juice is extracted, followed by crystallization to produce sucrose (López et al., 2009). The process meets the criteria for nonsynthetic classification according to Guidance NOP 5033-1 *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* (NOP, 2016).[2]

Dimethyl sulfoxide sources

Dimethyl sulfoxide is a widely used polar solvent that is synthesized through the oxidation of dimethyl sulfide, a byproduct of the paper and pulp industry (Xiang et al., 2017).

<u>Step 4: Vacuum distillation and emulsification</u>

Dimethyl sulfoxide is removed from the reaction mixture via vacuum distillation (Wagner et al., 1991), a common method for solvent removal in esterification reactions. Water is added to emulsify the sugar ester product and any unreacted fatty acid ester. The unreacted sugar and metal carbonate dissolve in the water.

<u>Step 5: Separation of emulsified product</u>

The emulsion is heated to separate the sugar ester from the aqueous solution containing unreacted sugar and metal carbonate (Farone & Serfass, 1998). Manufacturers can also use mechanical means to break the emulsion and separate the sugar ester.

<u>Step 6: Purification and recovery</u>

The sugar ester product is purified by dissolving any remaining unreacted fatty acid ester in ethyl acetate. Any residual dimethyl sulfoxide, alcohol, and ethyl acetate remaining in the reaction mixture from previous stages are recovered through distillation. Any unreacted, concentrated sugar is recovered for reuse. This step ensures that no raw materials are wasted (Farone & Serfass, 1998).

Ethyl acetate source

Ethyl acetate is synthesized by the esterification of ethanol and acetic acid (Gurav & Bokade, 2010).

In summary, the principal raw materials used in the preparation of SOEs are:

- octanoic acid – produced from both synthetic and nonsynthetic sources
- alcohol (methanol or ethanol) – produced from synthetic and nonsynthetic sources
- sucrose – usually produced from nonsynthetic sources

The manufacturing process involves the use of several processing aids, some of which may be nonsynthetic (*e.g.,* sodium bicarbonate), and others which are from synthetic sources (*e.g.,* sulfuric acid, potassium carbonate, dimethyl sulfoxide, and ethyl acetate).

<u>**Focus Question #2: Information needed on impact of SOEs on the environment and non-target organisms prior to biodegradation. Is there any available information on detrimental physiological effects of SOEs on soil organisms and insects that were not covered in the current TR?**</u>

Sucrose octanoate esters (SOEs) have a relatively low environmental impact, especially when used as biopesticides. Liu et al. (1996) noted that SOEs are a favorable option when compared to conventional synthetic pesticides due to

[2] Most sugar beets grown in the United States and Canada are genetically modified for herbicide resistance (ISAAA Inc., 2024; The Non-GMO project, 2023; The Sugar Assocation, 2017). However, inputs produced from herbicide-tolerant crops (such as soya and sugar beets) are often considered allowed by certifiers and material review organizations in organic crop production when purified.

their natural origin, biodegradability, and non-toxic effects on non-target organisms. However, we found only limited information evaluating the impact of SOEs on the environment and non-target organisms.

<u>Impact on the environment</u>

SOEs are readily biodegradable due to their chemical structure, which is based on sucrose and octanoic acid (T. Liu et al., 1996). Naturally occurring microorganisms in soil and water can break down these compounds. They biodegrade within approximately five days at temperatures ranging from 68ºF to 80ºF in both aerobic and anaerobic conditions (Figge & Haigh-Baird, 1997). The degradation process typically produces harmless byproducts such as carbon dioxide and water (Figge & Haigh-Baird, 1997). Some of the degradation products are incorporated as microbial biomass (Figge & Haigh-Baird, 1997).

<u>Impact on non-target organisms prior to biodegradation</u>

In 2020, the EPA evaluated SOEs potential impacts on non-target insects and other organisms (U.S. EPA, 2006a, 2006b, 2020). They determined that there is minimal potential for exposure and toxicity in non-target insects and fish, or other non-target organisms, soil, and water. The EPA established that SOEs have a minimal toxicity profile since their action is based on physical effects rather than biochemical toxicity. This characteristic makes their action specific to soft-bodies insects without producing general toxic metabolites, thus decreasing the likelihood of harming beneficial insects. Moreover, due to their biodegradable nature, the substances were found to pose minimal risk to mammals and birds, further supporting their ecological safety (U.S. EPA, 2020).

SOEs primarily target soft-bodied insects by physically disrupting the lipid layer in their cuticle, leading to dehydration and death (Li et al., 2008; McKenzie & Puterka, 2004). Insects with thicker, more robust exoskeletons are not affected (Michaud & McKenzie, 2004). The mechanism of action of SOEs does not rely on targeting a biochemical pathway common to all insects, therefore, SOEs have minimal effects on non-target organisms such as pollinators (*e.g.,* bees and ladybugs), earthworms, and other soil organisms (Chortyk et al., 1996; Michaud & McKenzie, 2004).

Michaud and McKenzie (2004) assessed the toxicity of SOEs on multiple beneficial insect species representing different orders within the citrus ecosystem. The study revealed that several beneficial insects, including lady beetles (*Coccinellidae*), lacewings (*Chrysopidae*), and red scale parasitoids (*Anthocoridae*), showed high survival rates when exposed to SOEs residues at approximately 8,000 ppm of application, a concentration corresponding to twice the recommended field rate required to kill soft-bodied pests.

<u>Detrimental physiological effects of SOEs on soil organisms and insects:</u>

SOEs' target soft-bodied insects on food and non-food crops, including (NOP, 2005):

- thrips
- aphids
- whiteflies
- psyllids
- mites

Livestock operations may use SOEs to control immature forms of certain gnat species and Varroa mites on adult honeybees (NOP, 2005). Koul et al. (2012) noted that SOEs are not effective controls for lepidopteran (moth) pests, and that insects generally can detoxify secondary compounds from plants (such as SOEs).

Soil organisms and non-target insects may be exposed to SOEs during and after applications until the compounds biodegrade in approximately five days. Direct and specific detrimental effects from SOEs on soil organisms have not been extensively documented. We did not find literature that reports detrimental physiological effects of SOEs on soil organisms, soil microbiome, or non-target insects. According to current literature, SOEs have low toxicity and biodegrade rapidly (Figge & Haigh-Baird, 1997; Koul et al., 2012; T. Liu et al., 1996). When applied according to EPA-approved label instructions, SOEs pose minimal risk to non-target insects and soil organisms.

<u>**Focus Question #3: An update on the efficacy, performance as well as health and environmental impacts of natural alternatives to SOEs will be very helpful.**</u>

Several natural compounds can serve as biopesticides, offering similar environmentally friendly, low-toxicity, and biodegradable characteristics as SOEs. These alternatives typically originate from plant extracts, microbial products, or other naturally occurring substances and are often used in sustainable agriculture and integrated pest management systems. We did not find studies that compare the efficacy or the non-targeted deleterious effects of these compounds to those of SOEs. Therefore, a study of these compounds and whether they could act as alternatives for SOEs is needed.

Neem Oil

Extracted from the seeds of the neem tree (*Azadirachta indica*), neem oil contains active compounds, such as azadirachtin, which has insecticidal properties (Bond et al., 2012; Chaudhary et al., 2017). Neem oil primarily targets soft-bodied insects such as aphids and whiteflies, as well as mites (Kilani-Morakchi et al., 2021; Tang et al., 2002). Neem oil works through multiple mechanisms to control soft-bodied insect pests. For example, azadirachtin acts as a powerful repellent, reduces insect feeding, and disrupts growth (Bond et al., 2012; Kilani-Morakchi et al., 2021; Shannag et al., 2015). Neem oil can also interrupt oviposition and sperm production in insects, thereby reducing breeding and production of offspring (Chaudhary et al., 2017).

Neem oil can be applied as a foliar spray (Sundaram & Curry, 1994), soil drench (Javed et al., 2008), seed treatment (da Costa et al., 2014), or as an ingredient in the diet of pests (Duarte et al., 2020).

Neem oil is biodegradable and has low impact on beneficial insects (Kilani-Morakchi et al., 2021). The biodegradability of neem oil is primarily due to its organic composition, consisting mainly of triglycerides, steroids and triterpenoids (Campos et al., 2016). These organic components are readily broken down by environmental factors such as light (Caboni et al., 2006), and by microorganisms in soil and water ecosystems (Campos et al., 2016). Specifically, azadirachtin, the primary active component in neem oil, has a relatively short half-life in the environment, ranging from:

- 3 to 44 days in soil (Bond et al., 2012)
- 48 minutes to 4 days in water (Bond et al., 2012)
- 15-60 days on crops such as cowpea and maize infested with *Callosobruchus maculatus* and *Sitophilus zeamais* (Tofel et al., 2016)

Azadirachtins and related compounds degrade rapidly when exposed to sunlight, with half-lives of ~11 hours for azadirachtin A and 5.5 hours for azadirachtin B (Caboni et al., 2006). This rapid breakdown ensures that neem oil does not persist in the environment, reducing the risk of long-term ecological impact.

Although beneficial as an insecticide, neem oil should be used carefully, as cases of neem oil poisoning in humans have been reported (Bhaskar et al., 2010; Mishra & Dave, 2013). These poisoning cases are primarily due to accidental oral consumption, resulting in toxic encephalopathy (Mishra & Dave, 2013) or bilateral vision loss (Bhaskar et al., 2010).

Pyrethrins

Pyrethrins are natural insecticides extracted from the flowers of chrysanthemums (*Chrysanthemum cinerariifolium*). Pyrethrins attack the nervous system of insects, primarily interacting with voltage-gated sodium channels in insect nerve cells, leading to their depolarization (Soderlund, 2012). This leads to paralysis and death.

Pyrethrins are effective against a broad range of pests, including flies, mosquitoes, beetles, and moths (Hodoșan et al., 2023). They degrade quickly in sunlight and have low persistence in the environment (Agency for Toxic Substances and Disease Registry, 2014). They are relatively non-toxic to humans and animals, but can harm beneficial insects such as bees and aquatic organisms if used improperly (Bond et al., 2014). Pyrethrins are used in both agricultural and household pest control, often as a natural alternative to synthetic insecticides (Hodoșan et al., 2023).

Bacillus thuringiensis (Bt)

Bacillus thuringiensis (Bt) is a spore-forming soil bacterium that has been widely used as a biopesticide for over 60 years (Kumar et al., 2021) It produces proteins known as delta-endotoxins (the proteins Cry and Cyt), which, when ingested by insects, bind to specific receptors located on the midgut epithelial cells (Bravo et al., 2007; Schnepf et al., 1998). The proteins then assemble to create pores in the cell membrane, which disrupt it and cause insect death (Bravo et al., 2007; Schnepf et al., 1998).

Bt is highly specific to target pests due to the receptor binding property of the Cry and Cyt proteins (Bravo et al., 2007). For Cry1A toxins, at least four different binding proteins have been described in different lepidopteran insects (Jurat-Fuentes & Adang, 2004; Knight et al., 1994; Vadlamudi et al., 1995; Valaitis et al., 2001). The bacterium also produces vegetative insecticidal proteins (Vip) and secreted insecticidal protein (Sip) which are toxic to specific insect groups (Kumar et al., 2021).

Bt is particularly effective against insects in the orders *Lepidoptera* (butterfly and moths), *Coleoptera* (Beetles), *Diptera* (flies and mosquitoes), and *Hemiptera* (true bugs) (Bravo et al., 2011; Palma et al., 2014; Sanahuja et al., 2011). In addition, researchers report that Bt is efficient at controlling nematodes (Bel et al., 2022), and mites (Erban et al., 2009; Yu et al., 1997). Thus, Bt affects a broader range of organisms than SOEs.

Researchers have raised concerns regarding Bt's non-targeted effects on beneficial insects (Federici, 2003). This topic continues to be an area of scientific debate, and more data is needed (Naranjo, 2009). Most evidence shows that Bt insecticides are safe for non-target organisms, especially compared to chemical insecticides (Federici, 2003; Singh et al., 2019). However, there are reports of non-targeted deleterious effects on several groups of insects, especially when there is taxonomic affinity of the non-target organisms to the groups targeted by the Bt insecticide (Naranjo, 2009).

For example, Nawrot-Esposito et al. (2020) demonstrated that Bt products, when used at concentrations that could be reached in the field upon spraying, impair the growth and developmental time of the non-target dipteran *Drosophila melanogaster* (common fruit fly) larvae. Similarly, Jneid et al. (2023) also demonstrated that Cry1A toxins disrupted physiological processes in *Drosophila melanogaster*.

Other studies have evaluated the impacts of Bt on non-target organisms through the expression of Bt genes in genetically engineered crops. Dively et al. (2004) discovered that lepidopteran *Danaus plexippus* (monarch butterfly) larvae mortality increased after eating Bt corn pollen. When the monarch butterfly larvae were exposed to Bt pollen on milkweed, 23.7% fewer larvae reached adulthood. Although transgenic Bt crops are not eligible for organic certification, the impacts on non-target organisms illustrate the potential for Bt insecticides to have adverse effects on non-target organisms.

Although one of the most widely used microbial insecticides, there have been reports of insect resistance to Bt. McGaughey (1985) reported that *Plodia interpunctella* (Indianmeal moth), a major lepidopteran stored grain pest, can develop resistance to Bt within a few generations. Resistance increased nearly 30-fold in two generations in a strain reared on a diet treated with Bt. After 15 generations, resistance was 100 times higher than the control level. Similarly, resistance alleles have increased substantially in *Helicoverpa zea* (corn earworm) as a result of field-evolved resistance to a Bt transgenic crop (Tabashnik et al., 2008).[3] Tabashnik et al., (2023) studied 25 years of global patterns of resistance to transgenic Bt crops in 24 pest species. Results revealed that the rapid evolution of practical resistance to Bt crops has reduced Bt efficacy in at least 11 pest species and 7 countries.

<u>Spinosad</u>

Spinosad is derived from the fermentation of the bacterium *Saccharopolyspora spinosa*. Spinosad targets the insect nervous system, causing excitation of the insect's neurons, leading to paralysis and death. Spinosad is effective against a variety of pests, including caterpillars, thrips, flies and leaf miners (Hertlein et al., 2011; Martelli et al., 2022). Spinosad breaks down quickly in the environment and is considered safe for humans and most beneficial insects, though it can be toxic to bees if applied directly to flowering plants (Mayes et al., 2003; Miles et al., 2002). According to Christen et al. (2019), Spinosad application (0.05, 0.5, and 5 ng/bee) for three different exposure times (24, 48, 72 hours) induced transcriptional alterations in genes associated with energy production in honeybees. Tomé et al. (2015) discovered that *Melipona quadrifasciata* (a stingless bee native to southeastern Brazil) exhibited high oral susceptibility to spinosad with an LD_{50} of 12.07 ng/bee. These reports highlight the hazardous nature of spinosad to bee populations.

<u>Other Botanicals</u>

Other plant-derived compounds have also been used for insect control, including essential oils derived from thyme and eucalyptus (Khater, 2012), and garlic extracts (*Allium sativum*). Garlic extracts contain sulfur compounds such as allicin, which have insecticidal and fungicidal properties. Garlic acts as a natural repellent by producing strong odors that deter pests like aphids, mosquitoes (including the Asian tiger mosquito), slugs, and mealworm beetles (Dusi et al., 2022; Plata-rueda et al., 2017; Tedeschi et al., 2011).

Plant pesticides are generally biodegraded by common soil microorganisms and have low persistence in the environment (Khater, 2012).

<u>Biological controls</u>

If properly applied, biological control agents can be effective against soft-bodied insect pests that are present in crops. Kundoo & Khan (2017) recommend that operators seek to identify infestations early while the pest population is still small, then release a corresponding beneficial insect predator. Many of these predators are in the family *Coccinellidae*, including ladybugs, which are effective predators against aphids, whiteflies, and mites. Biological

[3] An allele refers to a variant form of a gene. In the context of insect resistance to Bt, resistance alleles are genetic variations that confer the ability to survive exposure to Bt toxins, leading to an increase in their frequency within resistant populations over generations.

control agents are often paired with other pest control measures as part of an integrated pest management plan (Kundoo & Khan, 2017).

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All individuals comply with Federal Acquisition Regulations (FAR) Subpart 3.11—Preventing Personal Conflicts of Interest for Contractor Employees Performing Acquisition Functions.

References

Acme-Hardesty. (n.d.). *Caprylic acid product details and info*. Acme-Hardesty. Retrieved November 20, 2024, from https://www.acme-hardesty.com/product/caprylic-acid/

Agency for Toxic Substances and Disease Registry. (2014). *Public Health Statement for Pyrethrins and Pyrethroids*. https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=785&toxid=153

Babu, A. S., & Adeyeye, S. A. O. (2024). Chapter Seven—Extraction of sugar from sugar beets and cane sugar. In S. M. Jafari & S. Akhavan-Mahdavi (Eds.), *Extraction Processes in the Food Industry* (pp. 177–196). Woodhead Publishing. https://doi.org/10.1016/B978-0-12-819516-1.00007-7

Bai, F. W., Anderson, W. A., & Moo-Young, M. (2008). Ethanol fermentation technologies from sugar and starch feedstocks. *Biotechnology Advances*, *26*(1), 89–105.

Bedia, J., Barrionuevo, R., Rodríguez-Mirasol, J., & Cordero, T. (2011). Ethanol dehydration to ethylene on acid carbon catalysts. *Applied Catalysis B: Environmental*, *103*(3), 302–310. https://doi.org/10.1016/j.apcatb.2011.01.032

Bel, Y., Galeano, M., Baños-Salmeron, M., & Escriche, B. (2022). The use of *Bacillus thuringiensis* to control plant-parasitic nematodes. *Journal of Plant Science and Phytopathology*, *6*(2), 062–064. https://doi.org/10.29328/journal.jpsp.1001076

Bhaskar, M. V., Pramod, S. J., Jeevika, M. U., Chandan, P. K., & Shetteppa, G. (2010). MR imaging findings of neem oil poisoning. *American Journal of Neuroradiology*, *31*(7), E60–E61. https://doi.org/10.3174/ajnr.A2146

Bond, C., Buhl, K., & Stone, D. (2012). *Neem Oil General Fact Sheet*. National Pesticide Information Center, Oregon State University Extension Services. http://npic.orst.edu/factsheets/neemgen.html

Bond, C., Buhl, K., & Stone, D. (2014). *Pyrethrins General Fact Sheet*. National Pesticide Information Center, Oregon State University Extension. http://npic.orst.edu/factsheets/pyrethrins.html

Bravo, A., Gill, S. S., & Soberón, M. (2007). Mode of action of Bacillus thuringiensis Cry and Cyt toxins and their potential for insect control. *Toxicon: Official Journal of the International Society on Toxinology*, *49*(4), 423–435. https://doi.org/10.1016/j.toxicon.2006.11.022

Bravo, A., Likitvivatanavong, S., Gill, S. S., & Soberón, M. (2011). *Bacillus thuringiensis*: A story of a successful bioinsecticide. *Insect Biochemistry and Molecular Biology*, *41*(7), 423–431. https://doi.org/10.1016/j.ibmb.2011.02.006

Burdock, G. A., & Fenaroli, G. (2010). *Fenaroli's handbook of flavor ingredients* (6th ed). CRC Press/Taylor & Francis Group.

Buta, J. G., Lusby, W. R., Neal, J. W., Waters, R. M., & Pittarelli, G. W. (1993). Sucrose esters from *Nicotiana gossei* active against the greenhouse whitefly *Trialeuroides vaporariorum*. *Phytochemistry*, *32*(4), 859–864. https://doi.org/10.1016/0031-9422(93)85220-L

Caboni, P., Sarais, G., Angioni, A., Garcia, A. J., Lai, F., Dedola, F., & Cabras, P. (2006). Residues and persistence of neem formulations on strawberry after field treatment. *Journal of Agricultural and Food Chemistry*, *54*(26), 10026–10032. https://doi.org/10.1021/jf062461v

Campos, E. V. R., Oliveira, J. L. de, Pascoli, M., Lima, R. de, & Fraceto, L. F. (2016). Neem oil and crop protection: From now to the future. *Frontiers in Plant Science*, *7*, 1494. https://doi.org/10.3389/fpls.2016.01494

Cantrell, C. L., Dayan, F. E., & Duke, S. O. (2012). Natural products as sources for new pesticides. *Journal of Natural Products*, *75*(6), 1231–1242. https://doi.org/10.1021/np300024u

Castanheiro, J. (2021). Chitosan with sulfonic groups: A catalyst for the esterification of caprylic acid with methanol. *Polymers*, *13*(22), Article 22. https://doi.org/10.3390/polym13223924

Chaudhary, S., Kanwar, R. K., Sehgal, A., Cahill, D. M., Barrow, C. J., Sehgal, R., & Kanwar, J. R. (2017). Progress on Azadirachta indica based biopesticides in replacing synthetic toxic pesticides. *Frontiers in Plant Science*, *8*, 610. https://doi.org/10.3389/fpls.2017.00610

Chen, Y., Reinhardt, M., Neris, N., Kerns, L., Mansell, T. J., & Jarboe, L. R. (2018). Lessons in membrane engineering for octanoic acid production from environmental *Escherichia coli* isolates. *Applied and Environmental Microbiology*, *84*(19), e01285-18. https://doi.org/10.1128/AEM.01285-18

Chortyk, O. T., Pomonis, J. G., & Johnson, A. W. (1996). Syntheses and characterizations of insecticidal sucrose esters. *Journal of Agricultural and Food Chemistry*, *44*(6), 1551–1557. https://doi.org/10.1021/jf950615t

Christen, V., Krebs, J., Bünter, I., & Fent, K. (2019). Biopesticide spinosad induces transcriptional alterations in genes associated with energy production in honey bees (*Apis mellifera*) at sublethal concentrations. *Journal of Hazardous Materials*, *378*, 120736. https://doi.org/10.1016/j.jhazmat.2019.06.013

da Costa, J. T., Forim, M. R., Costa, E. S., De Souza, J. R., Mondego, J. M., & Boiça Junior, A. L. (2014). Effects of different formulations of neem oil-based products on control *Zabrotes subfasciatus* (Boheman, 1833) (Coleoptera: Bruchidae) on beans. *Journal of Stored Products Research*, *56*, 49–53. https://doi.org/10.1016/j.jspr.2013.10.004

Deng, X., Chen, L., Hei, M., Liu, T., Feng, Y., & Yang, G.-Y. (2020). Structure-guided reshaping of the acyl binding pocket of 'TesA thioesterase enhances octanoic acid production in *E. coli*. *Metabolic Engineering*, *61*, 24–32. https://doi.org/10.1016/j.ymben.2020.04.010

Desai, N., & Gruning, B. (1999). *Process for the preparation of sucrose fatty acid esters* (United States Patent No. US5945519A). https://patents.google.com/patent/US5945519A/en

Dively, G. P., Rose, R., Sears, M. K., Hellmich, R. L., Stanley-Horn, D. E., Calvin, D. D., Russo, J. M., & Anderson, P. L. (2004). Effects on monarch butterfly larvae (Lepidoptera: Danaidae) after continuous exposure to Cry1Ab-expressing corn during anthesis. *Environmental Entomology*, *33*(4), 1116–1125. https://doi.org/10.1603/0046-225X-33.4.1116

Duarte, J. P., Redaelli, L. R., Silva, C. E., & Jahnke, S. M. (2020). Effect of Azadirachta indica (Sapindales: Meliaceae) oil on the immune system of Spodoptera frugiperda (Lepidoptera: Noctuidae) immatures. *Journal of Insect Science*, *20*(3), 17. https://doi.org/10.1093/jisesa/ieaa048

Dusi, R. G., Morais, L. da S., Magalhães, N. M. G., Albernaz, L. C., Hamilton, C. J., & Espindola, L. S. (2022). Potential of garlic oil as a biopesticide against all *Aedes aegypti* life stages. *Industrial Crops and Products*, *181*, 114780. https://doi.org/10.1016/j.indcrop.2022.114780

Erban, T., Nesvorna, M., Erbanova, M., & Hubert, J. (2009). *Bacillus thuringiensis* var. *tenebrionis* control of synanthropic mites (Acari: Acaridida) under laboratory conditions. *Experimental and Applied Acarology*, *49*(4), 339–346. https://doi.org/10.1007/s10493-009-9265-z

Farone, W. A., & Serfass, R. W. (1998). *Sugar-ester manufacturing process* (United States Patent No. US5756716A). https://patents.google.com/patent/US5756716A/en?oq=US5756716A

Federici, B. A. (2003). Effects of Bt on non-target organisms. *Journal of New Seeds*, *5*(1), 11–30. https://doi.org/10.1300/J153v05n01_02

Figge, K., & Haigh-Baird, S. D. (1997). Biodegradation of sucrose poly fatty acid esters in soils. *Chemosphere*, *34*(12), 2621–2636. https://doi.org/10.1016/S0045-6535(97)00105-7

Gurav, H., & Bokade, V. V. (2010). Synthesis of ethyl acetate by esterification of acetic acid with ethanol over a heteropolyacid on montmorillonite K10. *Journal of Natural Gas Chemistry*, *19*(2), 161–164. https://doi.org/10.1016/S1003-9953(09)60048-7

Hertlein, M. B., Thompson, G. D., Subramanyam, B., & Athanassiou, C. G. (2011). Spinosad: A new natural product for stored grain protection. *Journal of Stored Products Research*, *47*(3), 131–146. https://doi.org/10.1016/j.jspr.2011.01.004

Hidzir, N., Abdullah, Z., & Md. Som, A. (2014). *Ethanol production via direct hydration of ethylene: A review*. International Conference on Global Sustainability and Chemical Engineering (ICGSE).

Hodoșan, C., Gîrd, C. E., Ghica, M. V., Dinu-Pîrvu, C.-E., Nistor, L., Bărbuică, I. S., Marin, Ștefan-C., Mihalache, A., & Popa, L. (2023). Pyrethrins and pyrethroids: A comprehensive review of natural occurring compounds and their synthetic derivatives. *Plants (Basel, Switzerland)*, *12*(23), 4022. https://doi.org/10.3390/plants12234022

Hu, J. S., Gelman, D. B., Salvucci, M. E., Chen, Y. P., & Blackburn, M. B. (2010). Insecticidal activity of some reducing sugars against the sweet potato whitefly, *Bemisia tabaci*, Biotype B. *Journal of Insect Science*, *10*, 203. https://doi.org/10.1673/031.010.20301

Hu, Y., Zhu, Z., Nielsen, J., & Siewers, V. (2019). Engineering Saccharomyces cerevisiae cells for production of fatty acid-derived biofuels and chemicals. *Open Biology*, *9*(5), 190049. https://doi.org/10.1098/rsob.190049

Huang, D., Jiang, X., Zhu, H., Fu, X., Zhong, K., & Gao, W. (2010). Improved synthesis of sucrose fatty acid monoesters under ultrasonic irradiation. *Ultrasonics Sonochemistry*, *17*(2), 352–355. https://doi.org/10.1016/j.ultsonch.2009.08.009

ISAAA Inc. (2024). *Advanced search—GM approval database: Sugar beets*. ISAAA. https://www.isaaa.org/gmapprovaldatabase/advsearch/default.asp?CropID=21&TraitTypeID=Any&DeveloperID=Any&CountryID=Any&ApprovalTypeID=Any

Ishida, T., Ogihara, Y., Ohashi, H., Akita, T., Honma, T., Oji, H., & Haruta, M. (2012). Base-free direct oxidation of 1-octanol to octanoic acid and its octyl ester over supported gold catalysts. *ChemSusChem*, *5*(11), 2243–2248. https://doi.org/10.1002/cssc.201200324

Javed, N., Anwar, S. A., Fyaz, S., Khan, M. M., & Ashfaq, M. (2008). Effects of neem formulations applied as soil drenching on the development of root-knot nematode *Meloidogyne javanica* on roots of tomato. *Pakistan Journal of Botany*, *40*(2), 905–910.

Jneid, R., Loudhaief, R., Zucchini-Pascal, N., Nawrot-Esposito, M.-P., Fichant, A., Rousset, R., Bonis, M., Osman, D., & Gallet, A. (2023). Bacillus thuringiensis toxins divert progenitor cells toward enteroendocrine fate by decreasing cell adhesion with intestinal stem cells in Drosophila. *eLife*, *12*, e80179. https://doi.org/10.7554/eLife.80179

Jurat-Fuentes, J. L., & Adang, M. J. (2004). Characterization of a Cry1Ac-receptor alkaline phosphatase in susceptible and resistant *Heliothis virescens* larvae. *European Journal of Biochemistry*, *271*(15), 3127–3135. https://doi.org/10.1111/j.1432-1033.2004.04238.x

Katada, N., II, Y., Nakamura, M., & Niwa, M. (2003). Oxidation of sulfur dioxide to sulfuric acid over activated carbon catalyst produced from wood. *Journal of The Japan Petroleum Institute - J JPN PET INST*, *46*, 392–395. https://doi.org/10.1627/jpi.46.392

Khater, H. F. (2012). Prospects of botanical biopesticides in insect pest management. *Pharmacologia*, *3*(12), 641–656.

Kilani-Morakchi, S., Morakchi-Goudjil, H., & Sifi, K. (2021). Azadirachtin-based insecticide: Overview, risk assessments, and future directions. *Frontiers in Agronomy*, *3*. https://doi.org/10.3389/fagro.2021.676208

Knight, P. J. K., Crickmore, N., & Ellar, D. J. (1994). The receptor for Bacillus thuringiensis CrylA(c) delta-endotoxin in the brush border membrane of the lepidopteran Manduca sexta is aminopeptidase N. *Molecular Microbiology*, *11*(3), 429–436. https://doi.org/10.1111/j.1365-2958.1994.tb00324.x

Koul, O., Singh, G., Singh, R., Middha, A., Walia, S., Shukla, P., & Kaul, V. K. (2012). Biorational glycol diesters as dietary toxins versus bioefficacy of sucrose octanoate against lepidopteran larvae. *Industrial Crops and Products*, *40*, 151–159. https://doi.org/10.1016/j.indcrop.2012.03.010

Krems Chem. (n.d.). *Fatty acid c8—Octanoic acid*. Krems Chem Austria. Retrieved November 20, 2024, from https://www.kremschem.com/en/products/fine-chemicals/speciality-fine-chemicals/fatty-acid-c8-octanoic-acid

Kumar, P., Madhu, K., Rituraj, B., Mahato, D. K., & Sharma, B. (2021). Bacillus thuringiensis as microbial biopesticide: Uses and application for sustainable agriculture. *Egyptian Journal of Biological Pest Control*, *31*(1). https://doi.org/10.1186/s41938-021-00440-3

Kundoo, A. A., & Khan, A. A. (2017). Coccinellids as biological control agents of soft bodied insects: A review. *Journal of Entomology and Zoology Studies*, *5*(5), 1362–1373.

Li, S., Song, Z., Liu, Z., & Bai, S. (2008). Characterization and insecticidal activity of sucrose octanoates. *Agronomy for Sustainable Development*, *28*(2), 239–245. https://doi.org/10.1051/agro:2007037

Liu, P., Chernyshov, A., Najdi, T., Fu, Y., Dickerson, J., Sandmeyer, S., & Jarboe, L. (2013). Membrane stress caused by octanoic acid in Saccharomyces cerevisiae. *Applied Microbiology & Biotechnology*, *97*(7), 3239–3251. https://doi.org/10.1007/s00253-013-4773-5

Liu, P., Choi, Y., Yang, Y., & White, M. G. (2010). Methanol synthesis from H2 and CO2 on a Mo6S8 cluster: A density functional study. *The Journal of Physical Chemistry A*, *114*(11), 3888–3895. https://doi.org/10.1021/jp906780a

Liu, T., Stansly, P. A., & Chortyk, O. T. (1996). Insecticidal activity of natural and synthetic sugar esters against Bemisia argentifolii (Homopetera: Aleyrodidae). *Journal of Economic Entomology*, *89*(5), 1233–1239. https://doi.org/10.1093/jee/89.5.1233

López, N., Puértolas, E., Condón, S., Raso, J., & Ignacio Álvarez. (2009). Enhancement of the solid-liquid extraction of sucrose from sugar beet (*Beta vulgaris*) by pulsed electric fields. *LWT - Food Science and Technology*, *42*(10), 1674–1680. https://doi.org/10.1016/j.lwt.2009.05.015

Loxdale, H. D., Balog, A., & Biron, D. G. (2020). Aphids in focus: Unravelling their complex ecology and evolution using genetic and molecular approaches. *Biological Journal of the Linnean Society*, *129*(3), 507–531. https://doi.org/10.1093/biolinnean/blz194

Martelli, F., Hernandes, N. H., Zhongyuan, Z., Wang, J., Ching-On, W., Karagas, N. E., Ute, R., Thusita, R., Robin, C., Kartik, V., Perry, T., Batterham, P., & Bellen, H. J. (2022). Low doses of the organic insecticide spinosad trigger lysosomal defects, elevated ROS, lipid dysregulation, and neurodegeneration in flies. *eLife*, *11*. https://doi.org/10.7554/eLife.73812

Mayes, M. A., Thompson, G. D., Husband, B., & Miles, M. M. (2003). Spinosad toxicity to pollinators and associated risk. *Reviews of Environmental Contamination and Toxicology*, *179*, 37–71. https://doi.org/10.1007/0-387-21731-2_2

McGaughey, W. H. (1985). Insect resistance to the biological insecticide Bacillus thuringiensis. *Science*, *229*(4709), 193–195. https://doi.org/10.1126/science.229.4709.193

McKenzie, C. L., & Puterka, G. J. (2004). Effect of sucrose octanoate on survival of nymphal and adult Diaphorina citri (Homoptera: Psyllidae). *Journal of Economic Entomology*, *97*(3), 970–975. https://doi.org/10.1603/0022-0493(2004)097[0970:eosoos]2.0.co;2

McKenzie, C. L., Weathersbee, A. A., & Puterka, G. J. (2005). Toxicity of sucrose octanoate to egg, nymphal, and adult *Bemisia tabaci* (Hemiptera: Aleyrodidae) using a novel plant-based bioassay. *Journal of Economic Entomology*, *98*(4), 1242–1247. https://doi.org/10.1603/0022-0493-98.4.1242

Michaud, J. P., & McKenzie, C. L. (2004). Safety of a novel insecticide, sucrose octanoate, to beneficial insects in Florida citrus. *The Florida Entomologist*, *87*(1), 6–9.

Miles, M., Mayes, M., & Dutton, R. (2002). The effects of spinosad, a naturally derived insect control agent, to the honeybee (Apis melifera). *Mededelingen (Rijksuniversiteit Te Gent. Fakulteit Van De Landbouwkundige En Toegepaste Biologische Wetenschappen)*, *67*(3), 611–616.

Mishra, A., & Dave, N. (2013). Neem oil poisoning: Case report of an adult with toxic encephalopathy. *Indian Journal of Critical Care Medicine: Peer-Reviewed, Official Publication of Indian Society of Critical Care Medicine*, *17*(5), 321. https://doi.org/10.4103/0972-5229.120330

Naranjo, S. E. (2009). Impacts of Bt crops on non-target invertebrates and insecticide use patterns. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *4*(11), 23.

Nawrot-Esposito, M.-P., Babin, A., Pasco, M., Poirié, M., Gatti, J.-L., & Gallet, A. (2020). Bacillus thuringiensis bioinsecticides induce developmental defects in non-target *Drosophila melanogaster* larvae. *Insects*, *11*(10), 697. https://doi.org/10.3390/insects11100697

NIH. (n.d.). *National Library of Medicine*. PubChem. https://pubchem.ncbi.nlm.nih.gov/compound/11430

NOP. (2005). *Sucrose octanoate esters technical report (Livestock)*. https://www.ams.usda.gov/sites/default/files/media/Sucrose%20TR%20Livestock.pdf

NOP. (2016). *NOP 5033-1: Decision tree for classification of materials as synthetic or nonsynthetic*. https://www.ams.usda.gov/sites/default/files/media/NOP-Synthetic-NonSynthetic-DecisionTree.pdf

NOSB. (2005). *Formal recommendation by the National Organic Standards Board (NOSB) to the National Organic Program (NOP): Sucrose octanoate esters*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP%20Rec%20Sucrose%20Octonate.pdf

NOSB. (2010a). *Formal recommendation by the National Organic Standards Board (NOSB) to the National Organic Program (NOP): Sunset review of National List substances (§205.603) allowed in livestock production*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP%20Final%20Rec%20Sunset%202012%20Rec%20Synthetic%20Substances%20Allowed%20in%20Organic%20Livestock.pdf

NOSB. (2010b). *Formal recommendation by the National Organic Standards Board (NOSB) to the National Organic Program (NOP): Reaffirmation of April 2010 NOSB sunset recommendations*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/NOP%20Crops%20Final%20Rec%20Reaffirming%20Prior%20Sunset%202012.pdf

NOSB. (2015). *Sunset 2017, NOSB final review. Livestock substances §§205.603-205.604*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/LS%202017%20Sunset%20Final%20Rvw_final%20rec.pdf

NOSB. (2018). *Formal recommendation from: National Organic Standards Board (NOSB) to: National Organic Program (NOP). Sunset review of substances at §205.603*. National Organic Program. https://www.ams.usda.gov/sites/default/files/media/LS2020SunsetFinalRecOct2018.pdf

OMRI. (2024). *OMRI Products Database* [Dataset].

Palma, L., Muñoz, D., Berry, C., Murillo, J., & Caballero, P. (2014). Bacillus thuringiensis toxins: An overview of their biocidal activity. *Toxins*, *6*(12), 3296–3325. https://doi.org/10.3390/toxins6123296

Pavia, D. L. (1995). *Organic Laboratory Techniques* (Third). https://d1wqtxts1xzle7.cloudfront.net/86524413/Organic_Laboratory_Techniques-libre.pdf?1653614508=&response-content-disposition=inline%3B+filename%3DOrganic_Laboratory_Techniques_Pavia_3RD.pdf&Expires=1732134222&Signature=QPsEJGvPM6Tv9WbhNgjNhVwlhL-QZeCi18kOqMs8u2ckZY2FNiut0IjgrkfL9Blo3ExIoqhpJtnMZfcqKYOCjubPivflSeAmgHV2dmUqBgnpKPAMWaIt-FhAJhjQj3ia23J~WKwmsrFZaAGh3ifkHJDoQS8WNY0ldvmMt4DtOqP2Ln~lqr967EQ4YrE6JF6l1SyJRDL7e1ljSTY1ZEqMCJEEAdfxWF3Fs2eDfCGyOp0CQWF6ieqPJU9yWvKF9kkrAM7sbyOVez15tnHIQH~t~M9xtfiov3XN9dWO9RMbTDYofUbQUpVOyPHNJvtgWmK0bO~iUZG51puDtfgevuRNwA__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA

Plata-rueda, A., Martínez, L. C., Santos, M. H. D., Fernandes, F. L., Wilcken, C. F., Soares, M. A., Serrão, J. E., & Zanuncio, J. C. (2017). Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae). *Scientific Reports (Nature Publisher Group)*, *7*, 46406. https://doi.org/10.1038/srep46406

PubChem. (n.d.). *Octanoic acid*. Retrieved November 12, 2024, from https://pubchem.ncbi.nlm.nih.gov/compound/379

Puterka, G. J., Farone, W., Palmer, T., & Barrington, A. (2003). Structure-function relationships affecting the insecticidal and miticidal activity of sugar esters. *Journal of Economic Entomology*, *96*(3), 636–644. https://doi.org/10.1603/0022-0493-96.3.636

Riemenschneider, W. (2000). Carboxylic Acids, Aliphatic. In Wiley-VCH (Ed.), *Ullmann's Encyclopedia of Industrial Chemistry* (1st ed.). Wiley. https://doi.org/10.1002/14356007.a05_235

Sanahuja, G., Banakar, R., Twyman, R. M., Capell, T., & Christou, P. (2011). Bacillus thuringiensis: A century of research, development and commercial applications. *Plant Biotechnology Journal*, *9*(3), 283–300. https://doi.org/10.1111/j.1467-7652.2011.00595.x

Schnepf, E., Crickmore, N., Van Rie, J., Lereclus, D., Baum, J., Feitelson, J., Zeigler, D. R., & Dean, D. H. (1998). Bacillus thuringiensis and its pesticidal crystal proteins. *Microbiology and Molecular Biology Reviews*, *62*(3), 775–806. https://doi.org/10.1128/mmbr.62.3.775-806.1998

Severson, R. F., Arrendale, R. F., Chortyk, O. T., Green, C. R., Thome, F. A., Stewart, J. L., & Johnson, A. W. (1985). Isolation and characterization of the sucrose esters of the cuticular waxes of green tobacco leaf. *Journal of Agricultural and Food Chemistry*, *33*(5), 870–875. https://doi.org/10.1021/jf00065a026

Severson, R. F., Arrendale, R. F., Chortyk, O. T., Johnson, A. W., Jackson, D. M., Gwynn, G. R., Chaplin, J. F., & Stephenson, M. G. (1984). Quantitation of the major cuticular components from green leaf of different tobacco types. *Journal of Agricultural and Food Chemistry*, *32*(3), 566–570. https://doi.org/10.1021/jf00123a037

Shannag, H. K., Capinera, J. L., & Freihat, N. M. (2015). Effects of neem-based insecticides on consumption and utilization of food in larvae of *Spodoptera eridania* (Lepidoptera: Noctuidae). *Journal of Insect Science*, *15*(1), 152. https://doi.org/10.1093/jisesa/iev134

Singh, T., Tiwari, Y., & Awasthi, G. (2019). Understanding the impact of Bacillus thuringiensis proteins on non-target organisms. *International Journal of Scientific Research in Biological Sciences*, *6*(2), 169–176.

Soderlund, D. M. (2012). Molecular mechanisms of pyrethroid insecticide neurotoxicity: Recent advances. *Archives of Toxicology*, *86*(2), 165. https://doi.org/10.1007/s00204-011-0726-x

Song, Z., Li, S., Chen, X., Liu, L., & Song, Z. (2006). Synthesis of insecticidal sucrose esters. *Forestry Studies in China*, *8*(3), 26–29. https://doi.org/10.1007/s11632-006-0019-2

Steinhauser, G. (2008). Cleaner production in the Solvay Process: General strategies and recent developments. *Journal of Cleaner Production*, *16*(7), 833–841. https://doi.org/10.1016/j.jclepro.2007.04.005

Sundaram, K. M. S., & Curry, J. (1994). Initial deposits and persistence of azadirachtin in fir and oak foliage after spray application of 'Margosan-O'® formulation. *Pesticide Science*, *41*(2), 129–138. https://doi.org/10.1002/ps.2780410209

Tabashnik, B. E., Fabrick, J. A., & Carrière, Y. (2023). Global patterns of insect resistance to transgenic Bt crops: The first 25 years. *Journal of Economic Entomology*, *116*(2), 297–309. https://doi.org/10.1093/jee/toac183

Tabashnik, B. E., Gassmann, A. J., Crowder, D. W., & Carriére, Y. (2008). Insect resistance to Bt crops: Evidence versus theory. *Nature Biotechnology*, *26*(2), 199–202. https://doi.org/10.1038/nbt1382

Tang, Y. Q., Weathersbee, A. A., & Mayer, R. T. (2002). Effect of neem seed extract on the brown citrus aphid (Homoptera: Aphididae) and its parasitoid *Lysiphlebus testaceipes* (Hymenoptera: Aphidiidae). *Environmental Entomology*, *31*(1), 172–176. https://doi.org/10.1603/0046-225X-31.1.172

Tedeschi, P., Leis, M., Pezzi, M., Civolani, S., Maietti, A., & Brandolini, V. (2011). Insecticidal activity and fungitoxicity of plant extracts and components of horseradish (Armoracia rusticana) and garlic (Allium sativum). *Journal of Environmental Science and Health. Part. B, Pesticides, Food Contaminants, and Agricultural Wastes*, *46*(6), 486–490. https://doi.org/10.1080/03601234.2011.583868

Tegelaar, K., Hagman, M., Glinwood, R., Pettersson, J., & Leimar, O. (2012). Ant–aphid mutualism: The influence of ants on the aphid summer cycle. *Oikos*, *121*(1), 61–66. https://doi.org/10.1111/j.1600-0706.2011.19387.x

The Non-GMO project. (2023). *The GMO high-risk list: Sugar beets*. Non-GMO Project. https://www.nongmoproject.org/blog/the-gmo-high-risk-list-sugar-beets/

The Sugar Assocation. (2017). *Gmo statement*. The Sugar Association. https://www.sugar.org/about/positions-principles/gmo-statement/

Tofel, K. H., Nukenine, E. N., Stähler, M., & Adler, C. (2016). Degradation of azadirachtin A on treated maize and cowpea and the persistence of *Azadirachta indica* seed oil on *Callosobruchus maculatus* and *Sitophilus zeamais*. *Journal of Stored Products Research*, *69*, 207–212. https://doi.org/10.1016/j.jspr.2016.08.011

Tomé, H. V. V., Barbosa, W. F., Martins, G. F., & Guedes, R. N. C. (2015). Spinosad in the native stingless bee *Melipona quadrifasciata*: Regrettable non-target toxicity of a bioinsecticide. *Chemosphere*, *124*, 103–109. https://doi.org/10.1016/j.chemosphere.2014.11.038

U.S. EPA. (2006a). *Sucrose Octanoate Esters (035300) Fact Sheet & Sorbitol Octanoate (035400)*. U.S. Environmental Protection Agency. https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_G-108_10-Jan-06.pdf

U.S. EPA. (2006b). *Biopesticides Registration Action Document: Octanoate Esters; Sucrose Octanoate Esters (PC Code 035300); Sorbitol Octanoate (PC Code 035400)*. U.S. Environmental Protection Agency. https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/decision_G-108_30-Mar-06.pdf

U.S. EPA. (2020). *Proposed registration decision for the new active ingredient sucrose octanoate esters pc code: 035300*. U.S. Environmental Protection Agency. https://downloads.regulations.gov/EPA-HQ-OPP-2020-0111-0003/attachment_1.pdf

Vadlamudi, R. K., Weber, E., Ji, I., Ji, T. H., & Bulla, L. A. (1995). Cloning and expression of a receptor for an insecticidal toxin of *Bacillus thuringiensis*(∗). *Journal of Biological Chemistry*, *270*(10), 5490–5494. https://doi.org/10.1074/jbc.270.10.5490

Valaitis, A. P., Jenkins, J. L., Lee, M. K., Dean, D. H., & Garner, K. J. (2001). Isolation and partial characterization of gypsy moth BTR-270, an anionic brush border membrane glycoconjugate that binds Bacillus thuringiensis Cry1A toxins with high affinity. *Archives of Insect Biochemistry and Physiology*, *46*(4), 186–200. https://doi.org/10.1002/arch.1028

Wagner, F. W., Dean, A., & Stryker, V. H. (1991). *Separation and purification of sugar esters*.

Wernig, F., Baumann, L., Boles, E., & Oreb, M. (2021). Production of octanoic acid in *Saccharomyces cerevisiae*: Investigation of new precursor supply engineering strategies and intrinsic limitations. *Biotechnology and Bioengineering*, *118*(8), 3046–3057. https://doi.org/10.1002/bit.27814

Wrona, O., Rafińska, K., Możeński, C., & Buszewski, B. (2017). Supercritical fluid extraction of bioactive compounds from plant materials. *Journal of AOAC INTERNATIONAL*, *100*(6), 1624–1635. https://doi.org/10.5740/jaoacint.17-0232

Xiang, J.-C., Gao, Q.-H., & Wu, A.-X. (2017). The Applications of DMSO. In *Solvents as Reagents in Organic Synthesis* (pp. 315–353). John Wiley & Sons, Ltd. https://doi.org/10.1002/9783527805624.ch7

Yan, Q., & Pfleger, B. F. (2020). Revisiting metabolic engineering strategies for microbial synthesis of oleochemicals. *Metabolic Engineering*, *58*, 35–46. https://doi.org/10.1016/j.ymben.2019.04.009

Yu, L., Berry, R. E., & Croft, B. A. (1997). Effects of *Bacillus thuringiensis* toxins in transgenic cotton and potato on *Folsomia candida* (Collembola: Isotomidae) and *Oppia nitens* (Acari: Orbatidae). *Journal of Economic Entomology*, *90*(1), 113–118. https://doi.org/10.1093/jee/90.1.113

Zhang, Q.-W., Lin, L.-G., & Ye, W.-C. (2018). Techniques for extraction and isolation of natural products: A comprehensive review. *Chinese Medicine*, *13*(1), 20. https://doi.org/10.1186/s13020-018-0177-x