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.

Pear Ester

Crops

Identification of Petitioned Substance

Chemical Names:
2,4-decadienoic acid, ethyl ester, (E,Z)
ethyl-(2E,4Z)-decadienoate
ethyl-2E,4Z-decadienoate
ethyl-(E,Z)-2,4-decadienoate
ethyl trans-2, cis-4-decadienoate

Other Names:
pear ester

Trade Names:
Cidetrak® DA MEC™ (EPA Reg. No. 51934-12)
Cidetrak® CMDA 90/60 (EPA Reg. No. 51934-13)
Cidetrak® CMDA Combo (EPA Reg. No. 51934-16)
Cidetrak® CMDA + LR (EPA Reg. No 51934-18)
Cidetrak® CMDA + OFM Meso (EPA Reg. No. 51934-21)

CAS Numbers:
3025-30-7

Other Codes:
FEMA No. 3148
BRI Product Code 433
OPP Code 144022

Summary of Petitioned Use

This full scope technical report provides information to the National Organic Standards Board (NOSB) in support of its review of pear ester. In September 2023, Trécé, Inc. submitted a petition for 2,4-decadienoic acid, ethyl ester, (E,Z), also known as pear ester, to be included as a crop pesticide material on the National List of Allowed and Prohibited Substances (hereafter referred to as "The National List") (Trécé, Inc., 2023). The petitioner requested that pear ester be included at 7 CFR 205.601 as a synthetic substance for use in monitoring, mating disruption, and [pest] control products.

While pheromones are listed at § 205.601(f) for insect management, pear ester acts as a kairomone (Trécé, Inc., 2023). Pheromones are chemical signals produced by plants or other organisms that are detected by members of the same species, whereas kairomones are chemical signals produced by plants or other organisms that are detected by a different species, often insects. Detection of kairomones produced by a plant leads to a fitness benefit for insects, such as avoiding a predator or finding a suitable host plant. According to the petitioner, synthetic pear esters are identical to the naturally occurring kairomones produced by pears and other fruit. The petitioner states that pear ester attracts codling moths to monitoring traps, helping pest control advisors track them. In turn, this information is used to help crop producers apply pesticides at the right time. Also, pear ester can be used to enhance the effect of other pheromones used in mating disruption controls (Trécé, Inc., 2023).

Characterization of Petitioned Substance

Composition of the Substance:

Pear ester (CAS No. 3025-30-7) is the ethyl ester of 2E,4Z-decadienoic acid (see *Figure 1*, below).

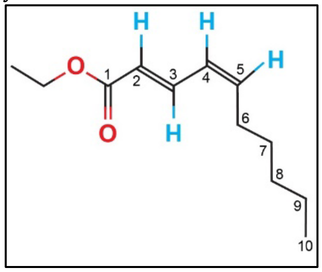

Figure 1: Chemical structure of pear ester. By convention, the carbon joining the two oxygen atoms (part of the carboxylic-ethyl ester acid group) is carbon number one. There is a double bond between carbons 2 and 3, and between carbons 4 and 5. When priority groups are on the same side, it is called cis-, or Z for Zusammen. The double bonds force the molecule into a planar configuration near those bonds.

Pear ester has moderate chemical stability, but the double bonds between carbon atoms are vulnerable to oxidation and photodegradation. Acids or bases can hydrolyze the ethyl ester, releasing ethanol and 2E, 4Z-decadienoic acid to the environment (US EPA, 2013).

Source or Origin of the Substance:

Pear ester was first isolated from ripe Bartlett pears (Jennings et al., 1964). The original experiments that identified pear ester as a kairomone used pear extracts (Light et al., 2001). Commercial pear essence contains about one-third pear ester by weight (Tucker et al., 2003). Pear ester used in commercial pest control formulations is produced by chemical synthesis (Light et al., 2017; Trécé, Inc., 2023; Tsubi et al., 1993). (Kairomone is defined in *Action of the Substance*.)

Properties of the Substance:

Pear ester is a colorless to slightly yellow liquid at room temperature and normal atmospheric pressure. It has the odor of ripe Bartlett pears. It has a high boiling point and a low melting point, and thus maintains its liquid form under extreme environmental conditions. It has a low solubility in water and is less dense than water (US EPA, 2013).

The octanol/water partition coefficient is about 4.4, and pear ester is about 10,000 times more soluble in octanol than in water (US EPA, 2013).[1] The high solubility of pear ester in lipid-like substances allows it to penetrate codling moth receptor structures with ease.

The vapor pressure of the pure substance is low, but because it has a relatively large Henry's constant, 7.54 x $10^{(-4)}$ atm-m^3/mol, it has a moderate volatility from sprays.[2] A saturated solution of pear ester in water at 25° C has a volatility near that of water. Because of its volatility, pear ester dissipates quickly in the environment. Manufacturers encapsulate volatile components of spray formulations to limit volatilization and produce products that have a lasting effect (US EPA, 2013).

Pear ester has a vapor density 6.8 times that of air. That means that when dispensers or sprays are added to tree canopies, pear ester vapors drift downward toward the base of the tree (Boudakian Research, 2023; US EPA, 2013).

[1] When a test substance is added to a mixture of octanol and water, some dissolves in octanol and the rest dissolves in water. The ratio of the concentration in octanol to the concentration in water is the partition coefficient, Kow. It is usually reported as a logarithm, logKow.

[2] In other words, pear ester evaporates more readily in field conditions than its vapor pressure alone would indicate.

Table 1: Properties of pear ester

Property	Value[a]
Physical state and appearance	Liquid at 25 °C
Odor	Odor of Bartlett pears
Taste	Not available
Color	Colorless to slight yellow
Molecular weight	196.28 g/mole
Specific gravity	0.905
pH	Not available
Solubility	8.588 mg/liter at 25 °C
pKa	Not available
pKb	Not available
Boiling point	248.8 °C (SDS); 258.4 °C (EPA)
Melting point	-60.3 °C
Critical temperature	Not available
Vapor pressure	0.0173 mm Hg at 25° C
Stability	Stable under normal conditions
Reactivity	Reacts with oxidizing agents, acids, and bases
Vapor density	6.8 times that of air
Partition coefficient octanol/water	4.36
Volatility from saturated solution in water	23.8 mm Hg at 25°C

Source: (Boudakian Research, 2023; US EPA, 2013)

<u>Specific Uses of the Substance:</u>

Pear ester is used in the control of insect pests, namely the codling moth, *Cydia pomonella* – an economically significant pest that principally affects apple, pear, and walnut crops (Trécé, Inc., 2023).

The codling moth has four life stages: adults, eggs, larvae, and pupae. The life cycle is synchronized with the weather by larval diapause, a form of hibernation. Larvae go into diapause in August and overwinter in this form. In late winter, they pupate, and emerge as adults in the early spring (Quarles, 1997; Steiner, 1940; Van Leeuwen, 1940; Witzgall et al., 2008).

Within a week after emergence from pupae as adults, mating is complete. Females lay up to 100-130 eggs, as isolated eggs, never as clusters, near developing fruit. Most of the reproductive activity associated with this first flight of adults is over by the end of April. There are a total of three flights each year in most areas (Quarles, 1997; Steiner, 1940; Van Leeuwen, 1940; Witzgall et al., 2008).

The larvae damage fruit by chewing their way inside. Once inside, the fruit is unmarketable (Caprile & Vossen, 2011).

Pear Ester and Monitoring/Timing

Pear ester can be used as a lure in traps to monitor populations of codling moth in orchards (Light et al., 2001). Successful monitoring can then be used to determine the timing and set action thresholds for treatments (Knight & Light, 2005).

Farmers and pest control professionals hang monitoring traps in orchards each year before mating populations of the codling moth emerge from their pupae in March (University of California Statewide IPM Program, 2015). The date of the first appearance of a codling moth in a monitoring trap is called the "biofix point." In California apple orchards, adults start to fly mid-March to early April, and the biofix point is during this time (trees bloom mid-April to mid-May) (University of California Statewide IPM Program, 2015).

Monitoring traps are baited with pheromones or pheromone-pear ester combinations. Combining pheromones with pear ester increases the number of male insects that are attracted to the trap (Joshi et al., 2011) (see Focus Question #1).

The biofix point is used to time insecticide applications or the start of pheromone mating disruption treatments. Approximately one month after the biofix point, insecticide sprays are applied to kill hatching larvae. The exact time for insecticide application is determined by measuring daily temperatures (Caprile & Vossen, 2011). *Evaluation Question #11* describes this timing in more detail.

Mating disruption programs must be started no later than the biofix point. Once mating disruption has started, monitoring traps with pheromone lures are no longer useful. At this point, the air is saturated with pheromones, and moths cannot find the traps. In contrast to pheromone traps, monitoring traps containing kairomones such as pear ester make it possible for farmers and pest control professionals to check the effectiveness of mating disruption (Knight, 2010; Knight et al., 2014, 2019; Trécé, Inc., 2023).

In California, the first flight of the codling moth is complete and the first generation of eggs laid by the time apple trees flower in April and May. Because the codling moth has two to three more mating flights in a season, further treatment may be needed. According to Integrated Pest Management experts, traps containing pear ester, and perhaps other kairomones, are essential to determine when to apply treatments (Caprile & Vossen, 2011; University of California Statewide IPM Program, 2015).

Traps baited with pear ester lures can also be used for mass trapping, to remove egg-laying females from orchards (Knight et al., 2022).

Pear Ester and Mating Disruption

Pear ester is also used as part of codling moth mating disruption treatments. Although pheromones alone are used, pheromones combined with a simultaneous release of pear ester may be more effective (Light et al., 2017) (see also *Focus Question #1*). These mating disruption treatments can be applied in two ways: via plastic dispensers or as microencapsulated cover sprays (University of California Statewide IPM Program, 2015). PVC dispensers have two reservoirs, one for the codling moth sex pheromone codlemone, (E, E)-8,10-dodecadien-1-ol (CAS No. 33956-49-9), and one for pear ester. Both materials passively diffuse from the dispensers into the air. There are standard dispensers and larger, "meso" dispensers that hold more active ingredient (Trécé, Inc., 2023).

Commercial formulations are described in *Combinations of the Substance*. Emission characteristics of pear ester from these dispensers are discussed below. Mating disruption dispensers loaded both with codling moth sex pheromone and pear ester can be more effective for mating disruption than dispensers with pheromone alone (Light et al., 2017) (see *Focus Question #1*).

Microencapsulated sprays of pear ester can also improve the effectiveness of mating disruption, can make some insecticides more effective (Light et al., 2017), and can even prevent fruit damage as a standalone spray (Kovanci, 2015). The commercial spray, DA MEC™, is a concentrated aqueous solution containing 5% microencapsulated pear ester (50 mg pear ester/ml) with 95% water and other inerts. Pure pear ester is encapsulated inside tiny, rigid, spherical, semipermeable plastic capsules of polyamide (Dietrich et al., 1989; Light & Beck, 2010). Their particle size ranges from 2 to 14 µm, but 68% of the capsules are less than 3 µm in diameter. The capsules are then added to an aqueous solution of coformulants and inerts to produce a final concentration of 5% pear ester (Cidetrak, 2020; Light & Beck, 2010).

DA MEC™ is usually applied at the rate of 12 ml/acre or 30 ml/ha. It is diluted in 100 gallons of water per acre before spraying (1 to 32,000 dilution). About 600 mg microencapsulated pear ester is applied per acre, or 1.5 g/ha. Air blast sprayers are used to spray tree canopies, and the diluted spray contains about 259,000 particles microencapsulated pear ester per ml. Though the usual spray is 12 ml DA MEC™/acre, the label allows single applications up to 70 ml/acre (3.5 g pear ester/acre). Repeated applications are limited to 12 ml, and the maximum allowed is 96 ml/acre/year (4.8 g pear ester/acre/year) (Cidetrak, 2020; Light & Beck, 2010).

For combined treatments, DA MEC™ is tank mixed with an insecticide or with a sprayable microencapsulated codlemone formulation (Cidetrak, 2020; Light & Beck, 2010).[3]

Emission characteristics of pear ester from dispensers and microencapsulated sprays are discussed below.

Emission Rates from Dispensers

The natural pear ester release rate from maturing Bartlett pears in an orchard is 3.7 g/acre/month (Trécé, Inc., 2023). An average month is about 30 days, so a pear orchard releases about 0.12 g/acre/day or about 120 mg/acre/day.

Release rates of pear ester from dispensers vary with temperature. Also, the amounts released are proportional to concentration, and emission rates drop with time. A standard formulation is Cidetrak CMDA 90/60 meso dispensers. For apples, these dispensers contain 900 mg codlemone and 600 mg of pear ester. For walnuts they contain 1440 mg codlemone and 960 mg of pear ester (Cidetrak, 2014).

Knight & Light (2014) measured the emission rates from these meso dispensers in apple orchards in 2011 and again in 2012. When averaged over the two-year period, emission rates for the first 74 days averaged 4.07 mg/day/dispenser. Those left for an additional 69 days lost an average 2.28 mg/day/dispenser (Knight & Light, 2014). Dispensers were in the field for an average of 143 days. Based on these averages we calculated the following emission rates that appear in *Table 2*, using the meso dispenser formulation and set up described by Cidetrak (2014).

Table 2: Approximate emission rates from pear ester dispensers

Application Parameters	Apples and pears	Walnut [c]
Maximum Meso Dispensers Set Up per Acre[a]	40	32
Dispenser pear ester Content[a]	600 mg	960 mg
Average Emission Rate: Day 1-74	4.07 mg/day/dispenser[b]	6.5 mg/day/dispenser
Calculated Maximum Average Emission Rate: Day 1-74	163 mg/acre/day	208 mg/acre/day
Average Emission Rate: Day 75-143	2.28 mg/day/dispenser[b]	3.65 mg/day/dispenser
Calculated Maximum Average Emission Rate: Day 75-143	91 mg/acre/day	117 mg/acre/day
Average Emission Rate: Overall 143 Day Treatment	127 mg/acre/day	162 mg/acre/day

[a] As described by (Cidetrak, 2014).
[b] Knight & Light (2014) measured the emission rates from these meso dispensers in apple orchards in 2011 and again in 2012. Calculations are averaged from data collected during the two experiment years.
[c] The numbers cited by Knight et al. (2014), 4.07 mg/day/dispenser (74 days) and 2.28 mg/day/dispenser (69 days) were for apple dispensers containing 600 mg pear ester. The theoretical calculations indicated here use the walnut dispenser formulation and assume emissions in walnut are proportional to those in apple.

In summary, maximum average emissions (74 days) in apple are 163 mg/acre/day and maximum average emissions (74 days) in walnuts are 208 mg/acre/day. Maximum average emissions in apple are 35.8% higher than natural pear orchards (120 mg/acre/day) and maximum average emissions in walnut are 73.3% higher.

The figures above are for one application of the dispensers. The label allows more than one application a year up to a maximum of 100 dispensers/acre/year for apple. That is an annual maximum of 60 grams/acre/year for pear ester and 90 grams/acre/year for codlemone, the sex pheromone. For walnuts, a maximum of about 62 dispensers/acre are allowed. Since pear ester emissions are degraded quickly and do not bioaccumulate, the exposure figures for one application of dispensers are a reasonable estimate of exposure (Cidetrak, 2014; US EPA, 2013).

Potency of Emissions

Pear ester is an extremely potent codling moth disruptant. It compares favorably with the codling moth sex pheromone, codlemone. The airborne concentration of codlemone needed to produce mating disruption in

[3] Sex pheromone of the codling moth.

apple orchards is 10 mg/ha/hr. or about 4.0 mg/acre/hr. (Howell et al., 1992). The average minimum amount of pear ester needed for behavioral disruption in an apple orchard was calculated above as 3.7 mg/acre/hr. These are the emissions from dispensers late in the season when concentrations in the dispenser are lower (Knight & Light, 2014).

Emission Rates from Sprays

Light & Beck (2010) measured neonate response to field application rates of DA MEC™ (1/32,000 dilution) in the laboratory. Assays during the first 14 days after the emergence of codling moth larvae showed that larvae spent more time in treated areas than on water controls. After 20 days, there was no significant difference in time spent. Based on this information, sprays are likely effective for 14 days.

Label spray rates of DA MEC™ are usually 600 mg pear ester/acre (Light & Beck, 2010). If sprays are effective for 14 days, average exposure over this time would be 42.8 mg pear ester/acre/day. A more accurate assessment involves measuring volatilization rates. Light & Beck (2010) measured emission rates of diluted DA MEC™ in the laboratory. They found that rates followed first order kinetics, where emission rates are proportional to amounts, which are higher at first, then decay exponentially with time.

The emissions from field application rates (1/32,000 dilution) were too small to be measured accurately. Light & Beck (2010) approximated field emission rates with two dilutions: 1/1000 and 1/3200. An exponential fit to the 1/3200 dilution is expected for first order kinetics, gives a good correlation with the data, and is used to calculate the estimates in Table 3. Light & Beck (2010) also used a power decay model with a higher correlation, but similar results.

Table 3: Approximate emission rates from pear ester sprays

Application rate	Emission rate	Equivalency compared to pear ester emissions from a pear orchard
Minimum label application (12 ml/acre)	Maximum 1-day Emission rate 86.4 mg/acre/day [b]	72%
Maximum label application (70 ml/acre)	250 mg/acre/day, Average Daily Emission for 14 days	208%
Maximum label application (70 ml/acre) [d]	504 mg/acre/day, Maximum 1-day Emission rate	400%

[a] Equivalencies are evaluated in comparison to the natural emissions rate of pear ester from pear orchards, 120 mg/acre/day (Trécé, Inc., 2023).
[b] Based on the work of Light & Beck (2010) the initial emission rate was 166.16 picograms per hour (pg./hr.). After 24 hrs., the rate is 142.1 pg./hr. The percent reduction is 14.4%. Emission rate is proportional to amount, and DA MEC™ field sprays contain 600 mg pear ester/acre. Therefore, 14.4% or 86.4 mg/acre volatilizes in 24 hours. The maximum exposure from these sprays is 86.4 mg/acre/day.
[c] After two weeks, 88.8% of the pear ester from the sprays is gone. Because of the relatively quick depletion, the label allows sprays every two weeks. The exposure, if all the spray volatilizes over the course of two weeks, is 42.8 mg/acre/day.
[d] The maximum 70 ml application can only be used once a year (Cidetrak, 2020).

The worst-case scenarios for the usual application, 86.4 mg pear ester/acre/day for maximum exposure, and 42.8 mg pear ester/acre/day for average exposure, will be used throughout this document (Kovanci, 2015; Light & Beck, 2010; Trécé, Inc., 2023). The greatest exposure possible is not from dispensers, but from maximum label use of DA MEC™ spray: 504 mg/acre/day, maximum one-day exposure, and 250 mg/acre/day, the maximum average over two weeks (Cidetrak, 2020; Light & Beck, 2010).

<u>Approved Legal Uses of the Substance:</u>

Pear ester appears on the FDA list of Substances Added to Food (*formerly EAFUS*) for use as a flavoring agent or adjuvant food additive (US FDA, 2024).

The EPA has registered pear ester formulations as pest control products (see *Combinations of the Substance* for a list of registered products). The EPA has also determined that, because of low toxicity, pear ester is exempt from the requirement of a tolerance for residues in or on food crops at 40 CFR 180.1323.

Action of the Substance:

Pear ester can (Hughes et al., 2003; Light et al., 2001; Light & Beck, 2012):

- improve codling moth monitoring.
- enhance mating disruption.
- disrupt egg laying.
- confuse larvae, making it harder for them to find, infest, and damage fruit.

Pear ester is a type of semiochemical called a kairomone. Semiochemicals are bioactive molecules released by an organism to signal or provoke a behavioral or physiological response (Klassen et al., 2023). Signaling may be between members of the same species or between two or more different species. Pheromones are released for communication between members of the same species. Kairomones convey communication signals between two or more different species (Klassen et al., 2023).

Adult males, adult females, and larvae have receptors for pear ester and separate receptors for the codling moth pheromone, codlemone (Ansebo et al., 2004; Light et al., 2017). When both types of receptors are activated, neural integration occurs in the moth brain.[4] Behavioral priority is given to this kind of signal, making combinations of pear ester and pheromones powerful drivers of codling moth behavior (Ansebo et al., 2004; Light et al., 2017). Pear ester can be detected in extremely small quantities by both adult male and female codling moths and larvae (Light et al., 2001). For instance, electroantennogram tests show detection at 7.9 nanograms (Light et al., 2001).[5]

Monitoring Traps

Codling moths are attracted in the field by traps baited with one microgram of pear ester. This amount is also the threshold detection dose for codlemone. High potency and field stability make pear ester valuable for pest management (Light et al., 2001).

As a kairomone and not a sex pheromone, pear ester lures both male and female codling moths, and both mated and unmated females. Because of this, traps baited with pear ester can capture both males and females (including mated and unmated moths). Since egg-laying females are attracted, monitoring traps can be used to more effectively establish action thresholds for Integrated Pest Management treatments (Knight & Light, 2005).

Pear ester traps do have limitations. They are most effective in walnut orchards, about half as effective in apple orchards, and not very effective in pear orchards (Light et al., 2001). In pear orchards, traps are overwhelmed with plant volatiles from the ripening crops. The disadvantage can be overcome by using lures with larger amounts of pear ester or by the addition of other kairomones (Knight et al., 2019).

Farmers and pest control professionals usually monitor codling moths using sex pheromone (like codlemone) lures, but the sex pheromone only attracts males (Light et al., 2001). Where mating disruption products are used, air saturation with pheromone makes it difficult for male codling moths to find the monitoring trap. In situations like this, pear ester is especially useful for monitoring codling moths (Light et al., 2001).

Combination Lures in Monitoring Traps

Knight et al. (2005) combined pear ester with codlemone to monitor codling moth in apples. Knight & Light (2005) used combinations of pear ester and codlemone to develop action thresholds for codling moth mating disruption treatments in apple orchards.

[4] Neural integration refers to a process by which neurons process different stimuli. Integration can lead to an increased or decreased probability that a neuron will fire.

[5] Insect antennae have chemical receptors. When a receptor is activated, an electrical nerve response is generated that can be amplified and measured.

Later experiments showed that monitoring with pear ester and codlemone combinations could be improved by the addition of acetic acid (Knight, 2010). Trials of added acetic acid and a number of other kairomones, such as farnesene, showed that lures could be formulated to attract other moth pests, such as:

- oriental fruit moth, *Grapholita molesta*
- the leafroller, *Pandemis pyrusana*
- obliquebanded leafroller, *Choristoneura rosaceana*
- eyespotted budmoth, *Spillonota ocellana*

Traps baited with pear ester, codlemone, and glacial acetic acid were effective for monitoring codling moth and the other leafroller species (Knight et al., 2014) (see *Focus Question #1*).

The addition of various volatile terpenoids to lures containing pear ester and acetic acid, but no sex pheromones, enhanced the capture of female codling moths by about three-fold (Knight et al., 2019).

Knight et al. (2014) monitored pome and stone fruit orchards for codling moth and oriental fruit moth populations simultaneously using lures that contained pear ester, other kairomones, glacial acetic acid, codlemone, and the oriental fruit moth sex pheromone. In another study, Knight et al. (2023) added LED lights to previous pear ester monitoring combinations to increase the number of codling moths captured.

Monitoring to Determine Effectiveness of Mating Disruption

When used in combination with codlemone in mating disruption dispensers, or in microencapsulated sprays, pear ester can enhance the effectiveness of mating disruption (Light et al., 2017). There are several measures of effectiveness. Monitoring traps baited with codlemone pheromone are used most often. The fewer moths trapped, the more effective the disruption. High levels of the mating disruption pheromone make it difficult for males to locate the traps, resulting in trap shutdown. Monitoring traps baited with tethered females are also used (Stelinski et al., 2013).

A more conclusive result is achieved by using monitoring traps baited with pear ester to catch females. The fewer mated females caught, the more effective the mating disruption (Knight, 2006). A practical measure is the amount of fruit damage. The less damage, the more effective the mating disruption. Of all the possible measurements of effectiveness, the easiest is trap shutdown, and the most important, from a grower standpoint, is the amount of fruit damage (Kovanci, 2015).

Limitations of Mating Disruption

Female moths release a sexual pheromone into the air (Witzgall et al., 2008). As the pheromone plume drifts over an orchard, males sense it and fly toward the female. Mating disruption treatments release relatively large amounts of pheromone, making it harder for males to find females. Large initial populations can work against mating disruption treatments. When populations are large, males can find females with visual cues. Farmers and pest control professionals sometimes use an insecticide treatment before starting a mating disruption program (Witzgall et al., 2008).

Immigration of already mated females from a nearby orchard can also overcome mating disruption treatments. If possible, the nearest orchard should be more than 400 m away. Border sprays of insecticides are sometimes used to limit immigration (Rothschild, 1982).

Sex pheromone treatments need to have uniform concentration throughout an orchard. If there are dead spots in the distribution, mating can occur in that area. There can also be problems with patchy codling moth distribution. Females prefer to lay eggs on trees that have the most fruit. When larvae pupate, males are already in the area waiting for females to emerge (Light et al., 2017; Witzgall et al., 2008).

Mating disruption is not mating prevention. According to Light et al. (2017), experiments have shown untreated apple orchards have 73-90% mated females, and orchards utilizing conventional pest controls have >77% mated females. When mating disruption treatments use pheromone only, 58-85% of females are mated, whereas mating disruption with combined pheromone and pear ester results in 64-71% mated females (Light et al., 2017) (see *Combinations of the Substance*).

To protect against fruit damage, it is not necessary to completely disrupt all mating (Jones et al., 2008). Just a delay in mating can reduce pest populations and damage. When female mating is delayed more than two days, there is a reduction in population density because the female is older and lays fewer eggs. Fewer eggs results in less fruit damage (Jones et al., 2008). Witzgall et al. (2008) report damage levels of 0.03 to 0.8% for California apple orchards using area-wide pheromone mating disruption.

Pear ester is a useful addition to Integrated Pest Management programs because it gives another layer of protection. If moths successfully mate and start laying eggs, pear ester confuses females that prefer to lay eggs near ripening fruit. Misplaced eggs lead to less fruit damage (Hughes et al., 2003). If eggs successfully hatch, larvae are also confused by pear ester and have trouble finding their way to fruit (Light & Beck, 2012).

Mating Disruption Dispensers

Pear ester has been combined with codlemone in mating disruption dispensers. At high doses of all substances, the combination is more effective than codlemone alone (Knight, Light, et al., 2012). Initial experiments using this combination, with codlemone concentrations near those of commercial products such as Isomate or Checkmate, often outperformed the commercial products. For instance, when codling moth activity was monitored with female-baited traps, combo dispensers containing 45 mg codlemone and 110 mg pear ester, or 45/75 or 75/45 ratios, were more effective for mating disruption in several cases than Isomate-C Plus containing 96.5 mg codlemone (Knight, Light, et al., 2012).

Mating Disruption Sprays

Pear ester microencapsulated formulations (DA MEC™) have been mixed with sprayable microencapsulated versions of codlemone. Kovanci (2015) compared DA MEC™ sprays with these pheromone sprays (PH MEC), or the two combined (combo) in apple orchards under high codling moth pressure. Late season fruit damage in untreated orchards was 25-36%. Each treatment was applied four times during the season. Sprays used 5 g DA MEC™ and 25 g PH MEC per hectare. Combo sprays were applied both in the label amount of water (635 liters/ha), and in Ultra Low Volume (ULV) (40 liters/ha).

Combined sprays were more effective in producing mating disruption than either pear ester or codlemone alone. Traps were baited with lures containing 3 mg pear ester, 3 mg of codlemone, or a combo of both, and were monitored weekly. DA MEC™ reduced trap captures 43%, PH MEC had a 61% reduction, and the combo had an 85% reduction, indicating that the combo yields the most effective mating disruption.

In the same study (Kovanci, 2015), more mated females (70%) were trapped with DA MEC™ than with PH MEC (57.5%) or the combo (68.8%), but the differences were not statistically significant. Late season pre-harvest fruit damage was reduced 54% by DA MEC™ alone, but reduction with PH MEC or the combo was 72%. Live larvae were reduced 65% by DA MEC™, 84% by PH MEC, and 85% by the combo. The combo was no more effective than sex pheromone alone (PH MEC) in reducing fruit damage. These figures are for the normal, high-volume spray. Fruit damage was reduced 93% by ULV combo sprays. Combo sprays were more effective than sex pheromone alone in reducing fruit damage only with ULV applications (Kovanci, 2015).

Insecticidal Sprays

DA MEC™ has also been tank-mixed with insecticides. Knight & Light (2013) tested microencapsulated pear ester sprays, later registered as DA MEC™, mixed with sprayable insecticides in apples. The sprayable pear ester improved efficacy of insecticides, such as phosmet, that work by contact with toxic residues. In apple orchards, combinations of pear ester and spinosad had 35.5% less damage than spinosad alone. Addition of pear ester to organophosphates and neonicotinoids led to a further reduction in damage of more than 50% (Knight & Light, 2013). Effects were lowered with insecticides that work through ingestion. Codling moth granulosis virus, which must be ingested, was not more effective at reducing damage to apple crops when combined with pear ester (Arthurs et al., 2007).

Combined sprays have shown to be more effective in walnuts (Light & Knight, 2011) than in apple or pear orchards (Knight & Light, 2013). In one study, pear ester sprays did increase the effectiveness of codling moth granulosis virus in walnuts (Light & Knight, 2011), but had little effect in apple or pear (Arthurs et al., 2007). Pear ester combinations with organophosphates or Insect Growth Regulators (IGRs) were also more effective in walnuts (Knight & Light, 2013).

Light & Knight, (2011) tested combinations of insecticides and pear ester sprays in walnut orchards. Sprays of 1.8 g pear ester/ha led to a significant reduction in codling moth kernel damage when compared to insecticide sprays alone. The additional reductions were 83% for chlorpyrifos, 76% for phosmet, 49% for methoxyfenozide, and 39% for codling moth granulosis virus. Significant reductions in kernel damage from the navel orangeworm were also seen with the combinations.

Action of Microencapsulated Sprays

Codling moth life stages are adults, eggs, larvae, and pupae. Codling moth larvae are the actual orchard pests. After hatching, they immediately try to find fruit, chewing their way inside—the proverbial worm in the apple (Light et al., 2001). Sprays of microencapsulated pear ester cause first instar larvae to spend more time walking around on leaves.[6] Due to this, they are less able to find fruit to infest (Hughes et al., 2003; Light & Beck, 2012).

Application of microencapsulated pear ester sprays alone can reduce fruit damage and increase larval mortality in apple and pear (Kovanci, 2015). No significant effect on kernel damage was found in walnut orchards with label rate applications of microencapsulated pear ester alone (Light & Beck, 2012; Light & Knight, 2011). But mixtures with insecticides were more effective in walnut (Light & Knight, 2011) than in apple (Knight & Light, 2013).

Pear ester treatments can also disrupt egg laying. Codling moths normally lay single eggs on leaves within 20 cm of developing fruit (Light & Beck, 2012). Pear ester treatments cause codling moths to lay eggs further away from fruit (Hughes et al., 2003).

Combinations of the Substance:

Combinations in Commercial Products

Pear ester dispensers contain coformulants such as pheromones and UV inhibitors in addition to the kairomone (see *Table 4* and *Focus Question #1* for further discussion). However, most inert ingredients in commercial pear ester products are not publicly disclosed.

Table 4: Commercial products containing pear ester (National Pesticide Information Center, 2024; Trécé, Inc., 2023)

Name	EPA Reg No.	Pear ester	Other pheromones?	Form	Target pests
Cidetrak® DA MEC™	51934-12	5%	-	Micro-encapsulated. May be further mixed with other pheromones and insecticides.	Codling moth, hickory shuckworm
Cidetrak CMDA 90/60	51934-13	1.2%	1.8% codling moth pheromone	Dispenser	Codling moth, walnut shuckworm
Cidetrak CMDA Combo	51934-16	1%	1.7% codling moth pheromone	Dispenser	Codling moth, hickory shuckworm
Cidetrak CMDA + LR	51934-18	1%	Dual dispenser: 1.7% codling moth pheromone (disp. 1); 4.3% leafroller pheromone (disp. 2)	Dual dispenser	Codling moth, hickory shuckworm, pandemic leafroller, oblique banded roller

[6] The larval form that initially hatches out of the egg is the first instar larva.

Name	EPA Reg No.	Pear ester	Other pheromones?	Form	Target pests
Cidetrak CMDA + OFM Meso	51934-21	0.9%	1.6% codling moth pheromone; 1.09% oriental fruit moth pheromone	Dispenser	Codling moth, oriental fruit moth, hickory shuckworm, macadamia nut borer, KOA seedworm
Bedoukian Pear Ester Technical	52991-27	93.4%	-	Technical grade active ingredient (TGAI)	For further formulation of other end-use products

Combinations in Experiments

Pear ester has been used experimentally in combination with the synthetic codling moth sex pheromone (codlemone) for monitoring (Knight et al., 2005) and mating disruption of the codling moth (Knight, Light, et al., 2012; Knight, Stelinski, et al., 2012). Researchers have combined pear ester with codlemone and navel orangeworm (*Amyelois transitella*) sex pheromone for simultaneous mating disruption of codling moth and navel orangeworm (Light & Knight, 2011). Researchers have used these combinations experimentally in monitoring traps (Knight, 2010; Knight et al., 2005, 2014), mating disruption dispensers (Light et al., 2017), and in microencapsulated sprays (Knight et al., 2018; Knight & Light, 2013; Kovanci, 2015).

Status

Historic Use:

Throughout the 20th century, food chemists analyzed the flavor profiles of many foods with the intent of producing synthetic chemical flavors (Knight et al., 2018). Pear ester is a major flavor component of Bartlett pears (Jennings et al., 1964). About one-third of commercial "pear essence" by weight is pear ester (Tucker et al., 2003). The chemical identity of pear ester, ethyl (2E, 4Z)-decadienoate, was determined through analysis and chemical synthesis of an identical compound (Jennings et al., 1964). Heinz & Jennings (1966) confirmed the results of Jennings et al. (1964).

From about 1970 onward, pest management professionals tried to chemically characterize host attraction for many insect pests. If there was a chemical basis for host attraction, that might be manipulated to change insect behavior and control the pest. Detailed attention was given to host plant volatiles with some success (Knight et al., 2018). However, many of the attractive plant volatiles were not specific enough or potent enough to be useful in pest management. Some promising candidates, such as (*E,E*)-*alpha*-farnesene, were chemically unstable in the field. A review of plant volatiles published in 1987 does not mention pear ester (Metcalf & Kogan, 1987).

In the 1980s, researchers favored pheromones over kairomones in pest management experiments. For instance, Metcalf & Kogan (1987) found 134 publications on pheromones, but only 14 on plant-produced kairomones in the *Journal of Chemical Ecology* from 1980 to 1985. Pheromones are used by insects to communicate with each other. Pheromones are very potent and highly specific. Although there is some overlap, mating pheromones are often unique to a species (Cardé & Minks, 1995).

Despite the relative neglect of kairomone research, Light et al. (2001) extracted several plant volatiles from ripe Bartlett pears. The best candidate for codling moth attraction was pear ester. Electroantennogram measurements showed both male and female adult codling moths, *Cydia pomonella*, could detect it in extremely small amounts. Light et al. (2001) concluded that pear ester was a very potent, highly specific codling moth kairomone.

The researchers performed field tests in walnut orchards to see if codling moth was attracted to pear ester (Light et al., 2001). They used a lure containing 1 mg of pear ester as an attractant in standard Pherocon ICP or diamond shaped IIB traps. Later experiments found that delta traps were more effective (Knight & Light, 2005).

Pear ester was patented as a codling moth kairomone on July 24, 2001 (Light, 2001) and on March 4, 2003 (Light, 2003). These publications stimulated further research (Knight et al., 2018; Light, 2016; Light et al., 2017). Pear ester products were granted EPA registration in 2011, and are now used in commercial pest management (Trécé, Inc., 2023).

Organic Foods Production Act, USDA Final Rule:
Pear ester is not mentioned in the Organic Foods Production Act nor in the USDA organic regulations at 7 CFR part 205. Pheromones, for insect management, are allowed per § 205.601(f); however, pear ester is a kairomone, not a pheromone.

International:
Pear ester is not mentioned by name in international organic standards that we reviewed (see *Table 5*, below). However, the Canadian organic standards allow pheromones and other semiochemicals. Pear ester is both a kairomone and a semiochemical and may therefore be permitted. Most of the international standards allow only pheromones and require that they be applied only in traps and dispensers.

Table 5: Pear ester and international organic standards

Standard	Applicable regulations	Allowed?	Source and use restrictions (if applicable)
Canada Organic Standards (CAN/CGSB 32.311-2020) (CAN, 2021)	Table 4.2. Substances for Crop Production.	Yes	Pear ester is not specifically listed, but pheromones and other semiochemicals are allowed. All sources are permitted. For pest control.
European Union Organic Standards (EU No. 2021/1165) (ECC, 2008)	Annex II. Pesticides, Plant Protection Products Section 4. Substances to be used in traps and/or dispensers	No	Pheromones, attractant sexual behavior disruptors only in traps and dispensers.
Japanese Agricultural Standard for Organic Products of Plant Origin (Japan, 2017)	Table 2. Agricultural Chemicals. Sex pheromone agent.	No	Only sex pheromones of insects harmful to crops permitted.
Codex Alimentarius Commission—Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods (GL 32-1999) (WHO, 2007)	Annex 2. Permitted Substances for the Production of Organic Foods Table 2. Substances for Plant Pest and Disease Control Section V. Traps	No	Pheromone preparations
IFOAM-Organics International (IFOAM, 2014)	Appendix 3. Crop Protectants and Growth Regulators Section V. Traps, Barriers, Repellents	No	Pheromones—in traps and dispensers only

Evaluation Questions for Substances to be used in Organic Crop or Livestock Production

<u>Evaluation Question #1:</u> Indicate which category in OFPA that the substance falls under: (A) Does the substance contain an active ingredient in any of the following categories: copper and sulfur compounds, toxins derived from bacteria; pheromones, soaps, horticultural oils, fish emulsions, treated seed, vitamins and minerals; livestock parasiticides and medicines and production aids including netting, tree wraps and seals, insect traps, sticky barriers, row covers, and equipment cleansers? (B) Is the substance a synthetic inert ingredient that is not classified by the EPA as inerts of toxicological concern (i.e., EPA List 4 inerts) [7 U.S.C. 6517(c)(1)(B)(ii)]? Is the synthetic substance an inert ingredient which is not on EPA List 4, but is exempt from a requirement of a tolerance, per 40 CFR part 180?
Pear ester is an active ingredient in monitoring trap lures for the codling moth, *Cydia pomonella* (Knight et al., 2005; Light et al., 2001). Pear ester is also an active ingredient in codling moth pheromone mating disruption formulations (Cidetrak, 2014; Knight & Light, 2014; Light et al., 2017). We did not find any

indication that pear ester is used as an inert ingredient in other pesticide products during our literature review. However, inert ingredients in pesticide products are typically confidential.

<u>Evaluation Question #2:</u> **Describe the most prevalent processes used to manufacture or formulate the petitioned substance. Further, describe any chemical change that may occur during manufacture or formulation of the petitioned substance when this substance is extracted from naturally occurring plant, animal, or mineral sources [7 U.S.C. 6502(21)].**
The prevalent process for manufacturing pear ester is the condensation reaction between the eight-carbon allyl alcohol, oct-1-yn-3-ol (CAS No. 818-72-4), and triethylorthoacetate (CAS No 78-39-7). The condensation product is heated with propanoic acid as a catalyst, and the subsequent Johnson-Claisen rearrangement gives ethyl 2E, 4Z-decadienoate. It is a convenient one-step synthesis with good yields (Trécé, Inc., 2023; Tsubi et al., 1993).

The following steps to produce pear ester are described by Tsubi et al. (1993):

1. 12.1 g (0.096 mol) of oct-1-yn-3-ol is heated under reflux at 140-150 °C with 100 g (0.616 mols) of ethylorthoacetate and 0.24 g (3.2 mmol) of a propanoic acid catalyst.
2. Every two hours, ethanol is removed by vacuum distillation, and more ethylorthoacetate (10 g) and propanoic acid (0.024 g) is added.
3. The mixture is refluxed at these temperatures for 6-8 hours until all the oct-1-yn-3-ol is consumed.
4. Most of the oct-1-yn-3-ol is converted into pear ester (82-91% yields). The rest likely polymerizes during distillation or is lost in side reactions.
5. Excess ethylorthoacetate is removed and recovered by vacuum distillation. Pear ester is also recovered by vacuum distillation, with a boiling point 80-85°C at 0.3 torr.

Pear ester has a molecular weight of 196.28 g/mol. The molecular weight of the alcohol is 126.04 g/mol, and that of the acetate is 162.22 g/mol. Typical yields are 15.4-17.2 g of pear ester, or 82-91% yield.

Relatively small amounts of these processing chemicals are needed to produce pear ester for the pest control market. Witzgall et al. (2008) estimated that 77,000 ha (190,000 acres) of apples and pears in North America are treated with mating disruption chemicals. Theoretically, all of the estimated acreage could be treated once by applying 4.6 metric tons of pear ester.[7] Two applications of the dispensers would use about 9.2 metric tons of pear ester.

The alcohol, oct-1-yn-3-ol, along with many other chemicals, is a by-product of petroleum processing, and is commercially available from Sigma Aldrich Chemical Company. To produce 9.2 metric tons of pear ester, 6.5 to 7.2 metric tons of the alcohol would be needed since yields are 82-91%.

Triethyl orthoacetate is used often in organic synthesis for acetylation and condensation reactions, and it is commercially available from Sigma-Aldrich. To produce 9.2 tons of pear ester would require 8.3 to 9.3 metric tons of the acetate.

<u>Evaluation Question #3:</u> **Discuss whether the petitioned substance is formulated or manufactured by a chemical process or created by naturally occurring biological processes [7 U.S.C. 6502(21)].**
Pear ester is manufactured by a chemical process. The prevalent manufacturing process produces synthetic pear ester. Below, we discuss the classification in more detail, using NOP 5033-1, *Decision Tree for Classification of Materials as Synthetic or Nonsynthetic* as a guide (NOP, 2016).

Classification: Johnson-Claisen condensation reaction method

1. *Is the substance manufactured, produced, or extracted from a natural source?*

No. It is produced by a condensation reaction between two chemicals that are by-products of petroleum processing. According to the decision tree, it is therefore synthetic.

[7] One application of Cidetrak 90/60 combo meso dispensers, applied with a maximum of 40 dispensers per acre, each containing 600 mg of pear ester would be used. That is about 24 g pear ester per acre.

Evaluation Question #4: Describe the persistence or concentration of the petitioned substance and/or its by-products in the environment [7 U.S.C. 6518(m)(2)].

Pear ester has moderate chemical stability in the field, which makes it useful as a pest control product (Light et al., 2001), but it does not persist in the environment away from treated areas. It dissipates and degrades and does not accumulate (US EPA, 2013). About 72% is degraded in 28 days by the microbes in sludge. The sludge test measures aerobic degradation of substances by microbes in the laboratory. Similar aerobic degradation is expected from microbes in a field situation. The double bonds in the molecule are vulnerable to oxidation and contact with water will slowly hydrolyze the ester to ethanol and 2E, 4Z-decadienoic acid. It is moderately volatile in the environment, and because of this volatility the EPA has exempted pear ester from a number of key environmental toxicity tests (Boudakian Research, 2023; US EPA, 2013).

Pear ester does persist in areas where it is used for treatment, as intended for controlled release formulations (Klassen et al., 2023). When used in controlled release dispensers, it is present in the field for 120-150 days (Trécé, Inc., 2023). It persists for about two weeks in microencapsulated controlled release sprays, and for about eight weeks in monitoring traps (Kovanci, 2015).

The polyamide microcapsules from the spray may persist for some time. These microcapsules are made through a process called interfacial polycondensation, in which two complementary monomers undergo polymerization when droplets of one are mixed into a suspension of the other. The active ingredient is also contained within the droplet. The polymerization occurs through condensation, through which the active ingredient is encapsulated (Cryer, 2011; Dubey et al., 2009).

We found no published information on the persistence of these microcapsules of pear ester in the environment. Microcapsules from dilute solutions of encapsulated methyl parathion can persist in soil for 32 months (Butler et al., 1981). Capsules of alachlor persist at least 47 days (Capri & Walker, 1993). For comparison, chlorpyrifos emulsified concentrate lasts 60 days, whereas the microencapsulated formulation lasts 120 days (Chen et al., 2014).

Sprayable microencapsulated formulations of pheromones are washed from tree canopies by rain. Ultraviolet light degrades the pheromone and the plastic microcapsules. It is likely that the same thing happens with microencapsulated pear ester (Waldstein & Gut, 2004; Wins-Purdy et al., 2007).

Evaluation Question #5: Describe the toxicity and mode of action of the substance and of its breakdown products and any contaminants. Describe the persistence and areas of concentration in the environment of the substance and its breakdown products [7 U.S.C. 6518(m)(2)].

Pear ester persistence is covered in *Evaluation Question #4* and *Evaluation Question #6*. Available information exploring the toxicity of pear ester is minimal. We did not find other literature that describes the toxicity of pear ester beyond what we include within this report.

The EPA evaluated pear ester and had few concerns about environmental toxicity. According to the EPA, "little or no exposure is expected for non-target species," and "it is not known to be toxic to any insect species or other non-target organism" (US EPA, 2013). When used at label application rates, adverse, non-target effects are not expected (US EPA, 2013). Pear ester is extremely specific for codling moth (Knight & Light, 2004).

Other species are attracted to pear ester only when the dose is increased or other kairomones are added to lures or dispensers (Knight et al., 2014, 2019). For instance, Light et al. (2001) found codling moth limit of detection in the laboratory was about 10 ng, while threshold detection for codling moth in the field was about 10 micrograms. Lures effective for monitoring codling moth contain 1 mg, and 10 mg lures attracted non-target insects (Light et al., 2001).

The EPA did not require testing for bird, fish, and aquatic invertebrate toxicity because pear ester is expected to quickly disperse and degrade in the environment (US EPA, 2013). See *Evaluation Question #6*.

However, the pear ester safety data sheet from Boudakian Research (Boudakian Research, 2023) states that pear ester is "very toxic to aquatic life with long lasting effects."

Pear ester has low toxicity to algae and water fleas. The EC_{50} (72 hrs.) for algae is 0.13 mg/liter.[8] The EC_{50} (48 hrs.) for the water flea is 1.4 mg/liter (Boudakian Research, 2023). Other non-target effects are discussed in *Evaluation Question #8*.

Pest management uses of pear ester are mostly confined to apple, pear, and walnut orchards. Some pear ester is used in monitoring traps (Knight et al., 2005; Knight & Light, 2005), but in terms of quantity, most pear ester is used in mating disruption products for apples and pears (Trécé, Inc., 2023). See *Evaluation Question #6* for more information on pear ester use rates and the implications for potential environmental contamination.

Evaluation Question #6: Describe any environmental contamination that could result from the petitioned substance's manufacture, use, misuse, or disposal [7 U.S.C. 6518(m)(3)].

Environmental Contamination from Production of Pear Ester

Production of pear ester by the Johnson-Claisen condensation and rearrangement (see *Evaluation Question #2*) is not likely to produce major environmental disruption. It is a one-step process where the components are refluxed together. Ethanol is released and can be recovered by distillation. Most of the processing chemicals are consumed in production or recycled. Vacuum distillation allows recovery of product and other reaction chemicals (Trécé, Inc., 2023). In reactions of this type, a very small amount of side reaction products is likely captured during distillation, or sticky polymeric residuals are left in the bottom of the flask, which would be dealt with according to Good Manufacturing Practices.

Relatively small amounts of these processing chemicals are needed to produce pear ester for the pest control market. The major use of pear ester in pest control is as a component of mating disruption dispensers for the codling moth. Witzgall et al. (2008) estimated that 77,000 ha (190,000 acres) of apples and pears in North America are treated with mating disruption each year.

A maximum of 9.2 metric tons of product would be applied over 190,000 acres each year (see *Evaluation Question #2*). Furthermore, pear ester is not known to be toxic (US EPA, 2013). Therefore, production and use of pear ester is not likely to lead to widespread environmental contamination. For comparison, about 150 million acres in the U.S. are treated with neonicotinoid insecticides each year (Krupke & Tooker, 2020).

Environmental Effects from Use of Pear Ester

According to the EPA, "When used in accordance with widespread and commonly recognized practice, it (pear ester) will not generally cause unreasonable adverse effects on the environment" (US EPA, 2013). The EPA reached this conclusion because pear ester exposures from treatments are similar to emissions from natural pear orchards. It is volatile and dissipates quickly in the environment. When it volatilizes, it readily undergoes oxidative photodegradation. Non-target effects are not expected from label application rates. The rate of environmental exposure from dispensers and microencapsulated sprays is a key factor in pear ester's low risk for environmental contamination (US EPA, 2013).

Volatility in the Environment

Volatility in the environment can be measured by Henry's law. A regulatory threshold is a Henry's law constant greater than 5×10^{-5} atm-m^3/mol. If the constant exceeds this threshold, the substance is considered highly volatile and dissipates quickly. The pear ester Henry's law constant is 7.54×10^{-4} atm-m^3/mol (Trécé, Inc., 2023). The volatility of a saturated solution of pear ester in water is near that of water (US EPA, 2013). Therefore, the substance is exempt from testing for bird, fish, and aquatic invertebrate toxicity.

[8] The EC_{50} is the concentration of a substance that produces a half-maximal response; that is, a response that is halfway between the baseline and maximum, after a specified time.

Degrades Quickly
The EPA states that pear ester dissipates quickly, and it undergoes oxidative photodegradation. This assertion makes sense, because there are two double bonds in the molecule that are vulnerable to oxidation (US EPA, 2013). According to the Boudakian SDS (Boudakian Research, 2023), activated sludge destroys 72% of pear ester (30 mg/liter) in 28 days. Pear ester then readily undergoes aerobic biodegradation (Boudakian Research, 2023).

Evaluation Question #7: Describe any known chemical interactions between the petitioned substance and other substances used in organic crop or livestock production or handling. Describe any environmental or human health effects from these chemical interactions [7 U.S.C. 6518(m)(1)].
Pear ester dispensers protect the formulation from other substances used in organic production. Pear ester is released as a gas from dispensers. Concentrations are low and should not interact with any pesticide sprayed on trees (see *Evaluation Question #6*). When microencapsulated pear ester sprays are used, the polyamide capsules should give some protection against pesticide formulations applied to trees.

Tank mixes of microencapsulated pear ester and other insecticides are used. But the encapsulated formulation must be chemically compatible with any tank mixes. Acids, bases, and oxidizing agents could be incompatible (Boudakian Research, 2023; Cidetrak, 2020; US EPA, 2013).

Insecticides that might be used with organic apples and pears include soap, oil, spinosad, neem oil, *Bacillus thuringiensis* (BT), codling moth virus, kaolin, and natural pyrethrins (Pfeiffer, 2017). Dispensers and microencapsulated pear ester sprays should not conflict with any of these. In fact, because pear ester increases movement of larvae, it should make insecticides that work by contact more effective (Knight & Light, 2013; Light & Knight, 2011).

For walnut orchards, tank mixes of microencapsulated pear ester were compatible with spinosad, codling moth granulosis virus, and other insecticides (Light & Knight, 2011). Pear ester made the other pesticides more effective (Light & Knight, 2011).

Tank mixes of microencapsulated pear ester with codling moth insecticides such as spinosad gave less consistent results when used on apple orchards. The combination reduced serious fruit injury but did not reduce superficial damage. The combination likely increased mortality, but the larvae were able to do some damage before they died (Knight & Light, 2013).

Evaluation Question #8: Describe any effects of the petitioned substance on biological or chemical interactions in the agro-ecosystem, including physiological effects on soil organisms (including the salt index and solubility of the soil), crops, and livestock [7 U.S.C. 6518(m)(5)].

Mating Disruption Changes the Pest Spectrum
Organic insecticides such as spinosad or pyrethrins can kill beneficial insects. Using mating disruption products with or without pear ester changes the pest spectrum in a pear orchard because less insecticide is needed, and the number of beneficial insects increase (Brunner et al., 1992). This means there are fewer pests like pear psylla, mealybugs, and mites in pear orchards where mating disruptors are used, because the pests are consumed by beneficial insects (Brunner et al., 1992).

Apple orchards treated with mating disruption products have fewer leafhoppers and leafminers, while aphid and mite populations are generally unchanged (Brunner et al., 1992). But mating disruption leads to an increase in pest leafrollers other than the codling moth. Because leafrollers can increase, there are mating disruption dispensers that simultaneously control codling moth and leafrollers (Brunner et al., 1992) (see *Combinations of the Substance*).

In addition, by prolonging the time before larvae find shelter inside fruit, predation can be enhanced. Lacewing releases should be more effective. Confused larvae may also be blown off the tree by wind, or washed off by rain or overhead irrigation (Light & Beck, 2012).

Trichogramma spp. use the vine mealybug sexual pheromone as a kairomone to find prey (Cocco et al., 2021). It is possible that either pear ester or codling moth sexual pheromone could be used by *Trichogramma* in this way, but no information has been published in CAB Abstracts on this subject.

Low Emissions

The amounts of pear ester added to the environment by monitoring traps are extremely small. Emissions from commercial monitoring lures are about 20-60 µg/day, since the lure itself is about 1-3 mg and it lasts about 8 weeks (Kovanci, 2015). The largest releases from dispensers, 208 mg/acre/day are about 4.8 µg/ft^2/day.

These amounts are likely too small to affect microbe survival or distribution, especially since pear ester is very volatile and degrades quickly (US EPA, 2013). Antibiotic action of pear ester is not mentioned in the EPA evaluation, the SDS, or the PubChem database (Boudakian Research, 2023; National Library of Medicine, 2024; US EPA, 2013).

Emissions from pear ester treatments are similar to natural emissions in a pear orchard. Therefore, treated areas should not produce unexpected consequences for natural flora and fauna (US EPA, 2013).

Effects on Non-Target Insects

Toxicity tests of pear ester on insects are rarely published. But Asche et al. (2023) found that pear ester solutions added to 17% sugar water were toxic to paper wasps, *Polistes dominula*. About 20% of paper wasp workers were killed (6.7%) or paralyzed (14.6%) after ingestion of an average 10.6 µl of sugar water containing 10% (w/v) pear ester.

About 10 µl of sugar water containing 10% (w/v) pear ester would contain about 1 µg pear ester. Each wasp consumed about 1 µg pear ester, and 6.7% died. Toxicity was extremely variable, and 80% of wasps were unaffected by this dose (Asche et al., 2023). Maximum exposure from dispensers is 4.8 micrograms/ft^2/day, less than 0.15 µg /ft^2/hour. The dispensers are not likely to be toxic to *Polistes dominula*.

Exposure of paper wasps to microencapsulated sprays is about 42.8 mg/acre/day, or about 1 µg/ft^2/day or 40 ng/ft^2/hr. This amount is not likely to be toxic to paper wasps. The maximum label application would be airborne exposure of about 5.8 µg/ft^2/day or 240 ng/ft^2/hr., an amount that is still not likely to be toxic. However, an air blast sprayer is used to apply the formulation (Light & Beck, 2010), which may disrupt paper wasps and other insects.

Yellowjackets, *Vespula vidua* and *V. pennsylvanic*, feed on pear, and are attracted by lures of 10 mg (Light et al., 2001), but especially 20-40 mg (Knight & Light, 2004). The use of pear ester at these levels can therefore impact other insects.

Some stinkbugs are attracted to pear ester. Low numbers appear in traps baited with 20 mg pear ester. Pear ester is structurally similar to the sex pheromone of the stinkbug, *Euschistus conspersus*; the stinkbug pheromone is the methyl ester of (E2), (Z4)-decadienoic acid, and pear ester is the ethyl ester (Light et al., 2001).

The pest moths *Hedya nubiferana*, *Cydia fagiglandana*, *Cydia splendana* are attracted to 10 mg pear ester lures. But 10 mg lures did not attract eight lepidopteran pest species that are common pests of many orchard crops (Knight & Light, 2004). However, pear ester attracts males of the oriental fruit moth, *Grapholita molesta,* in apples and pears, but not peach. Because of this, pear ester can be used for monitoring the pest in apple and pear, but not in peach (Molinari et al., 2010).

In addition to codling moths, monitoring traps also capture flies and honey bees, but the number captured can be minimized by choosing the most suitable trap color. White traps catch the most honey bees, while red and green traps catch the fewest (Knight & Miliczky, 2003).

Effects on Honey Bees

Pears require pollination, and most of that is done by bees. Su et al. (2022) showed that bee foraging is affected by pear flower volatiles. Electroantenogram measurements show that bees can detect at least 16 flower volatiles (Su et al., 2022). While the effect of pear *flower* volatiles on bee foraging behavior has been tested by researchers, pear *ester* has not been tested. Linalool and *alpha*-farnesene are two pear flower volatiles that Su et al. found were active in affecting bee foraging behavior. These compounds are sometimes used to increase the number of codling moths trapped by pear ester lures. Bees might be attracted to this kind of trap (Knight et al., 2019).

Bees are known to pick up particles of microencapsulated pesticide formulations (Barker et al., 1979). Effects were noticed with the first microencapsulated insecticide, the organophosphate methyl parathion. The size of the particles is near that of pollen, and the particles are taken back to the hive. If the pesticides are toxic, as in the case of methyl parathion, bees can be harmed and populations significantly affected (Barker et al., 1979).

Toxicity tests of pear ester on bees have not been published. If toxicity is similar to paper wasp, ingestion of 1 µg of pear ester might be toxic to some of them (Asche et al., 2023). It is also possible for microencapsulated pesticides to enter into bee products, such as honey and pollen. For example, researchers have found that both honey and pollen can be contaminated by microencapsulated methyl parathion (Atkins & Kellum, 1984). Foraging bees have been found with microcapsules in their midguts (Burgett & Fisher, 1980).

If bees have the same response as paper wasps, bees would have to pick up >8000 particles of microencapsulated pear ester and ingest them all to get any toxic effects.[9] Bees forage in flowers. DA MEC™ sprays are applied to tree canopies, and if the spray occurs while the trees are flowering, some bees might be adversely affected.

<u>Evaluation Question #9:</u> Discuss and summarize findings on whether the use of the petitioned substance may be harmful to the environment [7 U.S.C. 6517(c)(1)(A)(i) and 7 U.S.C. 6517(c)(2)(A)(i)].

Environmental damage is likely small, because small amounts are generally used (3 mg pear ester/tree; 600 mg pear ester/acre), and usage is confined to orchards. However, we cannot provide a thorough analysis because the EPA exempted pear ester and the formulations from many of the usual environmental toxicity tests (US EPA, 2013), and other studies detailing pear ester toxicity are limited.

Pear ester applications are generally expected to have benign effects on the environment (US EPA, 2013). Emissions from monitoring lures are very small, since the lure itself is about 1-3 mg and lasts about 8 weeks (Kovanci, 2015). Emission rates are discussed in detail in *Specific Uses of the Substance*.

Polyamide microencapsulated formulas of pear ester such as Cidetrak® DA MEC™ (EPA Reg. No. 51934-12) can be sprayed about every two weeks, and up to 8 times a year. The average pear ester emission rate of 42.8 mg/acre/day over a two-week period should not cause environmental toxicity. According to the EPA, pear ester is dispersed and destroyed quickly (Light & Beck, 2010; US EPA, 2013).

Once applied, microcapsules probably stay on the leaves until dislodged by wind and rain. That is the case for microencapsulated sprayable pheromones (Knight et al., 2004). When particles are dislodged by rain, they likely become part of runoff from an orchard (Trécé, Inc., 2023). We found no information on the environmental effects of pear ester polyamide microcapsules.

According to the safety data sheet, pear ester is a marine toxicant and hazard (Boudakian Research, 2023). Environmental damage may be mitigated by the low application rate of 12 g DA MEC™/acre or 30 g/ha. That is about 0.27 mg DA MEC™/ft^2. That is a small amount, but each ml of the usual diluted field spray contains about 260,000 particles (Light & Beck, 2010). There is no published information of the effects of

[9] The DA MEC™ spray contains about 259 microencapsulated pear ester particles/mg of diluted field spray, and 8288 x 10^3 pear ester particles/mg of concentrate (Light & Beck, 2010). Each 1 µg of concentrate contains about 8288 pear ester particles.

these particles on earthworms. If earthworms ingest them, birds would be exposed by eating earthworms. However, again, the amounts of pear ester involved are very small.

Once the microencapsulated particles reach the water, they might be ingested by fish or other aquatic creatures. The pear ester contained in the microparticles is an aquatic hazard (Boudakian Research, 2023). No density information is given (Light & Beck, 2010), but likely the polyamide particles are less dense than water. We found no information on whether the polyamide capsules are a hazard. The EPA did not require the product manufacturer to submit environmental toxicity tests of microencapsulated pear ester (US EPA, 2013).

Evaluation Question #10: Describe and summarize any reported effects upon human health from use of the petitioned substance [7 U.S.C. 6517(c)(1)(A)(i), 7 U.S.C. 6517(c)(2)(A)(i) and 7 U.S.C. 6518(m)(4)].
Pear ester has low acute toxicity to mammals, and the oral LD_{50} for rats is 4,027 mg/kg.[10] This number means pear ester is nearly non-toxic. Pear ester is an FDA approved food additive, and average human consumption in the U.S. is about 3 µg per day (US EPA, 2013).

According to the EPA, pear ester also has low chronic toxicity, and is not a likely developmental toxicant, or a mutagen. It is not on the EPA list of carcinogens, or on the IARC carcinogen list. It has not been tested for endocrine disruption (US EPA, 2013).

According to the pear ester safety data sheet, it may cause allergy or asthma symptoms or breathing difficulties if inhaled. Contact with skin or eyes may cause irritation (Boudakian Research, 2023).

Pear ester is a Generally Recognized as Safe (GRAS) food additive. The EPA exempted it from the need to establish food tolerance concentrations in 2013. The EPA concluded that "there is a reasonable certainty that no harm will result to the U.S. population from aggregate exposures to ethyl-2E-4Z-decadienoate (pear ester)" (78 FR 53051, August 28, 2013).

Occupational Exposure
The food tolerance exemption provided by the EPA does not include an evaluation for occupational exposure.

The maximum average pear ester that volatilizes into a walnut orchard from CMDA 90/60 meso dispensers is 208 mg/acre/day (see *Specific Uses of the Substance*). Dispensers used in apple and pear orchards contain less pear ester, and the maximum average is 163 mg/acre/day (Knight & Light, 2014). The amount of pear ester that naturally volatilizes in an untreated pear orchard is 120 mg/acre/day (Trécé, Inc., 2023). Occupational exposures should be less than this amount, as workers are not expected to be in the field 24 hours a day.

DA MEC™ sprays are not applied uniformly; only trees are sprayed. Since the vapor density of pear ester is about 6.8 times that of air (US EPA, 2013), the emissions drift downward from the tree canopy to the base of each tree. Workers might be exposed for 8 hours, so the pear ester emission rate considered over 8 hours is 70 µg /tree/8-hour day. Workers spending all day next to a treated tree are usually exposed to less than 70 µg of pear ester per day. The maximum label amount is 5.83 times greater or about 400 µg pear ester/day. This amount is well below the acute toxicity of 4027 mg/kg. Pear ester vapors are not likely a health problem for orchard workers.

Exposure to Polyamide Particulates
Sprays of about 30 g/ha DA MEC™ are applied to tree canopies with an air blast sprayer (Cidetrak, 2020). Very small amounts of DA MEC™ are used, but the sprays contain a large number of small polyamide particles. Each tree canopy receives about 500 million microencapsulated pear ester particles.[11] There might

[10] The LD_{50} is the amount of a substance needed to kill 50% of the animals in a population within a specific period.
[11] The number of apple trees in a commercial orchard is widely variable, around 188-1000 trees/ha. On average, there are very roughly about 500 apple trees/ha (Knight, 2006; Knight, Light, et al., 2012; Knight, Stelinski, et al., 2012; Knight & Light, 2005, 2014).

be a respiratory hazard from inhaling the plastic microparticles when the spray is applied by air blast sprayer to individual trees.[12] However, effects of exposure to the polyamide spherical capsules in the spray has not been evaluated by the EPA. There is a 4-hr re-entry restriction, so the greatest acute risk is probably during spray applications with an airblast sprayer. But the DA MEC™ label does not require respiratory protection for workers (Cidetrak, 2020).

Generally, chronic exposure to any airborne particles can lead to health problems. Zanobeti et al. (2000) found that chronic exposure to airborne particles less than 10 µm diameter (PM_{10}) led to increased hospital admissions for heart and lung disease for persons 65 years or older. An increase of 10 µg/m^3 of PM_{10} led to observed adverse effects.

Many later studies have confirmed the adverse effects from particulate exposure. The current 24-hr PM_{10} Standard is 150 µg/m^3 (89 FR 16202, May 6, 2024). $PM_{2.5}$ covers exposures below 2.5µm. The 24-hr $PM_{2.5}$ Standard is 35 µg/m^3 (89 FR 16202, May 6, 2024).

With DA MEC™ sprays, each tree is usually treated with 60 mg of a formulation containing polyamide microcapsules. Not all of this is polyamide, as there is also water and coformulants (Light & Beck, 2010). There is no monitoring data available for airborne particles of microencapsulated DA MEC™ sprays in orchards. Sprayable microencapsulated pheromone particles can be washed out of tree canopies by wind, rain, and overhead irrigation sprays. Pear ester likely meets the same fate (Knight et al., 2004).

In a worst-case scenario of all 60 mg of particles gradually drifting down over the course of 14 days, about 4.3 mg/tree would be airborne every 24-hr day. Workers would be exposed to 1.5 mg/tree over an 8-hr day. Each tree occupies a 20 m^2 footprint, and workers about 2 m tall would be exposed in a 40-m^3 air volume. Maximum 8-hr worst case chronic exposure would be about 0.0357 mg/m^3 or 36 µg/m^3. This exposure is below the U.S. 24-hr particulate standard of 150 µg/m^3 for PM 10 (89 FR 16202, May 6, 2024).

A more reasonable estimate would be exposure to the 3 mg of microencapsulated pear ester usually applied to each tree. Chronic exposure to microencapsulated pear ester would be about 2 µg/m^3 over an 8-hr day. This number is well below the PM_{10} standard of 150 µg/m^3 and is also below the $PM_{2.5}$ standard of 35 µg/m3 (89 FR 16202, May 6, 2024). The maximum label application of pear ester would lead to about 12 µg/m^3 over an 8-hr day. This exposure is still below federal standards. These calculations are highly speculative, but they might give at least an idea of chronic exposure potential.

We found no publications indicating harm to humans from pear ester or polyamide particulates. But according to the pear ester safety data sheet, pear ester may cause allergy or asthma symptoms or breathing difficulties if inhaled. Contact with skin or eyes may cause irritation (Boudakian Research, 2023).

<u>Evaluation Question #11</u>: Describe all natural (non-synthetic) substances or products which may be used in place of a petitioned substance [7 U.S.C. 6517(c)(1)(A)(ii)]. Provide a list of allowed substances that may be used in place of the petitioned substance [7 U.S.C. 6518(m)(6)].

Natural substances used instead of pear ester for codling moth control include codling moth granulosis virus, and other microbials such as *Beauveria bassiana*, *Metarhizium anisopliae*, and *Bacillus thuringiensis kurstaki* (Btk) (Caprile & Vossen, 2011). Applications must be timed to expose codling moth larvae (see *Codling Moth Life Cycle and Monitoring*). These substances function differently than pear ester and are not true "alternatives." Rather, these are substances that could also be used in codling moth pest management. In many cases, these substances could be used in conjunction with pear ester for increased effectiveness.

Each tree receives 60 mg DA MEC™ containing 5% or 3 mg microencapsulated pear ester. The concentrated solution contains about 8.3 million particles/mg (Light & Beck, 2010).

[12] The diluted field application spray contains about 260,000 particles/ml or about 260,000 particles/gram (Light & Beck, 2010).

Codling moth granulosis virus

There are a few commercially available products that use codling moth granulosis virus as the active ingredient (National Pesticide Information Center, 2024). Some of these are OMRI Listed as of May 2024, such as (OMRI, 2024):

- CYD-X® HP Insecticidal Virus High Potency Aqueous Suspension Biological Insecticide for Control of the Codling Moth (Certis)
- CYD-X® Insecticidal Virus An Aqueous Suspension Biological Insecticide for Control of the Codling Moth (Certis)
- Virosoft™ CP4 BIO-Insecticide (Biotepp, Inc.)

Field tests of codling moth granulosis virus in walnuts over a 3-year period in California showed 60-80% control (Vail et al., 1991). However, applications must be timed to coincide with egg hatch. The virus does not persist, so repeated applications are necessary. The codling moth must eat the virus for this method to be effective. It attacks the larval stage only and must be present at the larval point of entry into the fruit (Vail et al., 1991).

Another problem is that the virus may kill the codling moth larvae, but the larvae may survive long enough to infest fruit, therefore, fruit damage may not be reduced (Arthurs et al., 2007). Similarly, Btk and fungal treatments work best when applied at the early larval stage. Treatments must be timed with monitoring and the biofix point (Caprile & Vossen, 2011; University of California Statewide IPM Program, 2015).

Spinosad

Spinosad, a nonsynthetic substance used in organic agriculture is also an alternative. There are numerous commercially available products that use spinosad as the active ingredient (National Pesticide Information Center, 2024). Many of these are OMRI Listed (OMRI, 2024). Due to the number of spinosad products available, we recommend searching the National Pesticide Information Center database and cross-referencing products with data from material review organizations such as OMRI for a complete list.

Spinosad is very effective for control of caterpillars, such as the larval stages of the codling moth. Spinosad is applied three times at ten-day intervals, starting with egg hatch. It is more effective when mixed with 1% horticultural oil (Caprile & Vossen, 2011). According to Caprile & Vossen (2011), horticultural oil by itself gives inconsistent results.

Bacillus thuringiensis kurstaki (Btk) and pyrethrins

Btk and pyrethrins are not very effective for codling moth control. Btk must be ingested, and pyrethrins are quickly inactivated in the environment. Multiple applications must be used, and application timing must be very good (Caprile & Vossen, 2011). Commercial orchards have a very low tolerance for codling moth damage. While pyrethrin products are widely available, most (but not all) Btk products have had their registrations cancelled (National Pesticide Information Center, 2024). Because these products are not very effective for this application, we are not listing specific products. However, as with spinosad, interested parties can easily search these materials by using the National Pesticide Information Center database and cross reference products on OMRI and other material review organization websites.

Codling Moth Life Cycle and Monitoring

All of these materials rely on timing treatments with the codling moth life cycle. This timing relies on monitoring traps and measurement of degree-days to determine when treatment should start. A degree-day has elapsed when the average of maximum temperature and minimum temperature on a given day is one degree above 50°F, the codling moth developmental threshold (University of California Statewide IPM Program, 2015). When maximum temperatures are hotter than 88°F, the upper developmental threshold, 88°F is used as the maximum temperature (University of California Statewide IPM Program, 2015).

In California apple orchards, insecticidal sprays are applied at egg hatch, 200-250 degree-days after the biofix point. If there are a lot of moths, sprays are applied after 160 degree-days (Caprile & Vossen, 2011;

University of California Statewide IPM Program, 2014, 2015). In Washington, sprays are applied about 139 degree-days past biofix. The biofix point is at the end of April in Washington (Knight & Light, 2005).

In California walnut orchards, the first flight of the codling moth has two peaks. The first insecticide is applied at 300 degree-days past biofix during the first peak (University of California Statewide IPM Program, 2017).

The codling moth usually has three flights a year, and development depends on the number of sunny, warm days (degree-days). Pheromone monitoring traps can be used to time treatments with the appearance of codling moths in the traps (Witzgall et al., 2008). In orchards not treated with mating disruption, pheromone monitoring traps are adequate. Only males are attracted to sex pheromone traps, but this gives commercial orchards good data for males with which they can set action thresholds (Knight & Light, 2005; Light et al., 2001).

In orchards treated with mating disruption, monitoring is more effective with pear ester in combination with pheromones. Females are attracted to the combination, allowing action thresholds to be set for egg laying females (Knight & Light, 2005). To improve female capture, other substances such as acetic acid can be added to the monitoring traps (Knight et al., 2014, 2019).

Evaluation Question #12: Describe any alternative practices that would make the use of the petitioned substance unnecessary [7 U.S.C. 6518(m)(6)].

Cultural controls and mass trapping have been used in Integrated Pest Management programs to control the codling moth (Knight et al., 2022; Madsen et al., 1976). A labor-intensive cultural control is to bag each fruit as it develops. This approach prevents damage but might only be useful on small plots due to the labor needed (Caprile & Vossen, 2011). Sanitation is another important cultural control. Infested or dropped fruit should be removed to interrupt the codling moth life cycle. Pruning and thinning can also help reduce damage. These procedures are also part of fire blight management. Additionally, resistant species such as early maturing pears and apples can reduce damage from codling moths (Caprile & Vossen, 2011).

Another reasonably effective alternative to the use of pear ester for codling moth mating disruption is the use of codlemone without pear ester. Witzgall et al. (2008) cite an areawide mating disruption program in apple orchards that reduced the number of insecticide sprays from 2.9 to 0.5 a year over a 5-year period. Fruit damage was reduced from 0.8% to 0.03%. Areawide treatments reduce damage from immigration of already mated females. In general, though, codling moth mating disruption without pear ester is less effective (Kovanci, 2015; Light et al., 2017) (see *Focus Question #1*).

Monitoring traps using only codlemone are adequate for determining an initial biofix point for codling moth first flight (Knight & Light, 2005; University of California Statewide IPM Program, 2015), but codlemone lures alone are not useful after mating disruption programs are established (Trécé, Inc., 2023).

Integrated Pest Management programs with applications of insecticides such as spinosad and codling moth granulosis virus can be effective for organic codling moth management. However, the addition of pear ester increases the effectiveness of insecticide management (Caprile & Vossen, 2011; Knight & Light, 2013; Light & Knight, 2011).

Commercially available biocontrol includes releases of the parasitic wasp *Trichogramma platneri* and nematodes. *Trichogramma* is an egg parasitoid, therefore, its release must be timed for the egg stage. It is more effective in walnuts and pears than in apples. Timing involves establishing the biofix point with monitoring traps and counting degree-days. Monitoring is important for establishing release times (Caprile & Vossen, 2011).

Nematodes (*Steinernema feltiae*) target the larval and prepupal stages of the codling moth. They are most effective when applied to the tree trunks (wrapped in burlap) and the soil underneath the trees. Later larval instars crawl down the tree trunk to pupate on the tree or in the soil. Nematode applications must be timed for these prepupal stages (Kaya et al., 1984). Nematodes applied to tree trunks wrapped in burlap led to 80-95% moth mortality in California. Best results are obtained when nematodes are applied during wet, winter months (Kaya et al., 1984).

Focus Question

<u>Focus Question #1:</u> Compare the performance of pheromone-only lures with combination lures with pear ester or other kairomones.

Monitoring traps baited with combo lures of codling moth sex pheromone (codlemone) and pear ester can catch more moths than traps baited with codlemone alone or pear ester alone.
Joshi et al. (2011) compared monitoring traps baited with codling moth pheromone only (PH), pear ester only, and combinations of pear ester and pheromone. Experiments were conducted both in apple orchards treated with pheromone mating disruption dispensers (MD) and with those not using mating disruption dispensers.

The combination lure trapped significantly more codling moths in MD orchards than PH or pear ester lures (Joshi et al., 2011). Both males and females were trapped, but significantly more males were trapped with the combo lure than with pheromone only lures. The addition of pear ester enhanced the attractiveness of codlemone to males (Joshi et al., 2011).

In non-MD orchards, there was no significant difference in effectiveness between pheromone-only lures and the combination lure (Joshi et al., 2011). In both MD orchards and non-MD orchards, pheromone alone was a more effective attractant than pear ester alone (Joshi et al., 2011).

Results for trapped females vary according to conditions. Some research shows that combo lures can catch more females than pear ester alone (Knight et al., 2005; Light et al., 2001). Other research shows the combo caught few, or no females (Joshi et al., 2011; Trimble & El-Sayed, 2005).

Fernandez et al. (2010) compared lures baited with codling moth sex pheromone alone, pear ester alone, and combo lures containing both. Experiments were conducted in apple and pear orchards being treated with pheromone mating disruption over the course of two years. Combo lures attracted significantly more codling moths, both males and females over a season. Effects were significant for the first and second flights, but not always the third flight of the season (Fernández et al., 2010).

Combo monitoring lures containing pheromone and pear ester are less effective when mating disruption dispensers also contain both pheromone and pear ester.
Combo (pear ester + PH) lures are more effective in trapping males in apple, pear, and walnut, than PH-only lures. The combo is more effective in both untreated and in mating disruption orchards using PH-only dispensers (Light, 2016). However, with the development of mating disruption dispensers using both pear ester and codlemone, better lures were needed. The mating disruption dispensers were using the same substances as the monitoring lures, and trapping was less effective. Lures were improved by adding acetic acid or other kairomones to the lure (Knight et al., 2014; Light, 2016).

Addition of acetic acid to pheromone lures or combo lures of pear ester and pheromone resulted in increased trap effectiveness for females in conventional apple or walnut orchards and apple orchards treated with pheromone dispensers (Knight, 2010; Light, 2016).

Light (2016) treated walnut orchards with a variety of MD dispensers and monitored results with lures of pear ester, PH, combo (pear ester and PH), acetic acid (AA), and pear ester and AA, PH + AA. Female trap captures were greater with traps baited with dual lures, either pear ester and AA or combo and AA compared to lures containing only one attractant.

Combination dispensers with sex pheromone and pear ester increase the effectiveness of codling moth mating disruption compared to dispensers loaded only with codling moth sex pheromone.

Light et al. (2017) found that the addition of pear ester to pheromone dispensers loaded with codling moth sex pheromone enhanced the mating disruption effects of the pheromone. Large meso dispensers (50/ha) were used in a four-year study of walnut orchards. Efficacy was determined by counting the number of males caught in monitoring traps and by determining the mated status of captured females (Knight, 2006). There were significantly more unmated females (33%) with the combination treatment compared with pheromone alone (18-26%) or no treatment (6%). Combination treatments also reduced the number of multimated females. There were 6% in combo treatments, 13-18% in pheromone only, and 23% in untreated areas (Light et al., 2017).

Knight et al. (2014) studied apple orchards treated with standard codling moth sex pheromone dispensers for mating disruption versus those treated with dispensers containing sex pheromone plus pear ester. Monitoring traps baited with virgin codling moth females caught significantly fewer males in orchards treated with combo dispensers compared to pheromone dispensers alone. The authors concluded that combo dispensers were more effective for mating disruption compared to dispensers releasing only sex pheromone.

In wind tunnel experiments, Schmera & Guerin (2012) showed that adding pear ester, *R*(+)-limonene, linalool, or (*E*)-beta-farnesene to dispensers loaded with codling moth sex pheromone increased the proportion of males flying toward the pheromone source, and reduced reaction times to the stimulus.

Stelenski et al. (2013) concluded that pear ester by itself was a codling moth mating disruptant. However, they found that the combination of pear ester and codlemone was not significantly more effective than codlemone alone. It is difficult to draw a conclusion from this data because the authors speculated that their plot sizes were too small to yield a statistically meaningful result (Stelinski et al., 2013).

Report Authorship

The following individuals were involved in research, data collection, writing, editing, and/or final approval of this report:

- William Quarles, Ph.D., Bio-Integral Resource Center (BIRC), Berkeley, California
- Peter O. Bungum, Research and Education Manager, OMRI
- Tina Jensen Augustine, Technical Operations Manager, OMRI
- Ashley Shaw, Technical Research and Administrative Specialist, OMRI
- Meghan Murphy, Graphic Designer, OMRI
- Colleen Al-Samarrie, Technical Research Analyst, OMRI

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

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