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Matters related to the implementation of the Convention: implementation plans

Draft guidance on alternatives to dicofol

Note by the Secretariat

As is mentioned in the note by the Secretariat on the implementation plans (UNEP/POPS/COP.10/10), the annex to the present note sets out a draft guidance on alternatives to dicofol. The present note, including its annex, has not been formally edited.

* Face-to-face resumed meetings of the conferences of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade and the Stockholm Convention on Persistent Organic Pollutants are tentatively scheduled to take place in 2022.

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Annex

Draft guidance on alternatives to dicofol

March 2021

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1. Introduction

At its ninth meeting, the Conference of the Parties to the Stockholm Convention (COP) adopted decision SC-9/11 by which it listed dicofol to Annex A to the Convention for elimination without specific exemptions. In decision SC-9/9, the COP requested the Secretariat to develop guidance on alternatives to dicofol. The aim of this guide is to support Parties as they develop national implementation plans reflecting the addition of dicofol under the Convention in line with Article 7 of the Convention.

In its decision SC-6/8, the COP encouraged Parties to give priority to ecosystem-based approaches to pest control when choosing alternatives (UNEP/POPS/COP.6/33). As well, the fourth meeting of the International Conference on Chemicals Management (ICCM) adopted resolution IV/3: Highly hazardous pesticides, which supported concerted action to address highly hazardous pesticides in the context of the Strategic Approach with an emphasis on promoting agroecologically-based alternatives and strengthening national regulatory capacity to conduct risk assessment and risk management, including the availability of necessary information (SAICM/ICCM.4/15).

Dicofol is used as miticidal pesticide or acaricide on a wide variety of food, feed, and cash crops including apple, citrus, lichi, longan, pear, vegetables, tea, and cotton. It is also used on ornamentals such as orchids and roses. The dicofol risk management evaluation (UNEP/POPS/POPRC.13/7/Add.1) found over 25 technically feasible alternatives including chemical pesticides, biological controls (pathogens and predators), botanical preparations (plant extracts), and agroecological practices (such as are used in agroecology, organics and integrated pest management or IPM).

This document provides more information on the alternatives to dicofol that was described in the risk management evaluation. It focuses on the major crops where dicofol was used for control of mites to assist Parties in finding appropriate approaches that could be used to replace dicofol. These alternatives have been implemented in some countries and regions and are considered technically feasible. However, some of chemical alternatives have hazardous characteristics, including meeting the FAO/WHO criteria for highly hazardous pesticides[1], or a profile similar to that of dicofol. Therefore, **reference to an alternative in this document is not a recommendation or endorsement** as the alternatives have not been evaluated for their suitability and applicability in all situations. Before being used, alternatives will need to go through the appropriate national evaluation and approval processes.

This guide starts by outlining the features of an integrated pest management approach for the main crops on which dicofol has been used. It identifies physical, mechanical, and cultural approaches to minimise damage caused by mites. It then provides information on some biological agents that have been successfully used to control mites and highlights some of the alternative chemical pesticides that have been registered in at least one country to control mites which Parties might consider as alternatives to dicofol. The information was obtained primarily from Australia, Canada, the European Union (EU), India, the United Kingdom (UK) and the United States (US).

2. Integrated Pest Management

The Food and Agriculture Organization (FAO) defines integrated pest management (IPM) as "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms."[2]

IPM is an ecosystem-based strategy that uses a combination of techniques such as biological control, habitat manipulation, modification of cultural practices, and use of resistant varieties to prevent the occurrence of pests. Pesticides are selected and applied in a manner that minimizes risks to human health, beneficial and non-target organisms, and the environment. It focuses on measures that will keep pests from becoming a problem by addressing the environmental factors that affect a pest's ability to thrive. The monitoring of environmental conditions and pest activity on crops helps determine whether or not pest activity is a problem that warrants control, which results in minimising the use of pesticides. The combination of biological, cultural, mechanical and

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[1] The FAO/WHO Joint Meeting on Pesticide Management (FAO and WHO, 2008) defined highly hazardous pesticides to include pesticides that are listed as POPs under the Stockholm Convention (available http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/Report.pdf).

[2] Integrated Pest Management (FAO, undated) (http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/, accessed 2020-11-12).

physical methods, with the use of chemical controls as a last resource, is the most effective, long-term way to manage pests.[3] **Figure 1** illustrates the IPM crop cycle and **Box 1** below describes the different tools of IPM.

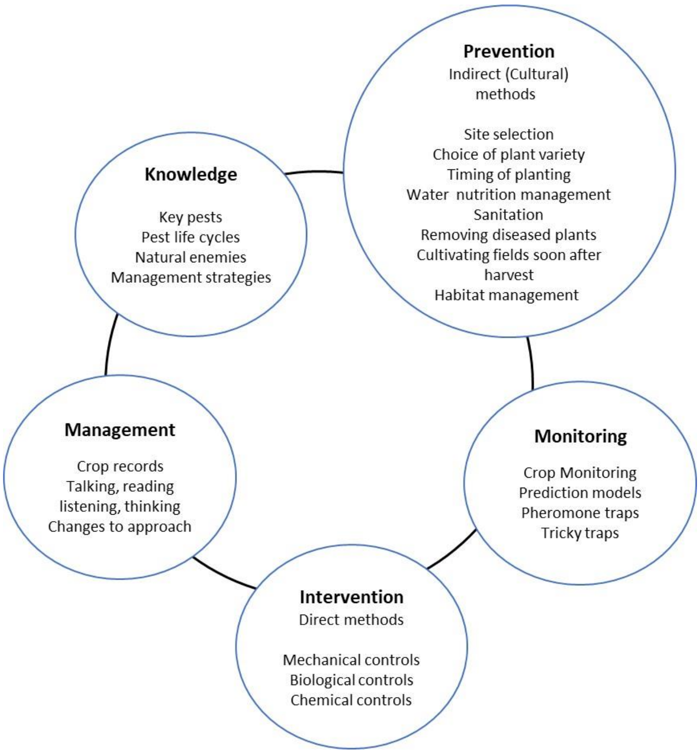

Figure 1. Integrated Pest Management Cycle

Adapted from: New South Wales Government. Vegetable Integrated Pest Management (McDougall 2011).

Box 1: Tools of Integrated Pest Management
Cultural controls Cultural controls are practices that reduce pest establishment, reproduction, dispersal, and survival. They include: crop rotation; inter-cropping; borders that act as trap crops or refugia for predators; pest resistant/tolerant cultivars; standard/certified seed and planting material; cultivation techniques, including watering and nutrient (fertiliser) management and sequential sowing/planting dates.[4] Cultural methods work hand-in-hand with biological control.
Mechanical and physical controls Physical control refers to mechanical or hand controls where the pest is actually attacked and destroyed. Physical controls are used mostly in weed control.[5] Horticultural oils, diatomaceous earth, insecticidal soap, vacuums, and water sprays have been used to control mites.[6] Hand picking of pests, sticky boards or tapes in greenhouses and traps or attractants are also forms of physical control.[7]

[3] UC IPM (undated) What is integrated pest management (https://www2.ipm.ucanr.edu/What-is-IPM/, accessed 2020-11-12).

[4] FAO (undated) Integrated pest management (http://www.fao.org/agriculture/crops/thematic-sitemap/theme/pests/ipm/en/, accessed 2020-11-12) and UC IPM (undated) op. cit.

[5] Alberta (undated) Physical control of pests (https://www.alberta.ca/physical-control-of-pests.aspx, accessed 2020-11-12).

[6] Hillock and Bolin (2017) Mechanical Pest Controls (Available http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2291/HLA-6432web.pdf).

[7] Hoffmann and Frodsham (1993) Integrated Pest Management Control Tactics (https://biocontrol.entomology.cornell.edu/ipm.php#phys, accessed 2020-11-12).

Biological control[8]

Biological control uses natural enemies – predators, parasites, pathogens, and competitors – to control pests and reduce their damage.[9] The use of natural enemies has a long history. There are three general approaches to biological control – conservation, importation and augmentation of natural enemies. Each of these techniques can be used alone or in combination in a biological control program.

In any biological control effort, conservation of natural enemies is a critical component. Conservation of natural enemies involves either, reducing factors which interfere with natural enemies or providing resources that natural enemies need in their environment. In an ecological approach to conservation the goal is to modify the intensity and frequency of disturbances in the environment to the point where natural enemies can function effectively. This may mean providing natural enemies access to alternate hosts, adult food resources, overwintering habitats, constant food supply, and appropriate microclimates. Interventions may need to occur at different scales –field, farm and area level.

Certain cultural practices enhance the effectiveness of biological control. Within fields, modification of tillage intensity and frequency (reduced tillage or no-tillage) can leave more plant residue on the soil surface and have a positive impact on predators (ground beetles and spiders). Intercropping can also modify the microclimate of crop fields making them more favourable for parasitoids. At the farm level, the presence and distribution of non-crop habitats can frequently be critical to natural enemy survival. Typical field border with flowering plants important in providing pollen, nectar, alternate hosts and refuges for natural enemies of pests in agricultural landscapes. Natural enemies are more dependent on refuge habitats than are pests and the greater abundance of these refuges in the overall landscape results in their higher diversity, abundance and ability to respond to prey numbers.

Importation of natural enemies, sometimes referred to as classical biological control, introduces an organism into the environment to control a pest. It is often used against exotic or nonindigenous pests.

Augmentation refers to mass-rearing beneficial insects that are then released to increase their populations in a field or greenhouse. Natural enemies are produced in insectaries, then used either inoculatively or inundatively. Augmentation is used where populations of a natural enemy are not present or cannot respond quickly enough to the pest population. It usually does not provide permanent suppression of pests, which may occur with importation or conservation.

Chemical control

Chemical control refers to the use of natural or synthetic pesticides. As noted above, in IPM, pesticides are used as part of an overall strategy that gives priority to other approaches. When pesticides are used in combination with other methods and only when needed this makes for more effective, long-term control of the pest in question. Preference is given to the pesticides that are least harmful to non-target organisms and applied in a way that minimizes their possible harm to people and the environment. This may mean the use pesticides of bait stations rather than sprays or targeted application of the pesticide rather than spraying an entire area.[10]

2.1 Economic viability of IPM

Many studies show that farmers' income can be higher under an IPM regime as compared to one that is more reliant on calendar spraying of pesticides.[11] A pilot study in three provinces in China that looked at alternatives to the use of dicofol demonstrated that IPM approaches were viable. Eliminating the use of dicofol contributed to food safety, human health and the preservation of the local and global environment. The use of an IMP approach also reduced the quantity and frequency of pesticide use, increased the quantity of crops and improved their quality, expanded market and export potential for the crop, and increased the farmers' income.

In the IPM demonstration for cotton dicofol consumption declined from 1,250 kg in 2010 to 0 kg in 2011 and 2012. Profit increased by Chinese Yuan (CNY) 15.43 million over the three years of the project (2010–2012). The financial success of the project encouraged other farmers to adopt IPM. In the citrus demonstration project, IPM reduced the

[8] This section is primarily taken from Landis DA and Orr DB (2009) Biological Control: Approaches and Application (https://ipmworld.umn.edu/landis, accessed 2020-11-12).

[9] UC IPM (undated) IPM - Integrative pest management. (https://ucanr.edu/sites/hdnmastergardeners/Resources_for_Home_Gardeners/IPM_-_Integrative_Pest_Management/, accessed 2020-11-12).

[10] UC IPM (undated) IPM - Integrative pest management, op. cit.

[11] CropLife International (2014) Integrated pest management (Available https://croplife.org/wp-content/uploads/pdf_files/Integrated-pest-management.pdf).

frequency and quantity of pesticide use with a 15–20% increase effectiveness of diseases control. The three years demonstration activities yielded an 80% higher average net profit – CNY 2,223.30/mu[12] in IPM plots compared to CNY 1,232.67 in non-demonstration plots; dicofol use went from 1,000–2,000 kg in 2010 to 0 kg in 2011. The third pilot was in an apple growing area. Over the three years (2010–2012), average net profit in plots using IPM was 25% higher than in non-demonstration plots – CNY 9,161.95/mu compared to CNY 7,312.6/mu. Dicofol use was 400–500 kg in 2010; none was used in 2011 and 2012.[13]

2.2 IPM in citrus fruits[14]

Mites that affect citrus trees include:

- Broad mite (*Polyphagotarsonemus latus*);
- Citrus bud mite (*Eriophyes sheldoni*);
- Citrus flat mite (*Brevipalpus lewisi);*
- Citrus red mite (*Panonychus citri*);
- Citrus rust mite or silver mite (*Phyllocoptruta oleivora*);
- Kanzawa spider mite or hydrangea mite (*Tetranychus kanzawai*);
- Six-spotted mite (*Eotetranychus sexmaculatus*);
- Texas Citrus mite (*Eutetranychus banksi*);
- Two-spotted spider mite or red mite (*Tetranychus urticae*);
- Yuma spider mite (*Eotetranychus yumensis*).

As in all IPM, it is necessary to monitor pests to determine if control is necessary. The mite of concern may differ at different stages of the growing season as shown for California:

- Pre-bloom: Monitor leaves for the citrus red mite and other mites. Look for natural enemies, especially the predatory mite, *Euseius tularensis*. Keep records and manage if needed;
- Bloom to petal fall: Monitor leaves for the citrus red mite and other mites. Look for natural enemies, especially *Euseius tularensis* and six-spotted thrips. Keep records and manage if needed;
- Fruit development: Look for other pests and their damage to fruit or damage to leaves and twigs, including the Yuma spider and the Kanzawa mite. Manage if needed;
- Late season: Continue to look for other pests and their damage to fruit or damage to leaves and twigs, including the Texas citrus and the Kanzawa mite. Manage if needed.

Cultural control for citrus fruit trees

Generally, mites are more of a problem when trees are water stressed. Adequate irrigation will reduce outbreaks. Since dust build up on trees favours the reproduction of several mites, controlling dust coming from nearby activity and roads will help reduce mite numbers.

Biological control for citrus fruit trees

Control options will differ depending on the mite. Predaceous mites, predaceous insects, and a virus regulate populations of the citrus red mite. The most important natural enemy is the predaceous mite (*Euseius tularensis*). Other predators include a small black lady beetle (*Stethorus picipes*), a predaceous dustywing (*Conwentzia 8arrette*), and the six-spotted thrips (*Scolothrips sexmaculatus*). In addition, a virus specific to citrus red mite which widespread in citrus-growing areas can rapidly reduce populations under warm, moderately dry conditions.

Broad mites often occur in conjunction with citrus rust mite and infestations are enhanced by the presence of Argentine ants. Populations of broad mite tend to be most severe in warm, humid conditions such as those found in

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[12] A Chinese measure of area: 1 mu = 0.067 hectare or 0.16474 acre.

[13] Chen Y, Kwan W (2013) Terminal Evaluation of the UNDP/GEF Project (Available https://erc.undp.org/evaluation/evaluations/detail/6991#).

[14] This section is based on Grafton-Cardwell et al. (undated) Pest Management Guidelines – Citrus (https://www2.ipm.ucanr.edu/agriculture/citrus/, accessed 2020-11-16).

greenhouses. No treatment thresholds have been developed for broad mite in citrus in California; in some cases, levels as high as 80% bud infestation have failed to cause consistent or predictable economic losses.

Citrus rust mites tend to occur along with broad mites and often in greater numbers. Both species thrive in warm, humid conditions. Once you find one or more infested fruit and if rust mites were a problem the previous year, watch the orchard closely. No effective natural enemies are known, but general mite predators feed on rust mites at times. In some cases, the infestation is localized and a spot treatment may be sufficient for control.

Presence of natural enemies are often sufficient to keep many mite populations in check. These include the six-spotted thrip (*Scolothrips sexmaculatus*), the spider mite destroyer (*Stethorus picipes*), minute pirate bugs (*Orius* species) and the predatory mite (*Euseius tularensis*).

Chemical control for citrus fruit trees

If conditions suggest that control is necessary, the University of California Statewide IPM Program identifies the following treatment options ranked with the pesticides having the greatest IPM value – the most effective and least harmful to natural enemies, honey bees, and the environment being listed first. To minimise the development of pesticide resistance, the choice of product also needs to take into account the mode of action:

- For the treatment of broad mites: abamectin with thiamethoxam plus narrow range oil; abamectin plus narrow range oil; cyantraniliprole with abamectin plus narrow range oil; spirodiclofen; fenpyroximate; and wettable sulfur;
- For the treatment of citrus bud mites: fenbutatin oxide plus narrow range oil; abamectin plus narrow range oil; cyantraniliprole with abamectin plus narrow range oil; narrow range oil; spirotetramat plus narrow range oil; and fenpyroximate;
- For the treatment of citrus red mites: non-bearing trees only – bifenazate; bearing trees – narrow range oil; acequinocyl; cyflumetofen; fenpyroximate; hexythiazox ;pyridaben; spirodiclofen; spirotetramat; and fenbutatin oxide;
- For the treatment of citrus rust mites (silver mites): spirodiclofen; diflubenzuron plus narrow range oil; abamectin plus narrow range oil; cyantraniliprole with abamectin plus narrow range oil; spirotetramat plus narrow range oil; micronized sulfur; wettable sulfur; and fenpyroximate;
- For the treatment of Kanzawa mites: abacmetin; and fenbutatin oxide;
- For treatment of two spotted spider mites: non-bearing trees – bifenazate; bearing trees – narrow range oil; acequinocyl; hexythiazox; pyridaben; fenpyroximate; spirodiclofen; abamectin plus narrow range oil; and fenbutatin oxide;
- For the treatment of Yuma spider mites: sulfur; and oil.

Please note that some of the pesticides identified in this section as well as in the following sections are not included in the risk management evaluation adopted by the POPs Review Committee (UNEP/POPS/POPRC.13/7/Add.1).

2.3 IPM in cotton[15]

Monitoring for the presence of pests is the initial stage of an IPM approach for mites on cotton. Various web-spinning spider mites can damage a cotton crop, such as:

- Strawberry spider mite (*Tetranychus turkestani*);
- Pacific spider mite (*Tetranychus pacificus*);
- Two-spotted spider mite (*Tetranychus urticae*);
- Carmine spider mite (*Tetranychus cinnabarinus*).

Sampling for spider mites on cotyledons or first true leaves should start as soon as plants emerge. During squaring, appearance of the first blooms and until the first open boll, examine the 5th mainstem node leaf from the top of the plant to monitor for mites. After the first open boll, sampling for spider mites can stop. Treat when the threshold for mites is surpassed and before defoliation occurs or the mite populations are high.

[15] This section is based on UC IPM (2015) Pest Management Guidelines: Cotton (Available http://ipm.ucanr.edu/PDF/PMG/pmgcotton.pdf).

Botanical, microbial, oil, or soap insecticides are generally less harmful to natural enemies than other pesticides. Avoiding early season, broad-spectrum insecticide applications will help preserve natural enemies of mites. When selective treatment options are applied early in the season, natural enemies are more likely to survive, which helps reduce the risk of pest outbreaks later in the growing season.

Biological control in cotton

To control spider mites it is important to preserve natural enemies as long as possible each season and to anticipate outbreaks following insecticide applications. Predatory mites and thrips are useful in the control of spider mite populations. More research is needed to confirm if the release of the western predatory mite, *Galendromus occidentalis* can be an effective tool.

Cultural control in cotton

Some varieties of cotton, such as pima cotton, are less susceptible to mites. Water-stressed plants will facilitate the outbreak of spider mites; therefore, it is important to ensure proper water management. Sprinkler irrigation has been observed to suppress spider mites.

Pesticides used in cotton

Pesticides that have been used to control mites in cotton in order of greatest IPM value include: abamectin; etoxazole; spiromesifen; fenproximate; bifenazate; hexythiazox; propargite; sulfur dust; insecticidal soap; and narrow range oil.

2.4 IPM in tea

Mites that are pests on tea include:[16]

- Red spider mite (*Oligonychus coffeae – Tetranychidae*);
- Scarlet mite (*Brevipalpus californicus, B. phoenicis – Tenuipalpidae*);
- Pink mite (*Acaphylla theae – Eriophyidae*);
- Purple mite (*Calacarus carinatus – Eriophyidae*);
- Broad mite (*Polyphagotarsonemus latus – Tarsonemidae*);
- Kanzawa spider mite (*Tetranychus kanzawai – Tetranychidae*).

Agro-ecosystem analysis (AESA) based integrated pest management emphasises growing a healthy crop. It includes weekly monitoring of the farm to ensure the growing conditions are optimal and to identify the presence of pests and disease at the earliest moment. Assessing the ratio of pests to beneficial insects supports the appropriate pest management decision.[17]

Cultural practices to control mites in tea[18]

Various cultural practices will reduce the susceptibility of tea to damage caused by mites. Using varieties that are more resistant can reduce damage from certain pests. For example, Chinese varieties are more susceptible to red spider and eriophyid mites and Assam cultivars to the scarlet mite. The Chinese clone Luxi white and wild teas rich in caffeine appear to be more resistant to mite attack.

Regular pruning of tea plants has been shown to minimise or eliminate damage from scarlet mite in Kenya and red spider mite in northeast India. Higher plucking intensity also leads to a reduction in pest populations. Adequate shading reduces the presence of red spider mites. The spread of mites can also be reduced with border plantings of *Adhatoda vesica* (Malabar nut), weed-free cultivation and prevention of incursions of animals from infested fields.

The optimal physical, chemical, and biological properties of soils determine the capability of a crop to resist or tolerate insect pests. For example, optimal fertilization improves the resistance of the tea plant to the scarlet mite and other pests, and inadequate drainage creates conditions conducive to the build-up of red spider mites.

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[16] Nadda G, Reddy SGE, Shanker A. 2013. Insect and mite pests of tea and their management. In *Science of Tea Technology*: 317-333.

[17] NIPHM (2015) AESA based IPM package for tea (Available: https://farmer.gov.in/imagedefault/ipm/tea.pdf).

[18] Hazarika, LK, Bhuyan M, Hazarika BN. 2009. Insect pests of tea and their management. *Annual Review of Entomology* 54: 267–84. DOI: 10.1146/annurev.ento.53.103106.093359.

Biological control of mites in tea[19]

Formulations of fungal agents such as *Beauveria bassiana*, *Verticillium lecanii*, *Paecilomyces fumosoroseus* and *Hirsutella thompsonii* have been found to be effective against pink, purple and red spider mites in tea crops. The neem product, azadirachtin, can control pink and purple mites. Various botanical extracts, such as *Tithonia diversifolia*, *Lantana camara*, *Allium sativum* and *Capsicum annuum*, are possible ways to control populations of red spider mites.

Chemical control of mites in tea

Oil sprays can be effective against eriophyid and red spider mites.[20] The Government of India *AESA Based IPM Package for Tea*[21] identifies a number of pesticides for the control of mites on tea including: azadirachtin (neem); bifenthrin; ethion; fenazaquin; fenpropathrin; fenpyroximate; flufenzine; spiromesifen; and sulphur.

Please note that not all pesticides included in *AESA Based IPM Package for Tea* are listed in the paragraph above; nor have all the botanical extracts referred to above been referred to in section 3.3.3.1 below.

2.5 IPM in vegetable crops[22]

This section provides an overview of IPM approaches for vegetable crops. Susceptibility to mites varies among vegetable crops. For information relevant for a particular crop please refer to available IPM guidance for specific crops such as found in the resources listed in section 2.8 below.

Spider mites of potential concern in vegetable crops include:

- Brown wheat mite (*Petrobia latens*);
- Carmine or red spider mite (*Tetranychus cinnabarinus*);
- Desert spider mite (*Tetranychus desertorum*);
- Pacific spider mite (*Tetranychus pacificus*);
- Spider mite (*Panonychus* species);
- Strawberry spider mite (*Tetranychus turkestani*);
- Red or two-spotted spider mite (*Tetranychus urticae*).

Other mites that may infest vegetable crops include:

- Broad or yellow mite (*Polyphagotarsonemus latus* Banks);
- Bulb mites (*Rhyzoglyphus* and *Tyrophagus* species);
- Dry bulb mite (*Aceria tulipae*);
- Spinach crown mite (*Rhyzoglyphus* species);
- Tomato russet mite (*Aculops lycopersici*);
- Wheat curl mite (*Aceria tosichella*).

Crops that are susceptible to spider mite infections include: beans (dry, lima, snap) table beet, sweet corn, cucumber, eggplant (aubergine or brinjal), melon, pepper, Irish and sweet potato, pumpkin, squash and tomato.

[19] BizEncyclopedia (2019) Integrated pest and disease management in tea plantations (https://www.bizencyclopedia.com/articles/view/6312/51, accessed 2021-02-12).

[20] BizEncyclopedia (2019) op. cit.

[21] NIPHA (2015) AESA based IPM package for Tea (available https://farmer.gov.in/imagedefault/ipm/tea.pdf).

[22] This section is a synthesis of information from: National Institute of Plant Health Management AESA Based IPM Packages (https://niphm.gov.in/IPMPackages.html); Rinehold J, Bell N, Waters T. 2018. Vegetable pests (https://pnwhandbooks.org/sites/pnwhandbooks/files/insect/chapterpdf/insect20-k-vegetables.pdf); University of California Statewide Integrated Pest Management Program (UC IPM) Pest management guidelines – agricultural pests (https://www2.ipm.ucanr.edu/agriculture/, accessed 2021-02-12).

Cultural practices to control mites in vegetables

Keeping fields and field margins clean of weed hosts for mite pests and maintaining habitat that attracts natural enemies are among cultural practices that will limit the number of pests. Mite outbreaks can occur when pesticides are used early in the growing season as this may impact populations of mite predators and other beneficial insects. Mite management requires early scouting. Because mites reproduce better on stressed plants, check areas of fields where plants are more stressed.

Dry, dusty conditions favour spider mite infestations, therefore, reducing dust, such as the dust caused by driving on dirt roads, may reduce their populations. Spider mites are usually less severe in sprinkler-irrigated fields compared to fields where furrow-irrigation is used. While healthy plants are less susceptible to mites, excessive nitrogen fertilization is associated with higher spider mite populations.

To reduce the population of mites avoid planting successive onion or garlic crops and fallow fields to allow organic matter to decompose completely. Crop rotation, planting mite-free garlic cloves or onion bulbs and hot water treatment of seed pieces will limit mite populations. It is recommended that onion or garlic not be planted immediately after *Brassica* species, corn, wheat, sudan grass or grass cover crops.

Biological control of mites in vegetables

There are a number of insect and mite predators, including some available commercially, that can keep spider mite populations under control, especially early in the growing season. These include:

- Anthocorid bugs (*Orius* spp.);
- Big-eyed bug (*Geocoris* species);
- Green lacewings (larvae of *Chrysoperla carnea, Chrysoperla zastrowii sillemi*, and *Mallada basalis*);
- Minute pirate bug (*Orius tristicolor* and other *Orius* species);
- Mirid bug (*Miridae*);
- Predatory coccinellid beetles,"ladybirds", "lady beetles", or "lady bugs" (*Stethorus punctillum, Stethorus punctum* and other *Stethorus* species);
- Predatory midges or cecidomyiid fly (*Aphidoletes aphidimyza*, *Anthrocnodax occidentalis*, and the predatory gall midge *Feltiella minuta*);
- Predatory mites (*Amblyseius alstoniae, A. womersleyi, A. fallacies)*, phytoseiid mites (*Phytoseiulus persimilis*), and the western predatory mite (*Metaseiulus occidentalis*);
- Staphylinid or rove beetle (*Oligota* species);
- Syrphid or hover flies (*Syrphidae* species).

The following biological agents are available and are suitable for certain vegetable crops: *Beauveria bassiana* - strain ANT, *Burkholderia* species, *Chenopodium ambrosioides*, *Chromobacterium subtsugae*, *Isaria fumosorosea*, and *Metarhizium anisopliae*. Products that include azadirachtin (neem oil), kaolin, and plant-derived essential oils (such as citronellol, clove oil, farnesol, garlic oil, geraniol, nerolidol, and rosemary oil) are also available, especially for home use.

Chemical control of mites in vegetables

The following pesticides have been registered to control mite on various vegetable crops: abamectin, acequinocyl, azadirachtin, bifenazate, bifenthrin, borate complex, cyflumetofen, etoxazole, hexythiazox, insecticidal soap, fenbutatin oxide, fenpropathrin, fenproxymate, fenpyroximate, mineral or petroleum oil, oxamyl, potassium salts of fatty acids, propargite, propylene glycol monolaurate, pyridaben, spiromesifen, and sulfur. The following combination products have also been registered for use: bifenthrin/avermectin, bifenthrin/gamma-cypermethrin, bifenthrin/zeta-cypermethrin chlorantraniliprole/lambda-cyhalothrin.

2.6 IPM in ornamental plants[23]

Important mite pests in ornamental plants include the two-spotted spider or red spider (*Tetranychus urticae*), Lewis (*Eotetranychus lewisi)*, bulb (*Rhyzoglyphus* species), cyclamen (*Stenotarsonemus pallidus* or *Phytonemus pallidus*), broad (*Plyphagotarsonemus latus*) and false spider or flat (*Brevipalpus* species) mites.

The two-spotted spider mite is a common pest as over 300 plant species can act as hosts. The Lewis mite is a pest of poinsettias. Bulb mites are pests of dahlia, freesia, gladiolus, hyacinth, iris, narcissus, orchid, and tulip. In addition to clyclamen, favoured host plants for cyclamen mites include the African violet, azalea, begonia, chrysanthemum, dahlia, delphinium, exacum, fuchsia, gerbera, geranium, gloxinia, kalanchoe, New Guinea impatiens, snapdragon, and strawberry. Gerbera, African violets, cyclamen, begonias, impatiens, verbena and gloxinia are among the plants that will host broad mites. False spider mite is a pest of a wide variety of greenhouse plants. It is commonly found on orchids, as well as on palms, privet, citrus, walnut, and other woody ornamentals and conifers.

Cultural practices to control mites in ornamental plants

The first step in managing mites is good sanitation: remove weeds in and near greenhouses; inspect new plants for mites before placing bringing them into the greenhouse or planting them in the field; and discard heavily infested plants taking precautions not to spread mites as you do so. Keep plants sufficiently watered, optimally fertilised, and under adequate lighting.

To reduce the risk of bulb mite infestations, prevent damage to bulbs and store them at low humidity. Steam pasteurization can control bulb mites in the soil. Only a few plants are affected by cyclamen mites. Discard the infested plants. Another option is to submerge the whole non-flowering plant in warm water. Plants infested with broad mite need to be identified quickly, removed and destroyed.

Biological control of mites in ornamental plants

The two-spotted spider mite thrives in greenhouse conditions. Pest outbreaks are more likely under very hot, dry conditions that favour the development of spider mites. Of tropical origin, the predator *Phytoseiulus persimilis* is well suited for controlling mites in greenhouses and can be used in conjunction with other predators. The predatory mite *Amblyseius fallacis* (*Neoseiulu fallacis*) shows promise for two-spotted spider mite control in floriculture. The black ladybug beetle (*Stethorus picipes*), known as the 'spider mite destroyer', is available commercially for both greenhouse and outdoor crops. Other biocontrol agents for mites include the gall midge *Feltiella acarisuga*, the predatory mite *Amblyseius californicus* and *Amblyseius swirskii*, which feeds secondarily on spider mites.

Predatory mites (*Hypoaspis* species) which feed on soil insects such as fungus gnats can help it the control bulb mites. *Hypoaspis aculeifer* has been used to control bulb mites in amaryllis, lily, and freesia. Predatory mites (*Amblyseius* species) and other generalist predators will feed on cyclamen mites but do not provide reliable control. have been identified for cyclamen mites.

Control of broad mites is difficult an no reliable biological controls have been identified, though predatory mites (*Amblyseius* species) and other generalist predators will feed on tarsonemid mites such as broad mites. While *Phytoseiulus persimilis* and other predatory mites may feed on false spider mites, their efficacy is still unknown.

Chemical control of mites in ornamental plants

There is a wide range of pesticide products available to control mites, spider mites in particular. **Box 2** below lists some of the pesticides that have been approved for use on ornamental plants grown in the field or in protected settings such as greenhouses.

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[23] This section is primarily derived from British Columbia (BC) Ministry of Agriculture (2016) *Mites in Floriculture*. (https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/plant-health/phu-mites-floriculture.pdf). A companion resource is the *Floriculture Production Guide* (https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/crop-production/floriculture-production-guide.pdf).

Box 2: Selected products to control mite pests in ornamental plants[24]

Active Ingredient	Mites Controlled[25]	Use Site and Plant
Abamectin	Two-spotted spider mites	Greenhouse
Acephate	Spider mites	Outdoor: arborvitae, azalea, *Callistemon, Camellia*, cypress, *Dahlia,* fir, *Gleditsia, Hemerocallis, Hydrangea, Ilex, Juniperus*, *Pachysandra, Phlox, Picea, Pinus, Primula, Quercus, Rosa, Tagetes, Tsuga, Viburnum* Christmas trees, tree nurseries, shelter belts Trunk injection for ornamental deciduous and coniferous trees in landscapes and farms Bladder gall mite on *Acer*
Acequinocyl	Two-spotted spider mite European red mite Spruce spider mite	Greenhouse and outdoor
Bifenazate	Two-spotted spider mite Lewis mite Spruce spider mites	Greenhouse and outdoor: Ornamentals and conifers
Calcium polysulphide (Lime Sulphur)	Blister mite Rust mite	Outdoor: Rosaceous trees and shrubs (*Malus*, *Pyrus*)
Canola oil	Mites (not specified)	Greenhouse and outdoor: Flowering, foliage and bedding plants, shade trees, shrubs, *Rosa*
Carbaryl	Eriophyid mites	Outdoor: *Acer,* arborvitae, azalea, *Betula, Buxus, Chrysanthemum, Cornus, Dianthus, Gladiolus, Hydrangea, Ilex, Juniperus, Pinus, Quercus, Rosa, Syringa, Ulmus, Zinnia*
Chlorfenapyr	Two-spotted mite	Greenhouse
Chlorpyrifos	Mites (not specified)	Greenhouses and nurseries: Arborvitae, *Juniperus*
Clofentezine	Two-spotted mite European red mite McDaniel mite	Outdoor: Outdoor deciduous nursery stock (including *Caragana, Clematis, Crataegus, Euonymus, Hedera, Malus, Potentilla, Prunus, Pyrus, Ribes, Rosa, Salix, Ulmus*) and herbaceous perennials
Cyflumetofen	Spruce spider mite	Outdoor: Bed and container-grown conifers, including Christmas trees
Dichlorvos	Two-spotted spider mite	Greenhouse
Dimethoate	All mites	Outdoor: Azalea, arborvitae, *Buxus, Camellia,* cedar, Christmas trees (*Abies balsamea, Picea, Pinus*), *Dianthus, Ilex, Poinsettia, Rosa*, *Taxus, Tsuga*
Etoxazole	Spider mites	Greenhouse: Ornamentals and cut flowers

[24] Source: BC Ministry of Agriculture (2016) Mites in Floriculture (https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/plant-health/phu-mites-floriculture.pdf) and BC Ministry of Agriculture (2020) *Pesticides Registered for use on Ornamental Crops* (https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/agriculture-and-seafood/animal-and-crops/crop-production/pesticides_registered_for_ornamental_crops.pdf).

[25] Pesticides that control the two-spotted spider mite will also control false spider mites.

Box 2: Selected products to control mite pests in ornamental plants[24]		
Active Ingredient	**Mites Controlled[25]**	**Use Site and Plant**
Fenbutatin oxide	Two-spotted spider mites Spruce spider mites	Greenhouse and outdoor: Greenhouse ornamentals Outdoor nursery stock
Fenpyroximate	Broad mite Spider mites Cyclamen mite	Greenhouse
Malathion	Two-spotted spider mites	Greenhouse and outdoor: Greenhouse *Antirrhinum, Chrysanthemum, Dianthus,* geranium, *Rosa* Outdoor ornamentals
Mineral oil	European red mite Two-spotted spider mite Spruce spider mite Red spider mites Pear blister mites Spruce spider mites	Greenhouse and outdoor: Ornamental plants, shade trees and shrubs Ornamental trees, evergreens (Christmas trees), and hardy shrubs Crabapple, *Berberis, Crataegus, Malus, Picea, Pinus, Prunus, Sorbus, Ulmus*
Naled	Two-spotted spider mite	Greenhouse and outdoor: Greenhouse roses and cut flowers Outdoor-grown arborvitae, *Aucuba,* azalea, *Campanula, Chrysanthemum, Dahlia, Magnolia* (Chinese), *Matthiola, Pittosporum, Privet, Rosa, Salix, Zinnia*
Potassium salts of fatty acids	Two-spotted spider mite	Greenhouse and outdoor: Ornamental and shade trees Greenhouse and outdoor-grown bedding, flowering, foliage and houseplants
Potassium salts of fatty acids with pyrethrins	Mites (not specified)	Greenhouse, interior plantings, shrubs and trees
Pyridaben	Two-spotted spider mite	Greenhouse and outdoor ornamentals
Spiromesifen	Two-spotted spider mite Broad mite	Greenhouse and outdoor ornamentals
Spirotetramat	Mites (not specified)	Outdoor: Field and container ornamentals except conifers
Metarhizium anisopliae	Spider mites (suppression)	Greenhouse ornamentals except conifers
Beauveria bassiana	Two-spotted spider mite (suppression)	Greenhouse ornamentals

2.7 IPM in greenhouses[26]

Pest management in greenhouses environment are complex especially then diverse number of crops, each with their own pest issues are grown together. The enclosed nature of the is conducive to the swift spread of a pest problem, but at the same time provides an environment where biological control can be used as an effective, low risk management approach.[27]

[26] This section is based on Murphy G, Ferguson G, Shipp L (2014) Mite Pests in Greenhouse Crops (http://www.omafra.gov.on.ca/english/crops/facts/14-013.htm, accessed 2021-02-16) and Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA, 2019) Crop Protection Guide for Greenhouse Vegetables 2020–2021 (available http://www.omafra.gov.on.ca/english/crops/pub835/pub835.pdf). Additional information on IPM in greenhouses is available at http://greenhouseipm.org/.

[27] Agriculture and Agri-food Canada (2017) Pesticide Risk Reduction Strategy for Greenhouse Floriculture (https://www.agr.gc.ca/eng/scientific-collaboration-and-research-in-agriculture/agriculture-and-agri-food-research-centres-and-collections/ontario/pest-management-centre/pesticide-risk-reduction-at-the-pest-management-centre/pesticide-risk-reduction-strategies/pesticide-risk-reduction-strategy-for-greenhouse-floriculture/, accessed 2021-02-17).

Mite pests in greenhouses include the two-spotted spider mite which has a host range of hundreds of plant species, including all major vegetable crops and many ornamental crops. Closely related are the carmine spider mite and Lewis mite. Other mites include: the microscopic broad and cyclamen mites; the tomato russet mite which belongs to a family of mites called gall mites; and the bulb mite which are pest of crops such as lilies, tulips, gladiolus, daffodils and amaryllis.

Management of spider mites in greenhouses

Essential to preventing infestation of spider mites in greenhouse is the vigilant monitoring of greenhouse and plant conditions. Inspection of new plant material entering the greenhouse to ensure it is plant free will reduce unintentional introduction of mites into the enclosure. Scrutiny of susceptible crops and varieties as well as areas of the greenhouse that are warmer and drier can help detect the presence of spider mites early before their population build up.

In vegetables a proper clean-up at the end of the crop rotation will reduce initial infestations in the crop that follows. Some mites go into diapause and shelter in the ground, hollow stems, pipe fittings, cracks and crevices. Proper sanitation practices can remove these habitats. Also monitor regularly in areas that were infested during the previous crop rotation.

Misting plants and raising the humidity will help suppress spider mite populations. A combination of predators may be used in controlling spider mites. *Phytoseiulus persimilis* feeds on spider mites only and will die if there are no mites to feed on. This means new spider mite infestations require new introductions of the predator. Other predatory mites that are tolerant to high temperatures (e.g. *Amblyseius Andersoni, Amblyseius californicus,*) or pesticides (e.g. *Amblyseius fallacis*) are also available. In addition, the small black lady beetle *Stethorus punctillum,* the gall midge *Feltiella acarisuga*, and the lace wing *Chrysopa carnea* will prey on mites. Beauveria bassiana PPRI 5339 can be used on cucumber, eggplant, lettuce peppers and tomatoes, and the fungal agent *Metarhizium anisopliae* reduces pest numbers in various crops such as cucumber, eggplant, lettuce, peppers, tomatoes and strawberries. Commercially available natural enemies of spider mites in greenhouse crops include the predatory mites *Galendromus occidentalis* and *Mesoseilus longipes*.[28]

Management of broad mite and cyclamen mite in greenhouses

The presence of these small mites usually only become visible by the damage they have caused to plants. To slow growth in numbers of broad and cyclamen mites, quickly remove infested plants or plant parts and ensure good weed control inside and outside the greenhouse.

Various predatory mites such as *Neoseiulus cucumeris, Amblyseius swirskii, Amblyseius californicus and Amblyseius andersoni* are reported to feed on broad and cyclamen mites. Greenhouse studies have found *Neoseiulus cucumeris, Amblyseius californicus* and *Amblyseius swirskii* to suppress broad mites on crops such as peppers and begonia. Best control occurs when predatory mites are in the crop before pest infestations start. Pesticides can control broad mites and cyclamen mites, though this may negatively impact biological control of other pests.

Management of the tomato russet mite

Tomato russet mites disperse though the greenhouse on the hands, clothing and equipment of workers. Their presence is normally only noted when damage is observed. Good housekeeping and hygienic practices as well as removing plants or affected plant parts will reduce their spread. Other measures include ensuring no potential host plants enter the greenhouse between plantings and thorough clean-up inside and outside the greenhouse.

Predatory mites such as *Amblyseius fallacis* and *Amblyseius swirskii* may have some potential for managing tomato russet mite. However, an integrated approach that includes monitoring, application of biocompatible pesticides and releases of predatory mites on plants showing symptoms is recommended.

Management of bulb mites

Careful inspection of bulbs for mites when they first arrive at the greenhouse is critical to minimise infestation. Bulb mites are often associated with bulb and root rot diseases; therefore, fungicide treatment may for these diseases may also help reduce mite infestations. The predatory mite *Gaeolaelaps aculeifer* (*Hypoaspis aculeifer*) and other soil-dwelling predators such as the rove beetle *Dalotia coriarial* (*Atheta coriaria*) may offer some control.

[28] Pundt L, Raudales R and Smith C, editors (2020) New England Greenhouse Floriculture Guide (http://negfg.uconn.edu/sectionB.php, accessed 2021-02-18).

Chemical control of mites in greenhouses

Two-spotted spider mites can quickly develop pesticide resistance. The use non-chemical control is important to minimize the development of pesticide resistance. Minimising pesticide applications and rotating among products with different modes of action can mitigate the development of resistance. When using pesticides ensure good coverage and that the pesticide reaches the mites and the eggs within and beneath the web. When the red diapausing mites are detected, use soap sprays on lightly infested leaves, and remove and destroy more heavily infested leaves. **Box 3** below identifies selected pesticides that can be used to control mites in greenhouses.

Box 3: Selected products to control mite pests in greenhouses[29]							
Pesticide	**Pest**	**Greenhouse Crop**					
		Cucumber	**Eggplant**	**Lettuce**	**Pepper**	**Tomatoes**	**Strawberries**
Abamectin	Two-spotted spider mite (*Tetranychus urticae*)	✓			✓	✓	
Acequinocyl	Two-spotted spider mite	✓	✓		✓	✓	
Bifenazate	Two-spotted spider mite	✓	✓		✓	✓	
Canola oil	Not specified	✓	✓	✓	✓	✓	✓
Chlorfenapyr	Two-spotted spider mite Broad mite (*Polyphagotarsonemus latus*)*	✓*	✓		✓	✓	
Etoxazol	Two-spotted and carmine spider mite					✓	
Fenbutatin oxide	Two-spotted spider mite	✓				✓	
Fenpyroximate	Two-spotted spider mite	✓	✓		✓	✓	
Mineral oil	Not specified	✓	✓		✓	✓	
Naled	Two-spotted spider mite	✓	✓		✓	✓	
Potassium salts of fatty acids	Two-spotted spider mite	✓	✓	✓	✓	✓	✓
Potassium salts of fatty acids with pyrethrins	Two-spotted spider mite	✓	✓	✓	✓	✓	
Pyridaben	Two-spotted spider mite	✓			✓	✓	
Spiromesifen	Two-spotted spider mite	✓	✓		✓	✓	

2.8 Sources of information on IPM

The following websites provide more information on IPM approaches for specific crops.

- FAO Asian Regional IPM - Pesticide Risk Reduction Programme: http://www.vegetableipmasia.org/crops/;
- IPM Package of Practices (Government of India, Department of Agriculture & Cooperation and Farmers Welfare): https://farmer.gov.in/ipmpackageofpractices.aspx;
- New York State Integrated Pest Management Program: http://nysipm.cornell.edu/;
- University of California State-wide IPM program: http://www.ipm.ucdavis.edu.

[29] Compiled from OMAFRA (2019) op. cit. (Available http://www.omafra.gov.on.ca/english/crops/pub835/pub835.pdf).

3. Non-chemical approaches to control mites

3.1 Cultural methods

Cultural methods are described in the IPM section above.

3.2 Mechanical Treatments

Mechanical treatments for spider mites include the use of horticultural oils, diatomaceous earth, insecticidal soap, vacuums and water sprays.[30]

Horticulture oils are petroleum-based products that form layers on plant parts that smother insects or provide a mechanical barrier to prevent damage.

Diatomaceous earth is considered a pesticide that is non-toxic to birds and mammals. The sharp edges of the ground diatoms scratch the waxy or oily outer layer of soft-bodied insects, which die eventually from dehydration; thus, it described as mechanical pest control method. It may also be called a mechanical barrier or repellent because some insects will not crawl on or feed upon plant foliage sprinkled with it.

Insecticidal soaps and detergents are effective against most small, soft-bodied arthropods such as spider mites, However, predatory mites are also easily killed by soaps.

Insect vacuums can remove certain insects from plants. These tools may use disposable cartridge lined with a non-toxic, sticky gel to trap insects that are captured.

Water pressure sprays will sometimes dislodge insects such as spider mites from foliage and plant stems. Spider mites can be rinsed off of plant leaves which helps reduce the potential for population booms. It is not effective on high populations, however.[31]

3.3 Biological methods

3.3.1 Predators

Arthropod predators can be found in almost all habitats. Predators of insects and mites include beetles, true bugs, lacewings, flies, midges, spiders, wasps, and predatory mites. Some predators are specialized, while others are generalists. Their ability to suppress pests varies. Some appear too late in the growing season while others may also prey on other natural enemies. Even if beneficial species have only a minor impact, they contribute to keeping overall pest populations low.[32] The sections 2.3 to 2.7 above mention potential predators. Principal mite pests and some of their natural enemies are highlighted in **Box 4** below.

Box 4: Selected mite pests and some of their natural enemies

Pest	Predator
Broad mite/cyclamen mite	*Amblyseius andersoni,* (mite) *Amblyseius californicus* (mite) *Amblyseius cucumeris* (mite) *with Orius insidiosus* (minute pirate bug) *Amblyseius swirskii* (mite) *Neoseiulus californicus* (mite) *Neoseiulus cucumeris* (mite) *Neosiulus fallacis* (mite)

[30] Hillock and Bolin (2017) Mechanical Pest Controls (Available http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2291/HLA-6432web.pdf).

[31] Clemson Cooperative Extension (2017) Integrated Pest Management for Spider Mites (https://hgic.clemson.edu/factsheet/integrated-pest-management-i-p-m-for-spider-mites/, accessed 2021-02-18).

[32] Hoffmann and Frodsham (1993) Natural Enemies of Vegetable Insect Pests (https://biocontrol.entomology.cornell.edu/predators.php, accessed 2020-11-26).

Box 4: Selected mite pests and some of their natural enemies	
Pest	**Predator**
Bulb mites	*Gaeolaelaps* (=*Hypoaspis*) *aculeifer* (mite) *Dalotia* (=*Atheta*) *coriaria* (rove beetle)* *Stratiolaelaps scimitus (Hypoaspis miles)* (fungus gnat)*
European red mite	*Galendromous occidentalis* (mite*)* *Stethorus punctillum* Weise (lady beetle) *Typhlodromus pyri* (mite)
Russet Mites	*Amblyseius andersoni* (mite) *Amblyseius cucumeris* (mite) *Amblyseius swirskii* (mite) *Galendromus occidentalis* (mite) *Neoseiulus californicus* (predatory mite)
Spider mites	*Amblyseius andersoni* (mite) *Amblyseius californicus* (mite) *Amblyseius fallacis* (mite) *Chrysopa* species (lacewing) *Chrysoperla* species (lacewing) *Galendromus occidentalis* (mite) *Orius* species (minute pirate bugs) *Phytoseiulus persimilis* (mite) *Stethorus picipes* (lady beetle)
Spider mite, Two-spotted or red spider mite (*Tetranychus urticae*)	*Amblyseius andersoni* (mite) *Chrysopa carnea* (lacewing) *Feltiella acarisuga* (midge) *Galendromus occidentalis* (mite) *Metarhizium anisopliae* (fungus) *Mesoseiulus longipes* (mite) *Neoseiulus* (=*Amblyseius*) *californicus* (mite) *Neoseiulus* (=*Amblyseius*) *fallacis* (mite) *Orius insidiosus* (minute pirate bug) *Phytoseiulus persimilis* (mite) *Stethorus punctillum* (beetle)
Tomato russet mite	*Amblyseius fallacis* (mite) *Amblyseius swirskii* (mite)
Various mites	*Coleomegilla maculata* (lady beetle) *Galendromous occidentalis* (mite) *Phalangium opilio* (spider) *Stethorus punctillum* Weise (beetle) *Zetzellia mali* (mite)

* May offer some control

3.3.2 Biopesticides

Biopesticides are certain types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. They include biochemical pesticides which are made from naturally occurring substances that control pests by non-toxic mechanisms such as substance that interfere with mating (e.g., pheromones) and scented plant extracts that attract insect pests to traps. Microbial pesticides are those that use a microorganism (e.g., bacterium, fungus, virus or protozoan) as the active ingredient.[33]

Pathogens are biological agents that cause disease in a targeted pest. There are several miticides that are based on fungi that will cause disease and kill mite pests. Examples of biological agents are listed in **Box 5** below. Please note that not all of the biological agents listed in this table were identified in the risk management evaluation (UNEP/POPS/POPRC.13/7/Add.1). Some of these agents are registered as pesticides.

Box 5: Examples of biological agents	
Fungal pathogens	
1. *Beauveria bassiana* strain GHA	
Description of the alternative	*Beauveria bassiana* is a naturally occurring entomopathogenic fungus causing white muscardine disease in foliar pests through contact action (UNEP/POPS/POPRC.8/INF/14/Rev.1). It occurs naturally in soils throughout the world. *B. bassiana* causes a disease in many types of insects. While organisms living in or near the soil have evolved natural defences to this fungus, it can be used as a biological insecticide against many other insects. GHA is one of many strains.[34]
Pest controlled / crop	*B. bassiana* strain GHA is used as a pesticide for controlling many kinds of insects and mites. It can be used on food crops and non-food crops both outdoors and indoors.[35] In the US, it has been used to control the two-spotted spider mite (*Tetranychus urticae*). Combination products of *B. bassiana* Strain GHA and pyrethrins are used to control various spider mites including the two-spotted spider mite, carmine spider mite (*Tetranychus cinnabarinus*), citrus rust mite (*Phyllocoptruta oleivora*), panicle rice mite (*Steneotarsonemus spinki*), Pacific spider mite (*Tetranychus pacificus*) and the clover mite (*Bryobia praetiosa*).[36] *B. bassiana* strain GHA is authorised for use in Austria, Finland, France, Greece Netherlands and Sweden for indoor applications to control sucking insects on tomatoes, cucumbers, and ornamentals.[37] In the UK it is permitted on some edible crops and ornamental plants grown in protected settings only.[38] Canada has registered products containing *B. bassiana* strain GHA to control of whitefly, aphids and thrips on greenhouse ornamentals and vegetables and for bed bugs.[39]
Risk	*B. bassiana* strain GHA is reduced-risk biopesticides. It is a moderate eye irritant and potential allergen and sensitizer.[40] The risk for humans, non-target organisms or the environment including groundwater is considered negligible. Data suggest a low risk to bees and other pollinators. The European Food Safety Authority (2013)[41] concluded that *B. bassiana* strain GHA posed a low risk to birds, mammals, fish, aquatic invertebrates, algae, and earthworms. There were data gaps with regards to pollinators, soil-dwelling

[33] US Environmental Protection Agency (undated) What are biopesticides? (https://www.epa.gov/ingredients-used-pesticide-products/what-are-biopesticides, accessed 2020-11-26).

[34] PMRA (2009) *Beauveria bassiana* strain GHA (Available http://publications.gc.ca/collections/collection_2010/arla-pmra/H113-9-2009-3-eng.pdf).

[35] US EPA (1999) *Beauveria bassiana* strain GHA (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-128924_01-Nov-99.pdf).

[36] See for example the label for Botanigard Maxx™ (Available https://www.bioworksinc.com/wp-content/uploads/products/botanigard-maxx/botanigard-MAXX-label.pdf).

[37] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-11-26).

[38] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-26).

[39] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-26).

[40] PMRA (2009) *Beauveria bassiana* strain GHA (Available http://publications.gc.ca/collections/collection_2010/arla-pmra/H113-9-2009-3-eng.pdf); EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-11-26).

[41] EFSA (2013) Conclusion on pesticide peer review (Available https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2013.3031).

	non-target arthropods and soil microorganisms. Residues of this pesticide are not expected to remain on treated food or feed.[42]
2. *Beauveria bassiana* strain ATCC 74040	
Description of the alternative	*B. bassiana* strain ATCC 74040 is a common pathogen of many insect species. It is a ubiquitous fungus found in a variety of soils and climatic conditions in around the world.[43]
Pest controlled / crop	In the US, the strain ATCC 74040 is approved for the control a wide range of pests (adults and larvae of many kinds of insects such as whiteflies, aphids, thrip, psyllid, grasshoppers, etc.) outdoors and in greenhouses on ornamental plants, turf grass, food and feed crops, fruit trees, and home ornamental gardens. Labelled uses include the control of the Bermuda grass mite (*Eriophyes cynodoniensis*) and tetranychid mites.[44] *B. bassiana* strain ATCC 74040 is approved for use in Greece, France, Luxemburg, Netherlands and Poland. The supported use is for the control of whiteflies on tomatoes in greenhouses.[45] It is approved for use in protected settings on all edible crops and on ornamental plants in the UK.[46]
Risk	Available information indicates that *B. bassiana* strain ATCC-74040 is a low-risk pesticide.[47] There is a potential to affect bees, therefore applicators need to avoid areas where honeybees are actively foraging or around bee hives. While it is not expected to cause significant adverse effects on non-target aquatic invertebrates in the environment, it is not to be applied directly to water or near surface waters. Precautions need to be taken not to contaminate water. The European Food Safety Authority concluded that *B. bassiana* strain ATCC-74040 posed a low risk to birds, mammals, fish, algae, earthworms, soil micro-organisms and non-target plants. There was insufficient data to assess the risk to aquatic invertebrates and pollinators for both the field and greenhouse uses as well as the risk to sewage treatment facilities from greenhouse use.[48]
3. *Beauveria bassiana* strain PPRI 5339	
Description of the alternative	*B. bassiana* strain PPRI 5339 is a naturally occurring fungus initially isolated from the larva of a tortoise beetle (*Conchyloctenia punctata*) collected in KwaZulu Natal, South Africa.[49]
Pest controlled / crop	In Canada[50] and Australia,[51] *B. bassiana* strain PPRI 5339 is registered for use in greenhouse or other protected setting. This pesticide will suppress various pests such as whiteflies, aphids, two-spotted spider mites and thrips on ornamental plants and vegetables in greenhouses or other protected settings. While available information

[42] US EPA (1999) *Beauveria bassiana* strain GHA (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-128924_01-Nov-99.pdf).

[43] EU Pesticides database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-26).

[44] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/, accessed 2020-11-26); US EPA (2000) *Beauveria bassiana* strain ATCC 74040 (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/decision_PC-128818_1-Sep-00.pdf).

[45] EU Pesticides database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-26).

[46] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/, accessed 2020-11-26)

[47] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/, accessed 2020-11-26); US EPA (2000) *Beauveria bassiana* strain ATCC 74040 (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/decision_PC-128818_1-Sep-00.pdf).

[48] EFSA (2013) Conclusion on pesticide peer review (Available https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2013.3031).

[49] EFSA et al. (2018) Conclusion on the peer review (Available https://efsa.onlinelibrary.wiley.com/doi/full/10.2903/j.efsa.2018.5230).

[50] PMRA (2017) Proposed Registration Decision PRD2017-19 (Available http://publications.gc.ca/collections/collection_2017/sc-hc/H113-9/H113-9-2017-19-eng.pdf)

[51] APVMA (2017) Public release summary (Available https://apvma.gov.au/sites/default/files/publication/27466-27466-80782_-_101640_-_broadband_od_insecticide_-_prs.pdf).

	supports the use of *B. bassiana* strain PPRI 5339 to control thrips and whiteflies in greenhouse vegetable crops and in greenhouse ornamental plants, as of November 2020, no EU member state had authorised its use.[52]
Risk	It is not possible to classify *B. bassiana* strain PPRI 5339 a low-risk pesticide in Europe at this time. There is potential for workers who inhale *B. bassiana* strain PPRI 5339 to become sensitised to it or develop an allergenic reaction. There is also sufficient uncertainty regarding impacts to non-target organisms.[53] This pesticide may be harmful to bees and aquatic organisms. Due to its impact on beneficial arthropods, it may not be compatible with IPM programs.[54]
4. *Hirsutella thompsonii*	
Description of the alternative	Originally isolated from the eriophyid mite in India, this fungus causes degeneration of the mite cuticle.[55]
Pest controlled / crop	No products containing *Hirsutella thompsonii* are currently registered in Australia,[56] Canada,[57] the EU, UK[58] and US.[59] There are products available in India for the control of pink, yellow and red mites in tea, rose, fruits, vegetables and plantation crops (apple, coconut, citrus, lychee, eggplant, chili, cucurbits, tomato, tea, roses, cotton).[60] *H. thompsonii* (Fisher var. *vinacea*) released on lemon trees in Tucuman, Argentina resulted in an initial 92% decrease in the citrus bud mite (*Eriophyes sheldoni* Ewing), but the persistence is unknown.[61] The strain Fisher var. *synnematosa* resulted in only about a 50% infection rate in the citrus bud mite and citrus rust mite (*Phyllocoptruta oleivora* Ashmead.
Risk	No information found.
5. *Isaria fumosorosea*	
Description of the alternative	*Isaria fumosorosea* is a naturally occurring insect fungus found in infected and dead insects, and in some soils. The fungus infects the host by penetrating the outer layer (cuticle) of the insect, and proceeding to grow until the insect dies.[62]
Pest controlled / crop	*I. fumosorosea* (strain Apopka 97) is authorised for use in Belgium, Cyprus, Finland, France, Greece, Netherlands, Poland, Portugal, and Sweden for the control of white flies on greenhouse cucumber, tomatoes.[63] In the US, *I. fumosorosea* (strain FE 9901) is registered for use to control of insect and mite pests (e.g. spider mites, broad mites, and rust mites) on vegetables, fruits, other food crops, ornamental plants, hemp, and tobacco, which are grown outdoors, in nurseries, and in greenhouses or other protected settings.[64]

[52] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-23)

[53] EU Pesticides Database op. cit.

[54] PMRA (2019) op. cit.

[55] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/index.htm, accessed 2020-11-20).

[56] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-11-20).

[57] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-20).

[58] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/index.htm, accessed 2020-11-20).

[59] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-20).

[60] Government of India. Bio-pesticide Registrant (http://www.ppqs.gov.in/divisions/cib-rc/bio-pesticide-registrant, accessed 2020-11-20); see also product catalogues such as https://www.biotech-int.com/Hirsutella%20thompsonii.html, and https://www.iplbiologicals.com/wp-content/uploads/2019/09/IPL Catalogue 2020.pdf (accessed 2020-11-20).

[61] Hajek AE et al. (2016) Classical Biological Control of Insects and Mites (Available https://cpb-us-e1.wpmucdn.com/blogs.cornell.edu/dist/3/3413/files/2013/08/BiocontrolCatalog081516-DC-bookmarked-1m0vxoh.pdf).

[62] US EPA (2011) *Isaria fumosorosea* Apopka Strain 97 (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-115002_01-Sep-11.pdf).

[63] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/active-substances/, accessed 2020-11-27).

[64] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-27).

Risk	In the EU, *I. fumosorosea* (strain Apopka 97) is classified as a low-risk active substance.[65] It is not toxic to mammals or birds,[66] but may be toxic to bees.[67]
6. *Metarhizium anisopliae*	
Description of the alternative	Many strains of the fungus *Metarhizium anisopliae* have been isolated worldwide from insects, nematodes, soil, river sediments, and decomposing organic material.
Pest controlled / crop	*Metarhizium anisopliae* strain F52 (referred to as Met F52) is approved in the US as a microbial pesticide for non-food uses in greenhouses and nurseries, and at limited outdoor sites not near bodies of water.[68] *M. anisopliae* strain F52 can infect larvae and adults of many insects, but is labelled for use on mites, thrips, ticks, whiteflies, and weevils. Labelled uses include vegetables (celery, lettuce, peppers, spinach, tomatoes) fruits (blackberry, cranberry, grape, raspberry, strawberry), ornamental plants and lawns/turf. In Canada *M. anisopliae* strain F52 is registered for the control of mites on fruiting vegetables (tomato, pepper, eggplant), cucumber, lettuce, strawberry and ornamentals in greenhouses and on outdoor turf.[69] It is authorised for use in 13 EU member states[70] and the UK.[71] It is also permitted in India, where many products are available on the market to control pests on a wide variety of crops.[72]
Risk	*M. anisopliae* is not toxic or infectious to mammals but inhalation of the spores can cause allergic reactions. It is not harmful to earthworms, lady birds, green lacewings, parasitic wasps, honeybee larvae, and honey bee adults (UNEP/POPS/POPRC.8/INF/14/Rev.1). However, it could be harmful to immature aquatic vertebrate and invertebrate species.[73]
7. *Verticillium lecanii (Akanthomyces muscarius strain Ve6; Lecanicillium lecanii; Lecanicillium muscarium strain Ve6)*	
Description of the alternative	*Verticillium lecanii* Viegas is a fungus first described in 1861. It is also known as *Akanthomyces muscarius* strain Ve6, *Lecanicillium lecanii*, *Lecanicillium muscarium* strain Ve6. It is used for controlling arthropod pests such as aphids and mites. As a biopesticide it is sprayed on pests while they are feeding off desirable plants. When pests come into contact with the spores, they get infected and finally die.[74]
Pest controlled / crop	The use of *V. lecanii* is permitted in India and there are products available on the Indian market to treat certain mites on various cereal, fruit, vegetable, and ornamental crops as well as on cotton, coffee and tea.[75] In Belgium, Denmark, France, Italy, Netherlands Portugal and UK, *L. muscarium* strain Ve6 is approved for use in greenhouse protected

[65] EU Pesticides Database op. cit.

[66] US EPA (2011) op. cit.

[67] UC IPM Bee precaution pesticide ratings (https://www2.ipm.ucanr.edu/beeprecaution/, accessed 2020-11-27).

[68] US EPA (2011) *Metarhizium anisopliae* strain F52 (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-029056_18-Apr-11.pdf); and US EPA (2003) Biopesticides registration action document (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/decision_PC-029056_18-Jun-03.pdf).

[69] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-20).

[70] EU Pesticide Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-20).

[71] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-20).

[72] Government of India. Bio-pesticide Registrant (http://www.ppqs.gov.in/divisions/cib-rc/bio-pesticide-registrant accessed 2020-11-20); see also product catalogues such as https://www.iplbiologicals.com/wp-content/uploads/2019/09/IPL Catalogue 2020.pdf and https://www.jaipurbiofertilizers.com/bio-insecticides.html, accessed 2020-11-20).

[73] US EPA (2011) Metarhizium anisopliae strain F52 (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-029056_18-Apr-11.pdf).

[74] *Verticillium* (https://www.bionity.com/en/encyclopedia/Verticillium.html, accessed 2020-11-20).

[75] Government of India. Bio-pesticide Registrant (http://www.ppqs.gov.in/divisions/cib-rc/bio-pesticide-registrant accessed 2020-11-20); see also product catalogues such as https://www.iplbiologicals.com/wp-content/uploads/2019/09/IPL Catalogue 2020.pdf and https://www.jaipurbiofertilizers.com/bio-insecticides.html (accessed 2020-11-20).

	crops to control whitefly and thrips on cucumber, strawberries, sweet pepper, tomato (whitefly only) and ornamentals, as well as field use in strawberries.[76] No products containing *V. lecanii* are currently registered in Australia,[77] Canada,[78] or the US.[79] Canada has issued a proposed registration decision for the use of *L. muscarium* strain Ve6 to suppress whiteflies on greenhouse tomatoes.[80]
Risk	*V. lecanii* has low toxicity following oral, inhalation and dermal exposures in experimental studies and no indication that it causes disease or genotoxic effects in humans.[81] It is a low risk to aquatic life and to non-target arthropods,[82] and is suitable for use in organic farming and for IPM.[83]
Other pathogens	
8. *Burkholderia species*	
Description of the alternative	The bacterial species in the genus *Burkholderia* are ubiquitous organisms in soil, rhizospheres, insects, fungi, and water.[84] Pesticide formulations of killed cells of *Burkholderia* species act on insect pests through enzymatic degradation of exoskeletal structures and interference with the moulting process leading to mortality through contact and/or ingestion. These pesticides are used to control or suppress many foliar feeding pests: caterpillars, foliage-feeding coleopteran, and soft-bodied insects such as aphids, whiteflies and plant sucking mites that infest crops and other plants.[85]
Pest controlled / crop	Heat-killed *Burkholderia* spp. strain A396 is registered in the US and products are available on the market for field and greenhouse use to suppress or control various pests including mites (citrus red mite, citrus rust mite, Pacific spider mite, six-spotted mite, Texas citrus mite, two-spotted spider mite, and Willamette spider mite) on a large variety of crops and ornamental plants (e.g. berries, cereals, citrus and other fruit trees, tree nuts, tobacco and vegetables such as cole crops, cucurbits, root vegetables, tomatoes, tubers).[86]
Risk	In the US, heat-killed Burkholderia spp. strain A396 cells and spent fermentation media is exempted from the requirement of a food tolerance (maximum residue limit).[87] May be harmful to bees.[88]
9. *Chromobacterium subtsugae*	
Description of the alternative	*Chromobacterium subtsugae* is a gram-negative, violet-pigmented bacterium with insecticidal and miticidal activity which was isolated from soil under an eastern hemlock in Maryland.[89]

[76] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-20).

[77] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-11-20).

[78] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-20).

[79] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-20).

[80] PMRA (2020). Proposed Registration Decision PRD2020-14. (Available https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-registration-decisions/2020/lecanicillium-muscarium-ve6-mycotal-biological-insecticide/document.html).

[81] PMRA (2020) op. cit.

[82] EU Pesticide Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/, accessed 2020-11-20).

[83] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/Reports/1402.htm, accessed 2020-11-20).

[84] Cordova-Kreylos AL, et al (2013) Isolation and characterization of *Burkholderia rinojensis* sp. nov., a non-*Burkholderia cepacian* complex soil bacterium with insecticidal and miticidal activities. *Applied and Environmental Microbiology* (79/24): 7669–78 (https://aem.asm.org/content/79/24/7669).

[85] US EPA (2014) Biopesticides registration action document (Available https://www.regulations.gov/document/EPA-HQ-OPP-2011-0010-0004).

[86] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-17).

[87] US EPA (2014) Op. cit.

[88] UC IPM Bee precaution pesticide ratings (https://www2.ipm.ucanr.edu/beeprecaution/, accessed 2020-11-17).

[89] US EPA (2011) Biopesticides registration action document (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/decision_PC-016329_27-Sep-11.pdf).

Pest controlled / crop	*C. subtsugae* strain PRAA4-1^T is registered in the US and products are available on the market to control insect and mite pests (e.g., citrus red mite, citrus rust mite, Pacific spider mite, six-spotted spider mite, Texas citrus mite and two-spotted spider mite) on agricultural and greenhouse crops, including vegetables, fruit, flowers, bedding plants, ornamentals, and turf.[90]
Risk	The US EPA concluded that overall *C. subtsugae* strain PRAA4-1^T did not pose significant risk to nontarget organisms but noted concerns for terrestrial arthropods, aquatic invertebrates, and honey bee. *C. subtsugae* strain PRAA4-1^T is exempted from the requirement of a food tolerance (maximum residue limit).[91]

3.3.3 Biochemical formulations

Biochemical pesticides are either naturally occurring substances or identical to naturally occurring substances. They function through non-toxic, non-lethal modes of action, such as disrupting the mating pattern of insects, regulating growth, or acting as repellants. Biochemical pesticides are important to IPM programs.[92]

There are a number of plant extracts formulated as acaricides.[93] A few are highlighted in **Box 6** below. Please note that the risk management evaluation (UNEP/POPS/POPRC.13/7/Add.1) lists many different plant extracts not listed here. Some plant extracts are mentioned in the IPM sections above. Please also note that some publications list biopesticides as chemical pesticides.

Box 6: Examples of biochemical formulations
Plant extracts
Clove oil (CAS No. 8000-34-8) is an essential oil of the clove plant whose active components are eugenol, eugenyl acetate, and beta-carophyllene methyl eugenol. Clove oil may be used as an insecticide, acaricide, fungicide or herbicide. It is mainly used in crops, for post-harvest protection, and in food storage. Target pests include aphids, armyworms, beetles, cutworms, mites, weevils, flies, wasps, and hornets. Under experimental conditions, a formulation containing 20% clove oil, 40% cottonseed oil and 10% garlic oil (GC-Mite) was effective for the control of the two-spotted spider mite (*Tetranychus urticae*) with nearly 100% mortality after 21 days. Clove oil has also shown to control dust mites, the copra mite, and mange mites in rabbits.[94]
Cinnamon oil (CAS No. 8015-91-6): The most important biologically active substances in cinnamon are cinnamaldehyde (CAS No. 104-55-2) and eugenol (CAS No. 97-53-0). The oil is use as an insecticide and acaricide. The main mode of action appears to be as a repellent. Cinnamaldehyde is registered in the US as an insecticide/miticide to control pests on a wide variety of crops (vegetables, fruits, fruit trees, ornamentals, lawns, etc.).[95] Cinnamon oil has been found effective on the American house dust mite (*Dermatophagoides farina*), and the European house dust mite (*Dermatophagoides pteronyssinus*) and the mange mite found on rabbits (*Psoroptes cuniculi*). An 80% mortality after 7 days was observed in two-spotted spider mite (*Tetranychus urticae*) in a study of a combination product containing cinnamon, rosemary, clove oil and garlic extract.[96]
Garlic oil (CAS No. 8000-78-0): Garlic is a food crop with both therapeutic and pesticidal effects. It contains a variety of sulfur-containing compounds with strong anti-bacterial and anti-fungal action. Garlic is used as an insecticide with both repellent and biocidal properties. Exposure to garlic extract decreases fecundity in the two-spotted spider mite (*Tetranychus urticae*). An LD50 of 7.5 mg/ml has been reported, with an LD90 of 13.5 mg/ml.[97]

[90] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-17).

[91] US EPA (2011) op cit.

[92] US EPA Toxicity Testing and Risk Assessment Glossary (https://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/termsandacronyms/search.do, accessed 2020-11-17).

[93] Godfrey LD (2011) Spider mites (Available http://ipm.ucanr.edu/PDF/PESTNOTES/pnspidermites.pdf).

[94] Baker et al. (2018) Cinnamon & cinnamon oil profile (Available https://hdl.handle.net/1813/56120).

[95] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-10).

[96] Baker et al. (2018) op. cit.

[97] Baker and Grant (2018) Garlic & garlic oil profile (Available https://hdl.handle.net/1813/56126).

Mint and mint oils are a class of active ingredients derived from selected members of the plant genus *Mentha* and include cornmint oil (CAS No. 68917-18-0), peppermint oil (CAS No. 8006-90-4) and spearmint (CAS No. 8008-79-5). Peppermint is the primary source of menthol (CAS No. 89-78-1 and 2216-51-5). Mint and mint oils and have antimicrobial properties and also act as repellents. They are used post-harvest against storage pests, as acaricide and nematicide for both plants and animals, and for various other purposes. An efficacy study of several essential oils found that a rate of 10 µl/L peppermint oil could achieve 100% mortality in *Tetranychus urticae* at 25°C. However, several other studies found beneficial mites (*Phytoseiulus persimilis* or *Neoseilus californicus*) to be as or more susceptible to mint oils (spearmint and peppermint) than the spider mite *T. urticae*.[98]
Neem oil is extracted from seeds of the neem tree, *Azadirachta indica*, which is native to India. Neem oil contains several insecticidal and fungicidal chemical compounds, including azadirachtin and salannin. This oil is processed into several types of products. Clarified hydrophobic extract of neem oil contain mainly fatty acids and glycerides and function like insecticidal soap and other horticultural oils. These extracts are contact pesticides and work best against soft-bodied pests, such as aphids, whiteflies, spider mites, and mealybug and scale nymphs. Neem products have low mammalian toxicity and do not cause skin irritation in most formulations.[99] Some neem-based products make use of concentrated azadirachtin, which can be used to control a wide range of pests, including caterpillars, sawflies, flea beetles, weevils, aphids, and leafhoppers (See also section 3.3.3.3 below). Azadirachtin works well against the immature stages of chewing pests by making the juvenile unable to molt. Azadirachtin has various modes of action. It can act as a feeding deterrent, deterrent to egg-laying, repellent, direct toxin, or insect growth regulator.[100]
Rosemary oil (CAS No. 8000-25-7) is primarily a mixture of monoterpenes (alpha-pinene, 1,8 cineole, and camphene). Its primary pesticidal use is as an insect repellent. A study found rosemary oil to be an effective contact toxicant (LC50 of 13.19 ml/L) against two-spotted spider mites (*Tetranychus urticae*). The LC100 for rosemary oil was 20 ml/L for the control of mites on beans and 40 ml/L on tomatoes. Hexacide™ (a product containing rosemary oil) controlled two-spotted spider mites (*T. urticae*) on strawberries with about 90% kill, and achieved 100% mortality of Pacific mite (*Tetranychus pacificus*) on grapes after 14 days.[101]
Thyme oil (CAS No. 8007-46-3): Combination products that include thyme oil have been registered to control mites in the US.[102] Thyme oil is not approved in the EU.[103] Thyme oil has been found effective against the two-spotted spider mite (*Tetranychus urtica*), reducing egg laying and resulting in 100% mortality at a 1% concentration. In an efficacy study thyme oil was able to achieve 100% mortality of *T. urticae* at a rate of 5 µl/L and temperature of 25°C.[104]

[98] Baker and Grant (2018) Mint and mint oil profile (Available https://hdl.handle.net/1813/56133) and Baker et al. (2018) Peppermint & peppermint oil profile (Available https://hdl.handle.net/1813/56135).

[99] Borden MA et al. (2018) Natural products for managing landscape and garden pests in Florida (https://edis.ifas.ufl.edu/in197, accessed 2020-11-10).

[100] Borden MA et al. (2018) op. cit.

[101] Baker BP, Grant JA (2018) Rosemary & rosemary oil profile (Available https://hdl.handle.net/1813/56138).

[102] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-25).

[103] EU Pesticides Database https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/ (accessed 2020-11-25).

[104] Baker and Grant (2018) Thyme & thyme oil profile (Available https://hdl.handle.net/1813/56143).

Other biopesticides

Abamectin (CAS No. 71751-41-2)

Description of the alternative: Abamectin is a natural fermentation product the soil bacterium *Streptomyces avermitilis*. It is a mixture of avermectins containing about 80% avermectin B 1a and 20% avermectin B 1b. Once ingested it paralyses the insect and mite pests which results in their death. It can be used as an insecticide, nemacide, or miticide.[105]

Pest controlled / crop: Abamectin has been a widely used chemical pesticide since 1986. It is registered in Australia,[106] Canada,[107] EU,[108] India,[109] UK[110] and US.[111] Abamectin is used to control various pests such as leafminers, psyllids and mites (e.g., broad mite, brown citrus rust mite, carmine mite, citrus rust mite, European red mite, Maori mite, McDaniel spider mite, Pacific spider mite, pear rust mites, two-spotted spider mites, and yellow mite). It is approved for use on food crops, trees, turfgrass, nursery and outdoor ornamental plants including cotton, caneberries, dry beans, fruit trees (e.g., apples, citrus, pears, stone fruits), fruiting vegetables (e.g., cucurbits, eggplants, peppers, tomatoes), grapes, herbs, hops, leafy vegetables, mint, pistachio, potatoes, strawberries and tree nuts.

Risk: EU harmonised classification and labelling codes are: H300 – Fatal if swallowed; H330 – Fatal if inhaled; H361d – Suspected of damaging the unborn child; H372 – Causes damage to organs through prolonged or repeated exposure (nervous system); H400 – Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long-lasting effect.[112]

Azadirachtin (CAS No. 11141-17-6)

Description of the alternative: Azadirachtin is an extract of fruit from the neem tree (*Azadirachta indica*). It interferes with the moulting of immature arthropods and reproduction in the adult. It also acts as repellant which deters pests from feeding and laying eggs on treated plants.[113] When the natural neem oil is removed from the seeds and treated with alcohol, virtually all of the azadirachtin and related substances separate from the oil itself. The remaining oil - without the azadirachtin - is called clarified hydrophobic extract of neem oil.[114]

Pest controlled / crop: Azadirachtin is registered in the US. Products are available of the market to control insects and mites (Banks mite, clover mite, citrus rust mite, citrus red mite, European red mite, hemlock rust mite, honey locust mite, Pacific mite, russet mite, spruce mite, and two-spotted spider mite) on a large range of crops food crops, trees, turfgrass, and ornamental plants grown outdoors, indoors, in greenhouses, or other protected settings and in nurseries.[115] It is also registered in Australia for the control of two-spotted mites, aphids and whitefly in floriculture and ornamentals and fungus gnats in potting soil.[116] It is authorised for use in 22 EU member states and the UK for the control of spider mites in protected settings.[117] Azadirachtin is registered for use in India with products available on the market to control a diversity of pests and on a wide range of crops.[118]

Risk: Azadirachtin degrades naturally and is not harmful non-target organisms. However, it should be applied when honeybees are foraging. Care must be taken not to contaminate water and it should not be applied directly to water.[119]

3.4 Additional information on non-chemical alternatives

Information on alternative methods is available from OISAT, an online information service for non-chemical pest management in the tropics: http://www.oisat.org/. The Cornell University Cooperative Extension

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[105] US EPA (2004) Ecological risk assessment for abamectin (Available https://archive.epa.gov/pesticides/chemicalsearch/chemical/foia/web/pdf/122804/122804-2004-11-15a.pdf).

[106] APVMA PubCRIS database Search (https://portal.apvma.gov.au/pubcris, accessed 2020-11-27).

[107] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-27).

[108] European Chemicals Agency (https://echa.europa.eu/substance-information/-/substanceinfo/100.059.628, accessed 2020-11-27).

[109] Government of India (http://www.ppqs.gov.in/divisions/cib-rc/registered-products, accessed 2020-11-27).

[110] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-27).

[111] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-27).

[112] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-11-30).

[113] PMRA (2018) Proposed Re-evaluation Decision PRVD2018-10 (https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-re-evaluation-decisions/2018/azadirachtin/document.html, accessed 2020-11-27).

(https://nysipm.cornell.edu/) has many resources including the Biological Control Site (https://biocontrol.entomology.cornell.edu/index.php).

4. Chemical Alternatives

Examples of chemical alternatives to dicofol are listed in **Box 7** below. Please note that a few products not listed in the risk management evaluation (UNEP/POPS/POPRC.13/7/Add.1) are included here; however, not all products referred to in the IPM sections above are necessarily listed here.

Box 7: Examples of chemical alternatives	
1. Acequinocyl (CAS No. 57960-19-7)	
Description of the alternative	Acequinocyl belongs to the class of quinoline insecticides/miticides. The US EPA considers acequinocyl a “reduced risk” pesticide.[120]
Pest controlled / crop	In the US, acequinocyl is registered for the control of various mite species: broad mite citrus red mite, European red mite, false spider mites, pacific spider mite, southern red mite, spruce spider mite, strawberry spider mite, Texas citrus mite, two-spotted spider mite and Willamette spider mite.[121] It can be used on a variety of crops including the following: avocado, bushberry, caneberry, cherry, citrus fruit, guava, low growing berries, pome fruits, small tropical and subtropical fruits, cucurbit vegetables, dried and shelled beans, edible podded beans, fruiting vegetables, succulent soybean, tree nuts and hops. In Canada, acequinocyl is registered to control various mites in commercial greenhouses and shadehouses, on container-grown ornamental, floral, foliage and nursery crops, and in commercial greenhouses on cucumbers, peppers, tomatoes and eggplants. It is also registered for use on pome fruit, field grown ornamentals, caneberry, dry shelled bean, field grown eggplant, summer squash, tree nuts and hops.[122] It is an active substance approved under Regulation (EC) No 1107/2009 in the EU[123] and is registered for use on certain fruit trees (apples, cherries, pear plum) in the UK.[124]
Risk	Under the EU harmonised classification and labelling the following hazard codes apply to acequinocyl**:** H317 – May cause an allergic skin reaction; H370 – Causes damage to organs (lung) (inhalation); H373 – May cause damage to organs through prolonged or repeated exposure (blood system); H400 – Very toxic to aquatic life; H410 – Very toxic to aquatic life with long-lasting effect.

[114] US EPA (2001) Azadirachtin (121701) Clarified Hydrophobic Extract of Neem Oil (025007) (Available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_G-127_01-Oct-01.pdf).

[115] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-27).

[116] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-11-27).

[117] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en accessed 2020-11-30) and Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-30).

[118] Government of India. Registered Products (http://www.ppqs.gov.in/divisions/cib-rc/registered-products, accessed 2020-11-30); see also product catalogues, for example: https://www.indiamart.com/agrilife/bio-pesticides.html; https://www.jaipurbiofertilizers.com/bio-insecticides.html (accessed 2020-11-30).

[119] US EPA (2001) op. cit.

[120] US EPA (2003) Acequinocyl (available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-006329_26-Sep-03.pdf).

[121] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-27).

[122] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-27).

[123] European Chemicals Agency (https://echa.europa.eu/information-on-chemicals, accessed 2020-11-27).

[124] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-27).

2. Bifenazate (CAS No. 149877-41-8)	
Description of the alternative	Bifenazate is a carbaxate compound that is used as a miticide.[125] Its selectivity means that it does not adversely affect biological control organisms such as beneficial/predaceous mites or insects.[126]
Pest controlled / crop	In the US, bifenazate is registered for use on food and non-food crops (avocado, berries, caneberry, citrus, cucurbit vegetables, currants, dates, figs, fruiting vegetables, grapes, vine climbing small fruits, herbs, low-growing berries, persimmon, potato, succulent peas, beans, and shelled soybean, mint, pome fruits, stone fruits, tree nuts, tropical fruits; Christmas trees/conifers nurseries, cotton, and Timothy grass). It is effective against the following pests: Banks grass mite, brown almond mite, citrus red mite, clover mite, European red mite, McDaniel spider mite, Pacific spider mite, pecan leaf scorch mite, six-spotted mite, southern red mite, spruce spider mite, strawberry spider mite, two-spotted spider mite, Willamette spider mite and western flower thrips.[127] In Australia, bifenazate is registered for use to control mites on certain fruits, vegetables and nuts.[128] It is registered in Canada as a selective miticide on ornamental plants grown outdoors, greenhouses or other protective settings.[129] It is also registered for use on certain vegetables, fruits and nuts and as seed treatment (grass, mint, and herbs). It is authorised for use as an acaricide in 21 EU member states[130] and the UK (strawberries in protected settings).[131] It is listed as an existing active ingredient in India.[132]
Risk	In the EU harmonised classification and labelling system, bifenazate is characterised by following hazard codes: H317 – may cause an allergic skin reaction; H319 – causes serious eye irritation; H373 – may cause damage to organs through prolonged or repeated exposure; H400 – very toxic to aquatic life; and H410 – very toxic to aquatic life with long lasting effects.[133]
3. Bifenthrin (CAS No. 82657-04-3)	
Description of the alternative	Bifenthrin is a broad-spectrum non-systemic insecticide/miticide of the pyrethroid and pyrethrin class. They alter nerve function, which causes paralysis in target insect pests (also called ‘knockdown’) which eventually results in death.[134]
Pest controlled / crop	Bifenthrin controls a variety of insects including aphids, ants and wasps, maggots and flies, caterpillars and moths, beetles, grasshoppers, mites, spiders, ticks, thrips, fleas, and other arthropod pests. In Australia, bifenthrin is registered for use on a variety of crops (e.g.: banana, barley, canola, clover, cotton, ornamentals, peas and beans, tomatoes, and wheat) to control selected mites such as banana spider mite, blue oat or pea mite, bryobia mite, red legged earth mite, red spider mite, spider mite, strawberry spider mite, tomato mite, tomato russet mite, two-spotted mite, and two-spotted spider mite.[135]

[125] US EPA (1999) Bifenazate (availabe https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-000586_01-Jun-99.pdf).

[126] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).

[127] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).

[128] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-11-30).

[129] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-30).

[130] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).

[131] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/prodsearch.asp, accessed 2020-11-30).

[132] Central Insecticides Board. Insecticide search (https://pesticides-registrationindia.nic.in/Search/frmInsecticideSearch.aspx, accessed 2020-11-30).

[133] European Chemicals Agency (https://echa.europa.eu/information-on-chemicals, accessed 2020-11-30).

[134] US EPA (2020) Bifenthrin (available https://www.regulations.gov/document?D=EPA-HQ-OPP-2010-0384-0299).

[135] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2021-02-10).

	Bifenthrin is registered in Canada.[136] It is registered for use in India[137] where products are available to control broad range of foliar pests in various crops including cereals, citrus, cotton, fruit, grapes, ornamentals and vegetables.[138] Currently bifenthrin is not approved for use in either the EU or UK.[139] Bifenthrin was first registered in the US 1989, registered for use in a variety of indoor and outdoor residential and commercial areas, including use in food handling establishments and as a pet shampoo, as well as on a variety of agricultural and livestock settings.[140] Products are available to control mites, such as the Banks grass mite, broad mite, Carmine mite, European red mite, Pacific spider mite, spider mites, spruce spider mite, two-spotted spider mite, and yellow mite, on various crops (brassicas and turnip greens, caneberries, cilantro and coriander, corn, cotton, cucurbits, dried beans and peas, fruiting vegetables, grapes, hops, lettuce, okra, peanuts, pears, peas and beans, root crops, soya beans, spinach, tobacco, tomatoes and tomatillos, tree nuts and certain ornamentals).[141]
Risk	The EU harmonised classification and labelling codes for bifenthrin are: H300 – fatal if swallowed; H317 – may cause an allergic skin reaction; H331 – toxic if inhaled; H351 – suspected of causing cancer; H372 – causes damage to organs through prolonged or repeated exposure; H400 – very toxic to aquatic life; H410 – very toxic to aquatic life with long-lasting effects.[142]
4. Clofentezine (CAS No. 74115-24-5)	
Description of the alternative	Clofentezine belongs to the tetrazine class of chemicals. It is a contact miticide that interferes with cell growth and differentiation at egg stage and early larval stages. It is used to control mites on a wide range of crops.[143] Given its mode of action, clofentezine is useful addition to a rotation of pesticides in resistance management.[144]
Pest controlled / crop	In the US, clofentezine is registered to control eriophyid mites, European red mite, McDaniel spider mite, Pacific spider mite, two-spotted spider mite, and the yellow spider mite on a variety of vine fruits, small fruits, fruit trees (pomes, stone fruit), nut trees, and Christmas trees. In Canada, clofentezine is registered for use on apple and pear trees to control European red mites, McDaniel spider mites and two-spotted spider mites. It is also registered for use on peach and nectarine trees to control European red mites and two-spotted spider mites, and to control two-spotted spider mites on raspberries, strawberries and outdoor deciduous nursery stock.[145] Clofentezine is also registered as a miticide on certain crops, ornamentals and turf in Australia and its use as an acaride is permitted in the EU and UK. It is identified as a new registration in India.[146]
Risk	In the EU harmonised classification and labelling system, clofentezine is harmful in contact with skin (H312) very toxic to aquatic life (H400), and is harmful to aquatic life

[136] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2021-02-10).

[137] Government of India (2021) Insecticides/pesticides registered under section 9(3) of the Insecticides Act, 1968 for use in the country as on 01.01.2021 (available http://www.ppqs.gov.in/divisions/cib-rc/registered-products).

[138] See product labels, for example: https://dir.indiamart.com/impcat/bifenthrin.html, https://www.dhanuka.com/details/markar (Accessed 2021-02-10).

[139] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-02-10) and Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/proanddsearch.asp, accessed 2020-02-10).

[140] US EPA (2020) Bifenthrin (available https://www.regulations.gov/document?D=EPA-HQ-OPP-2010-0384-0299).

[141] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2021-02-10).

[142] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-02-10).

[143] EFSA (2014) Reasoned opinion (available https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2014.3860)

[144] PMRA (2013) Proposed Re-evaluation Decision PRVD2013-05, Clofentezine (https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-re-evaluation-decisions/2013/clofentezine.html, accessed 2020-02-10).

[145] PMRA (2013) op. cit.

[146] Central Insecticides Board. Insecticide search (https://pesticides-registrationindia.nic.in/Search/frmInsecticideSearch.aspx, accessed 2020-11-30).

	with long lasting effects (H412).[147] In Canada, labels need to include the following warnings: Toxic to birds; toxic to small mammals; toxic to aquatic organisms.[148] The US EPA has assessed the potential cumulative exposure to clofentezine and concluded that the excess lifetime cancer risk was negligible (in the range of 1×10^{-6}).[149]
5. Cyantraniliprole (CAS No. 736994-63-1)	
Description of the alternative	Cyantraniliprole is an anthranilic diamide insecticide (ryanoid class) effective against a cross spectrum of chewing and sucking pests. It is a systemic insecticide which is effective through ingestion and contact. It affects ryanodine receptors in insect muscle, causing paralysis and death of the insect.[150]
Pest controlled / crop	Cyantraniliprole controls or supress a variety of insects on turf (golf courses and sod farms only), outdoor ornamentals and greenhouse ornamentals. It also controls a variety of insect pests on fruits and vegetables, oilseeds, greenhouse ornamentals and outdoor ornamentals.[151] It is approved for use in Australia, Canada, EU, India, UK and US.[152] In Australia, combination products containing a mixture of cyantraniliprole and diafenthiuron are registered to control two-spotted mite in cucurbits and field fruiting vegetables.[153] In Canada, combination products of cyantraniliprole and abamectin are registered to control pests on celeriac, potatoes, tuberous and corm vegetables, leafy greens, fruiting and cucurbit vegetables, apples, pears, and leaf petioles vegetables. Mites controlled include: the Broad mite, Carmine spider mite, European red mite, McDaniel mite, spider mites, pear rust mite, tomato russet mite, two-spotted spider mite, and yellow mite.[154]
Risk	Cyantraniliprole is potentially toxic to non-target terrestrial plants, aquatic organisms, beneficial insects and bees.[155]
6. Cyflumetofen (CAS No. 400882-07-7)	
Description of the alternative	Cyflumetofen is a benzoylacetonitrile compound that interferes with cell metabolism and acts as contact acaricide with spider mites.[156] Given its mode of action, cyflumetofen is useful for the management of pesticide resistance in mites.
Pest controlled / crop	Cyflumetofen is registered in the US. Products are available for control of mites (Banks grass mite, brown almond mite, brown wheat mite, carmine spider mite, citrus red mite, European red mite, McDaniel spider mite, pacific spider mite, spruce spider mite, strawberry spider mite, Texas citrus mite, two-spotted spider mite, Willamette spider mite, and Yuma spider mite) in citrus, grapes, pome fruits, stone fruit, strawberries, tomatoes, and tree nuts as well as on ornamentals indoors or outdoors, certain

[147] European Chemicals Agency (https://echa.europa.eu/substance-information/-/substanceinfo/100.070.641, accessed 2020-11-27).

[148] PMRA (2014) Re-evaluation Decision RVD2014-04 – Clofentezine (available https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/cps-spc/alt_formats/pdf/pubs/pest/_decisions/rvd2014-04/RVD2014-04-eng.pdf).

[149] US EPA (2020) Clofentezine - Pesticide Tolerances. *Federal Register* (85): 67285 (https://www.federalregister.gov/documents/2020/10/22/2020-23400/clofentezine-pesticide-tolerances).

[150] PMRA (2019) Proposed Registration Decision PRD2019-13, Cyantraniliprole and Ference Insecticide (https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/cyantraniliprole-ference-insecticide/document.htm, accessed 2021-02-10).

[151] PMRA (2019) op. cit.

[152] Australia: https://portal.apvma.gov.au/pubcris (accessed 2021-02-10); Canada: https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php accessed 2021-02-10); EU: https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/ (accessed 2021-02-10); India: https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx (accessed 2021-02-10); UK https://secure.pesticides.gov.uk/pestreg/ (accessed 2021-02-10); and US: https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1 (accessed 2021-02-10).

[153] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2021-02-10).

[154] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2021-02-10).

[155] PMRA (2019) op. cit.

[156] PMRA (2014) Registration Decision RD2014-24, Cyflumetofen (https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/registration-decision/2014/cyflumetofen-rd2014-24.html, accessed 2021-02-10).

	greenhouse-grown vegetables, and certain vegetable transplants for the home consumer market.[157] It is also registered in Canada,[158] 13 EU member states (use in ornamentals is supported),[159] India,[160] and UK.[161]
Risk	Although the US EPA identified potential ecological hazards, the Agency supported the registration of cyflumetofen because, overall, it presents lower risk to human health and the environment than other registered miticides. In the EU harmonised classification and labelling the following hazard codes have been assigned: H317 – May cause an allergic skin reaction; H351 – Suspected of causing cancer. [162] In Canada, the product label must include a hazard statement indicating that this pesticide is toxic to non-target terrestrial plants and aquatic organisms.[163]
7. Cyfluthrin (CAS No. 68359-37-5)	
Description of the alternative	Cyfluthrin and beta-cyfluthrin are non-systemic synthetic pyrethroid insecticides. They are composed if are both mixtures of four cyfluthrin isomers. Beta-cyfluthrin is an enrichment of the two most efficacious isomers. Pyrethroids and pyrethrin work by altering nerve function, causing paralysis in target insect pests, eventually resulting in death.[164]
Pest controlled / crop	Cyfluthrin provides effective management of key pests in crops such as alfalfa, cotton, corn, wheat, rice, soybean, sunflower, tree nuts, citrus, blueberries, grapes, and many vegetables.[165] Cyfluthrin is registered for use in Australia, Canada, and India.[166] In the US it is registered for residential and indoor and outdoor use to control of Banks grass and clover mites in flowers, lawns, trees, shrubs, and ground covers.[167] It is no longer approved for use in the EU or the UK.[168]
Risk	In the EU harmonised classification and labelling the following hazard codes have been assigned: H300 – Fatal if swallowed; H331 – Toxic if inhaled; H400 – Very toxic to aquatic life; H410 – Very toxic to aquatic life with long-lasting effects.
8. Etoxazole (CAS No. 153233-91-1)	
Description of the alternative	Etoxazole is pesticide in the diphenyloxazole class of miticides/ovicides. It prevents treated eggs from hatching and treated juvenile mites from moulting successfully. While it does not kill adults, treated adult females lay significantly fewer viable eggs.[169]

157 US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-27).

158 Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-27).

159 EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).

160 Government of India. Registered products (as of 2020-06-30) (available http://www.ppqs.gov.in/divisions/cib-rc/registered-products, accessed 2020-11-30).

161 Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/default.asp, accessed 2020-11-27)

162 European Chemicals Agency (2020) Table of harmonised entries in Annex VI to CLP (https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp, accessed 2020-11-27).

163 PMRA (2014) Registration Decision RD2014-24, Cyflumetofen (https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/registration-decision/2014/cyflumetofen-rd2014-24.html, accessed 2020-11-27).

164 US EPA (2020) Cyfluthrin and beta-cyfluthrin (available https://downloads.regulations.gov/EPA-HQ-OPP-2010-0684-0115/content.pdf).

165 US EPA (2020) op. cit.

166 Australia: https://portal.apvma.gov.au/pubcris; Canada: https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php; India: https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx (accessed 2021-02-10).

167 US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2021-02-10).

168 EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/active-substances/, accessed 2021-02-10).

169 PMRA (2015) Etoxazole (Available https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/registration-decision/2015/etoxazole-rd2015-21.html, accessed 2020-11-30).

Pest controlled / crop	Etoxazole is registered in the US to control the avocado brown mite, Banks grass mite, carmine spider mite, European red mite, McDaniel spider mite, Pacific spider mite, spruce spider mite, strawberry spider mite, two-spotted spider mite, Willamette spider mite and yellow spider mite on the following crops: on caneberry, Christmas trees, corn, cotton, cucurbit vegetables, hops, low-growing berry (blueberry, cranberry, strawberry, etc.), mint, pepper and eggplant, pome fruit, soya bean, stone fruit, non-bearing fruit trees, tree nuts, tropical and sub-tropical fruit, and vine climbing small fruit (gooseberry, grape, kiwi, etc.).[170] In Canada, etoxazole is used for the control of mites in greenhouse tomatoes and greenhouse ornamentals.[171] It is authorised for use as an acaricide in 15 EU member states[172] and the UK (protected eggplant and tomatoes).[173] It is registered in India and recommended for controlling the red spider mite (*Tetranychus urticae*) on tea and eggplant.[174]
Risk	Under EU harmonised classification and labelling, hazard statement codes for etoxazole are: H400 –Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long lasting effects.[175]
9. Fenazaquin (CAS No. 120928-09-8)	
Description of the alternative	Fenazaquin is a quinazoline pesticide used to control mites and insects (especially whiteflies). Once the pest absorbs it through either ingestion or dermal exposure, it affects cell metabolism.[176]
Pest controlled / crop	Fenazaquin is registered in the US. It is used to control a wide variety of mites: *tetranychida* (such as the Banks grass mite, brown mite, carmine spider mite, citrus red, mite European red mite, McDaniel spider mite, and two-spotted spider mite); *eriophyidae* (such as the apple rust mite, blueberry bud mite, citrus bud mite, and citrus rust mite) *tarsonemidae* (e.g. broad mite); as well as certain insects (e.g. Asian citrus psyllid grape leafhopper, greenhouse whitefly, pear psylla, and silverleaf whitefly) and certain diseases (e.g. Alternaria leaf spot, and powdery mildew). It can be applied to a wide variety of food crops and some ornamentals, including: avocado, bushberry, caneberry, citrus fruit, cucurbit vegetables, fruiting vegetables, hops, edible-podded legume vegetable, succulent pea and bean, dried shelled pea and bean, low-growing berry, mint, pome fruit, stone fruit, vine climbing small fruit, tree nuts, Christmas tree and Christmas tree plantations, ornamental plants in greenhouse or shade house and ornamental landscape plantings.[177] It is authorised for use as an acaricide in greenhouses in six EU member states (France, Hungary, Italy, Poland, Portugal and Spain),[178] and UK (greenhouse ornamentals).[179] It is also registered in India where it is identified as a highly effective miticide on chilli (yellow mite), eggplant (red spider mite), okra (red spider mite), tomato (two-spotted spider mite), and tea (red spider mite, pink mite, purple mite scarlet mite).[180]

170 US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30)

171 PMRA (2015) op. cit.

172 EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-11-30).

173 Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-30).

174 India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).

175 European Chemicals Agency. 2020. Table of harmonised entries in Annex VI to CLP (https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp, accessed 2020-11-30).

176 US EPA (2007) Fenazaquin (available https://nepis.epa.gov/Exe/ZyPDF.cgi/P100C23P.PDF).

177 US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).

178 EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-11-30).

179 Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-11-30).

180 India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).

Risk	The EU harmonised classification and labelling hazard statement codes for fenazaquin are: H301 – Toxic if swallowed; H332 – Harmful if inhaled; H400 – Very toxic to aquatic life; H410 – Very toxic to aquatic life with long lasting effects.[181] It is classified as highly toxic in India.[182]
10. Fenbutatin oxide (CAS No. 13356-08-6)	
Description of the alternative	Fenbutatin oxide is a miticide used to control mites, aphids, thrips, mealybugs, whiteflies and scale fruit trees, nut trees and other food crops.[183]
Pest controlled / crop	Fenbutatin oxide is registered in the US to control many different mites (e.g. apple rust mites, black flat mites, broad mites, Carmine mites, Carpini spider mites, citrus red mites, European red mites, McDaniel spider mites, red mites, Texas citrus mites, and two-spotted spider mites). It can be used on fruits (grape papaya strawberry raspberry), fruit trees (apple, cherry, citrus, pear, peach, plum, prune, nectarine), tree nuts (other almonds, pecans, pistachios and walnuts), some vegetables (eggplant) and ornamentals (greenhouse and outdoor ornamentals, landscape ornamentals and Christmas trees).[184] Fenbutatin oxide is registered in Australia to control mites on various fruits, vegetables and ornamentals.[185] In Canada it is registered for use on greenhouse cucumbers, greenhouse tomatoes, ornamental plants and nursery stock.[186] Fenbutatin oxide is listed as a new pesticide the Central Insecticides Board's database.[187]
Risk	While overall of low acute toxicity, fenbutatin oxide is classified as a restricted use pesticide due to very high toxicity to aquatic organisms.[188] The EU harmonised classification and labelling hazard codes for fenbutatin oxide are: H315 – Causes skin irritation; H319 – Causes serious eye irritation; H330 – Fatal if inhaled; H400 – Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long-lasting effects.[189]
11. Fenpyroximate (CAS No. 134098-61-6)	
Description of the alternative	Fenpyroximate is a pyrazole contact insecticide/miticide which is used to control mealybugs, leafhoppers, whiteflies, and mites on a variety of agricultural crops and ornamental plants.[190]
Pest controlled / crop	In the US, fenpyroximate is registered for use on various fruit and vegetable crops and ornamental plants: almonds, pistachios, bananas, beans, succulent, low-growing berries (excluding cranberries), bushberries (excluding cranberries), caneberries, citrus fruits, corn, cottonseed, fruiting vegetables, hops, leaf petiole vegetables, melons, non-bearing deciduous fruits, tree nuts and vines, peanuts, peppermint/spearmint, pome fruits, potatoes, squash/cucumbers, stone fruits, tree nuts, tropical and subtropical fruits, tuberous and corm vegetables, vine climbing small fruits, greenhouse cucumbers and tomatoes, and ornamental trees, vines, shrubs, foliage, and flowering plants.[191] Use of fenpyroximate on cranberries is not supported and will be formally cancelled through the Federal Register.[192]

[181] EU Pesticides Database https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/ (accessed 2020-11-30).

[182] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).

[183] US EPA (2007) Fenbutatin Oxide (Available https://archive.epa.gov/pesticides/reregistration/web/pdf/0245fact.pdf).

[184] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).

[185] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-11-30).

[186] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-30).

[187] Central Insecticides Board. Insecticide Search (https://www.pesticides-registrationindia.nic.in/Search/frmInsecticideSearch.aspx, accessed 2020-11-30).

[188] US EPA (2007) Fenbutatin Oxide (available https://archive.epa.gov/pesticides/reregistration/web/pdf/0245fact.pdf).

[189] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-11-30).

[190] US EPA (2020) Fenpyroximate (available https://www.regulations.gov/document/EPA-HQ-OPP-2014-0572-0051).

[191] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1 (accessed 2020-11-30).

[192] US EPA (2020) op. cit.

	Fenpyroximate controls or suppresses spider mites, tarsonemid mites, and whiteflies. It is effective against a large number of mites including the apple rust mite, mint bud mite, Pacific spider mite, avocado brown mite, banks grass mite, pear rust mite, broad mite, pecan leaf scorch mite, carmine mite, persea mite, citricola scale, plum nursery mite, citrus bud mite, citrus flat mite, six-spotted mite, citrus red mite, strawberry spider mite, citrus rust mite, Texas citrus mite, cyclamen mite, tomato russet mite, European red mite, two-spotted spider mite, hazelnut-filbert bud mite, McDaniel mite, and Willamette spider mite. It is also effective in controlling various insect pests.[193] In the EU, fenpyroximate is authorised for use in 17 member states with its use restricted to the control of mites in applications where there is no risk of spray drift.[194] In Australia, fenpyroximate is registered for the control of two-spotted mites and European red mites in apples and pears.[195] It is registered for use in India and considered very effective for controlling red spider, pink and purple mites on tea, yellow mites on chilli and the eriophyid mite of coconut.[196] It is also registered for use on cotton.
Risk	Under the EU harmonised classification and labelling fenpyroximate has been assigned the following hazard codes: H301 – Toxic if swallowed; H317 – May cause an allergic skin reaction; H330 – Fatal if inhaled; H400 – Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long lasting effects.[197] It is classified as a highly toxic in India.[198]
12. Formetanate (CAS No. 23422-53-9)	
Description of the alternative	Formetanate or formetanate hydrochloride is a carbamate pesticide whose mode of action is cholinesterase inhibition. It is a broad spectrum miticide that can affect larval, nymph, and adult stages of the pest.
Pest controlled / crop	Formetanate is registered in the US to control insects and mites including the European red mite, McDaniel spider mite, rust mites (such as the pear rust mite), and the two-spotted spider mite. It can be used on the following crops: alfalfa, citrus fruit (grapefruit, lemons, limes, oranges, tangelos, and tangerines), pomes (apples and pears), and stone fruit (peaches, nectarines, plums, and prunes).[199] It is available in Canada for the control of the European red mite and two-spotted spider mite on nectarines.[200] It is authorised in 11 EU member states. Supported uses include the control of biting and sucking insects on ornamental shrubs and tomatoes.[201] Formetanate hydrochloride is listed as a new pesticide the Central Insecticide Board's database.[202]
Risk	Under the EU harmonised classification and labelling formetanate has been assigned the following hazard codes: H300 – Fatal if swallowed; H317 – May cause an allergic skin reaction; H330 – Fatal if inhaled; H400 – Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long lasting effects.[203] The label in Canada includes the following warnings: Toxic to aquatic organisms; toxic to birds; toxic to small wild animals; and toxic to certain beneficial insects.[204]

[193] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).
[194] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).
[195] APVMA PUBCRIS data base (https://portal.apvma.gov.au/pubcris, accessed 2020-11-30).
[196] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).
[197] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).
[198] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).
[199] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-11-30).
[200] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-30).
[201] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).
[202] Central Insecticides Board. Insecticide Search (https://www.pesticides-registrationindia.nic.in/Search/frmInsecticideSearch.aspx, accessed 2020-11-30).
[203] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).
[204] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-11-30).

13. Hexythiazox (CAS No. 78587-05-0)	
Description of the alternative	Hexythiazox is an acaricide used for the control of eggs and larvae of many different species of mites on a wide variety of food crops.
Pest controlled / crop	In the US, hexythiazox is registered for use on fruit trees (including citrus), fruiting vines, cereals, beans, tomatoes, nuts, ornamental evergreen trees, and certain grasses for the control of many different species of mites (Banks mite, Carmine spider mite, citrus red mite, European red mite, McDaniel spider mite, Pacific spider mite, pecan leaf scorch mite, six-spotted mite, spruce spider mite, strawberry spider mite, two-spotted spider mite, and the Willamette mite). Hexythiazox will not control adult spider mites. To reduce the development of resistance in mites, the number of applications is limited to a maximum of once per year. Hexythiazox is authorised for use in 22 EU member countries and the UK for the control of spider mites in apples, grapes and citrus fruit. It is also registered in Australia for the control of two-spotted mites and European red mites on apples, pears, stone fruit, and ornamentals and for control of two-spotted mites on strawberries.[205] This product is not be used for the control of mites known or suspected to be resistant to either hexythiazox or clofentezine. Hexythiazox is registered in India for use on apple trees (European red mite), chilli (yellow mite *Polyphagotarsonemus latus*) and tea (scarlet mite *Brevipalpus phoenicis* and red spider mite *Oligonychus coffeae*) .[206]
Risk	While US EPA has classified hexythiazox as "Likely to be carcinogenic to humans". In its chronic health assessment, the U EPA concluded that exposure to hexythiazox is not expected to pose a cancer risk.[207] Under the EU harmonised classification and labelling hexythiazox has been assigned the following hazard codes: H400 – Very toxic to aquatic life; and H410 – very toxic to aquatic life with long lasting effects.[208] It is classified as slightly toxic in India.
14. Propargite (CAS No. 2312-35-8)	
Description of the alternative	Propargite is a pesticide used to control mites on a variety of field, fruit, and vegetable crops, as well as ornamental plants. Propargite is an organosulfur miticide. Its mode of action involves the inhibition of magnesium-stimulated ATPase. It causes local irritation at the site of contact. It was first registered as a pesticide in the U.S. in 1969.[209]
Pest controlled / crop	Propargite is registered in the US to control the Banks grass mite, broad mite, citrus red mite, citrus rust mite, clover mite, European red mite, false spider mites, McDaniel spider mite, mint bud mite, Pacific spider mite, six-spotted mite, strawberry spider mite, Texas citrus mite, two-spotted spider mite on various crops: Almonds, beans (dry), berries, citrus and various other fruits (non-bearing), corn, cotton, hops, mint, potatoes, jojoba, peanut, sorghum, walnuts, conifers and seed crops of alfalfa, carrot, clover, and sugar beet.[210] Propargite is registered in Australia for use on apples (carmine mite, European red mite), bananas (carmine mite), beans (carmine mite, spider mites), cotton (cotton mite), hops (carmine mite), ornamental plants (carmine mites, European red mite, false spider mite) passion fruits (passion vine mite), pears (carmine mite), stone fruits (biological control of mites, carmine mite, European red mite), strawberries (biological control of mites, carmine mite), tomatoes, (carmine mite, spider mites) and vegetables (carmine mite,

[205] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris (accessed 2020-11-30).

[206] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-11-30).

[207] US EPA (2020) Hexythiazox; pesticide tolerances. Federal Register 85: 3697 (https://www.federalregister.gov/documents/2020/07/20/2020-14394/hexythiazox-pesticide-tolerances).

[208] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en/, accessed 2020-11-30).

[209] CalEPA (2014) Propargite (Omite) risk characterization document (available https://www.cdpr.ca.gov/docs/risk/rcd/propargite_2014.pdf).

[210] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-12-02).

	spider mites). Product labels indicate that progargite can be applied where biological control is being practised on apples, stonefruit and strawberries. [211] In India, propargite is registered for the control of mites on apples (European Red mite, two-spotted mite), chillies, eggplants (two-spotted spider mite) and tea (red spider mite).[212] It is not registered in Canada,[213] the EU[214] or the UK.[215]
Risk	Though propargite is of low oral and dermal toxicity, it is a restricted use pesticide in the US due to its effects on the eyes and skin irritation.[216] Under EU harmonised classification and labelling propargite has been assigned the following hazard codes: H315 – Causes skin irritation; H318 – Causes serious eye damage; H331 – Toxic if inhaled; H351 – Suspected of causing cancer; H400 – Very toxic to aquatic life; and H410 – very toxic to aquatic life with long lasting effects.[217] The Government of India notes that propargite is toxic to aquatic organisms and therefore should not be used near water bodies, aquaculture or pisciculture. It also notes that due to its skin and eye irritation potential, personal protective covering should be used.[218]
15. Pyridaben (CAS No. 96489-71-3)	
Description of the alternative	Pyridaben is a pyridazinone pesticide with long residual activity registered in several countries to control insects and mites. It is a non-systemic pesticide with rapid knock down action and acts by affecting cellular metabolism.[219]
Pest controlled / crop	Pyridaben is registered in the US for the control of insects and mites including the apple rust mite, broad mite, citrus bud mite, citrus flat mite, citrus red mite, citrus rust mite, European red mite, false spider mites, McDaniel spider mite, Pacific spider mite, peach silver mite, pear rust mite, pecan leaf scorch mite, pink citrus rust mite, six-spotted mite, southern red mite, Texas citrus mite, two-spotted spider mite and Willamette spider mite. It can be used on fruits including berries, citrus, grapes, pomes, small fruits and stone fruits, tree nuts, and certain vegetables.[220] In Australia, pyridaben is registered to control certain mites on apples, pears (including Nashi pears), stone fruit, bananas, grapes and roses. Mites controlled include the bunch mite (*Brevipalpus lewisi*), European red mite (*Panonychus ulmi*), strawberry mite (*Tetranychus lambi*) and two-spotted mite (*Tetranychus urticae*).[221] In Canada, pyridaben is registered for the control of mites, whiteflies and pear psylla on greenhouse and outdoor ornamentals, greenhouse food crops (peppers, cucumbers and tomatoes), orchard crops, raspberries and strawberries. Pyridaben's mode of action makes it a valuable tool in resistance management of mites and whiteflies.[222] It is authorised in 12 EU member states. Uses supported by available data are the control of mites and white fly on citrus fruits and greenhouse tomatoes.[223] In India it is registered

[211] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-12-02).

[212] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-12-02).

[213] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-02).

[214] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-12-02).

[215] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/default.asp, accessed 2020-12-02).

[216] US EPA (2010) Propargite (available https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-097601_18-May-10.pdf).

[217] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-12-02).

[218] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-12-02).

[219] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/569.htm, accessed 2020-12-03).

[220] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-12-03).

[221] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-12-03).

[222] PMRA (2016) Pyridaben (https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/public/consultations/proposed-re-evaluation-decisions/2016/pyridaben/document.html, accessed 2020-12-02).

[223] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-12-03).

	to control the red spider mite on tea, yellow mite on chilli, and the white fly on cotton.[224]
Risk	Under EU harmonised classification and labelling, pyridaben has been assigned the following hazard codes: H301 – Toxic if swallowed; H331 – Toxic if inhaled; H400 – Very toxic to aquatic life; and H410 – Very toxic to aquatic life with long lasting effects.[225] Labelling in Canada includes the following cautionary statements: This product is toxic to aquatic invertebrates, plants, fish and terrestrial plants; toxic to bees, beneficial arthropods, small wild mammals, aquatic organisms, and non-target terrestrial plants.[226]
16. Spirodiclofen (CAS No. 148477-71-8)	
Description of the alternative	Spirodiclofen is a tetronic acid which affects mite development. It is a contact pesticide that acts on mite eggs, all nymphal stages, and adult females (adult males are not affected). It is structurally similar to spiromesifen. Target pests include *Panonychus*, *Phyllocoptruta*, *Brevipalpus*, *Aculus* and *Tetranychus* species.[227]
Pest controlled / crop	Spirodiclofen is registered in the US to control insects and mites including the apple rust mite, avocado brown mite, avocado red mite, blister mites, broad mite, brown mite, carmine spider mite, citrus bud mite, citrus flat mite, citrus red mite, citrus rust mite, European red mite, false spider mites, flat mite, hemlock rust mite, McDaniel spider mite, Pacific spider mite, peach silver mite, pear rust mite, pecan leaf scorch mite, pink citrus rust mite, silver mite, six-spotted mite, spruce spider mite, Texas citrus mite, two-spotted spider mite, Willamette spider mite, and the Yuma spider mite. It can be used on tree fruits (avocado, black sapote, canistel, mamey sapote, mango, papaya, sapodilla, star apple; citrus; pome fruit; stone fruit), tree nuts, grapes, hops, and Christmas tree plantations.[228] Spirodiclofen is approved in Canada to control mites (apple rust mite, blueberry bud mite, European red mite, McDaniel spider mite, peach silver mite, pear rust mite, two-spotted spider mite) in blueberry, pome fruit (apple, crab-apple, loquat, mayhaw, oriental pear, pear, quince) stone fruit (apricot, cherry, nectarine, peach, plum, prune), tree nuts (almond, beech nut, brazil nut, butternut, cashew, chestnut, chinquapin, filbert, hickory nut, macadamia nut, pecan, walnut), and hops.[229] The use of spirodiclofen is no longer supported in the EU.[230] On 6 January 2020 the registration for spirodiclofen was withdrawn in the UK with authorisation to use existing stocks until 31 January 2022.[231]
Risk	According to the EU harmonised classification and labelling, spirodiclofen may cause cancer (H350), is very toxic to aquatic life with long lasting effects (H410), is suspected of damaging fertility (H361f), may cause damage to organs through prolonged or repeated exposure (H373) and may cause an allergic skin reaction (H317).[232] In Canada the label must indicate that the product is toxic to bees, toxic to certain beneficial insects (e.g., predatory mites) and toxic to aquatic organisms and non-target terrestrial plants.[233]

[224] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-12-03).

[225] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-12-03).

[226] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-02).

[227] US EPA (2005) Spirodiclofen (available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-124871_11-Aug-05.pdf).

[228] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-12-04).

[229] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-04).

[230] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/, accessed 2020-12-04).

[231] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/prodsearch.asp, accessed 2020-12-04).

[232] European Chemicals Agency (https://echa.europa.eu/substance-information/-/substanceinfo/100.130.204, accessed 2020-12-04).

[233] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-04).

17. Spiromesifen (CAS No. 283594-90-1)	
Description of the alternative	Spiromesifen is a tetronic acid with a chemical structure similar to spirodiclofen. It is used to control whiteflies and mites on fruit, vegetables and ornamental plants.
Pest controlled / crop	Spiromesifen is registered in the US control insects (whiteflies) and mites on field crops, vegetables, low-growing berries and ornamental plants. It can control many species of mites such as: Banks grass mite, blister mites, boxwood mite, broad mite, carmine spider mite, cyclamen mite, desert spider mite, false spider mite, honey-locust spider mite, Pacific spider mite, rust mites, southern red mite, strawberry spider mite, spruce spider mite, tomato russet mite, tumid spider mite, and two-spotted spider mite.[234] In Canada, spiromesifen is registered for the control of mites and whiteflies on field, vegetable and fruit crops, as well as greenhouse vegetables and ornamentals.[235] It is authorised for use in greenhouse applications on fruits, vegetables and ornamentals in 11 EU member states[236] and is registered India as an insecticide/miticide for the control of red spider mites in eggplant and tea; yellow mites in chilli, European red mites and red spider mites in apples, and whiteflies and mites in tomato and cotton.[237]
Risk	Spiromesifen is considered toxic to aquatic organisms, non-target terrestrial plants, and beneficial organisms (e.g. bees, predatory and parasitic insects, spiders, and mites).[238] The US EPA has classified spiromesifen as “not likely to be carcinogenic to humans”.[239] According to EU harmonised classification and labelling notifications received, potential hazards of spiromefisen include: may cause an allergic skin reaction (H317), is harmful if inhaled (H332), is very toxic to aquatic life (H400) and is very toxic to aquatic life with long lasting effects (H410).[240]
18. Tebufenpyrad (CAS No. 119168-77-3)	
Description of the alternative	Tebufenpyrad belongs to the pyrazole class of pesticides and is used to control mites on fruit trees and other crops. It is a non-systemic pesticide that acts as a mitochondrial electron transport inhibitor on contact or through ingestion.[241]
Pest controlled / crop	Tebufenpyrad was registered in the US in 2002 for use on ornamental plants grown in commercial greenhouses. All uses were cancelled in 2014.[242] It is registered in the EU[243] and in the UK.[244] Labelled uses include the control of mites in top fruit, strawberries and ornamental plant production, the two-spotted spider mite and damson hop aphid in hops.[245] It is registered in Australia for use on apple (carmine mite, European red mite), cucumber (European red mite, two-spotted mite) ornamental flowers and shrubs (carmine mite) peach (carmine mite, European red mite) and pear (carmine mite, European red mite).[246]
Risk	The US EPA concluded that there was “suggestive evidence of carcinogenicity, but not sufficient to assess human carcinogenic potential” of tebufenpyrad. It is very highly toxic

[234] US EPA Pesticide Product and Label System https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-12-04).

[235] Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-04).

[236] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-12-04).

[237] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2020-12-04).

[238] Canada Canada. Product Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php, accessed 2020-12-04).

[239] US EPA (2018) Spiromesifen – Pesticide Tolerances. Federal Register (83): 45844 (https://www.federalregister.gov/documents/2018/09/11/2018-19760/spiromesifen-pesticide-tolerances).

[240] European Chemicals Agency (https://echa.europa.eu/substance-information/, accessed 2020-12-04).

[241] Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/612.htm, accessed 2020-12-04).

[242] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2020-12-04)

[243] EU Pesticides Database https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2020-12-04).

[244] Pesticides Register of Great Britain and Northern Ireland Authorised Products (https://secure.pesticides.gov.uk/pestreg/, accessed 2020-12-04).

[245] Refer to product labels, for example, Masai™ (BASF) (https://agrobaseapp.com/united-kingdom/pesticide/masai-2) or Clayton Bonsai ™ (Clayton Plant Protection 2017) (https://claytonpp.com/wp-content/uploads/2018/06/Bonsai_Label_12.11.19.pdf).

[246] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2020-12-04).

	to fish but practically non-toxic to birds.[247] According to the EU harmonised classification and labelling tebufenpyrad is toxic if swallowed (H301), may cause an allergic skin reaction (H317), is harmful if inhaled (H332), may cause damage to organs (gastrointestinal tract, oral route) through prolonged or repeated exposure. (H373), is very toxic to aquatic life (H400) and is very toxic to aquatic life with long lasting effects (H410).[248]
19. Thiamethoxam (CAS No. 153719-23-4)	
Description of the alternative	Thiamethoxam is a systemic, neonicotinoid insecticide with unique spectrums of activity that act on the nicotinic acetylcholine receptors (nAChRs) of the central nervous system of insects.
Pest controlled / crop	Thiamethoxam products were first registered in US on 1999. Thiamethoxam is used to control a range of insect pests, such as aphids, whiteflies, thrips, caterpillars, beetles, flies, and stinkbugs. Thiamethoxam also targets the citrus rust mite. It is applied on a wide variety of crops (e.g. corn, cotton, soybeans, root and tuber vegetables, pome fruit, stone fruit, berries, tree nuts, legumes, cereal grains, and oilseed crops and herbs), non-agricultural use sites such as turf, poultry houses, and ornamental plants.[249] It is also registered for use in India.[250] In Australia combination products that include thiamethoxam are registered to control mites on tomatoes and ornamentals as well as seed treatment to control red legged earth mite in canola and cereals.[251]
Risk	Thiamethoxam has been assigned the following EU harmonised classification and labelling codes: H302 – Harmful if swallowed; H400 – Very toxic to aquatic life; H410 – Very toxic to aquatic life with long-lasting effects. [252] Labels in the US include the following cautions: Harmful if inhaled or absorbed through skin; Causes moderate eye irritation; This pesticide is toxic to wildlife and highly toxic to aquatic invertebrates; This pesticide is highly toxic to bees.[253]

[247] US EPA (2002) Tebufenpyrad (available https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-090102_26-Aug-02.pdf).

[248] European Chemicals Agency (https://echa.europa.eu/information-on-chemicals/, accessed 2020-12-04).

[249] US EPA (2020) Clothianidin and thiamethoxam (available https://www.epa.gov/sites/production/files/2020-01/documents/clothianidin_and_thiamethoxam_pid_final_1.pdf)

[250] India. Registered Pesticides and Label System (https://www.pesticides-registrationindia.nic.in/Search/frmProductSearch.aspx, accessed 2021-02-10).

[251] APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris, accessed 2021-02-10).

[252] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/active-substances/, accessed 2021-02-10).

[253] US EPA Pesticide Product and Label System (https://iaspub.epa.gov/apex/pesticides/f?p=PPLS:1, accessed 2021-02-10).

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