Draft guidance on alternatives to methoxychlor

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1. Introduction

At its eleventh meeting, the Conference of the Parties (COP) to the Stockholm Convention on Persistent Organic Pollutants (POPs) adopted decision SC-11/9 by which it listed methoxychlor to Annex A to the Convention for elimination without specific exemptions. In decision SC-11/7, the COP requested the Secretariat to develop guidance on alternatives to methoxychlor. This guide aims to support Parties as they develop national implementation plans reflecting the addition of methoxychlor 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). In addition, the fifth meeting of the International Conference on Chemicals Management (ICCM) adopted resolution V/11: Highly hazardous pesticides, which endorsed the formation of a global alliance on highly hazardous pesticides with the goal of taking effective measures to phase out highly hazardous pesticides in agriculture where the risks have not been managed and where safer and affordable alternatives are available; and to promote transition to and make available those alternatives (SAICM/ICCM.5/4).

Methoxychlor is an organochlorine pesticide that has been used as a replacement for DDT, an ectoparasiticide in veterinary practice, and an insecticide against a wide range of pests, including houseflies and mosquitos, cockroaches, chiggers, and various arthropods commonly found on field crops, vegetables, fruits, stored grain, livestock, domestic pets, and the elm bark-beetle vectors of Dutch elm disease. It has been used to control pests in barns, grain bins, mushroom houses, other agricultural premises, garbage containers, sewer access holes, and sewage disposal areas. Methoxychlor may have been applied to large areas such as beaches, estuaries, lakes, and marshes by aerial application. In the US approximately 28% of methoxychlor was used for home and garden purposes, 15% for industrial and commercial purposes, and 57% for agricultural purposes (UNEP 2022).

Since methoxychlor has been used for a wide variety of target pests and crops, the number of agricultural practices that may be adopted as alternatives are extensive. This document can only provide a high-level overview of alternatives that have been implemented in some countries and regions and are considered technically feasible. However, some of chemical alternatives have hazardous characteristics, including PBT[1] or POPs characteristics and meeting the Food and Agriculture/World Health Organization (FAO/WHO) criteria for highly hazardous pesticides[2]. 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. The non-chemical alternatives to methoxychlor include integrated pest management (IPM), sustainable agroecological and organic agricultural practices, biological control systems and botanical preparations, as well as physical barriers and hygiene practices.

In order to assist Parties identify possible alternatives to methoxychlor, this guide starts by outlining the features of an integrated pest management approach and identifies physical, mechanical, and cultural approaches to minimise pest damage. It then provides information on some biological agents that have been used and highlights some of the alternative chemical pesticides that were identified in the risk management evaluation (UNEP/POPS/POPRC.17/13/Add.1, UNEP, 2022) which are registered in at least one country. 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

[1] PBT substances are substances that are persistent, bioaccumulative and toxic (https://chemsafetypro.com/Topics/CRA/Overview_and_Comparison_of_PBT_and_vPvB_Criteria_in_EU_and_USA.html, accessed 2024-03-14)

[2] 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 (http://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/Code/Report.pdf).

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."[3]

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 physical methods, with the use of chemical controls as a last resource, is the most effective, long-term way to manage pests.[4] **Figure 1** illustrates the IPM crop cycle and **Box 1** below describes the different tools of IPM.

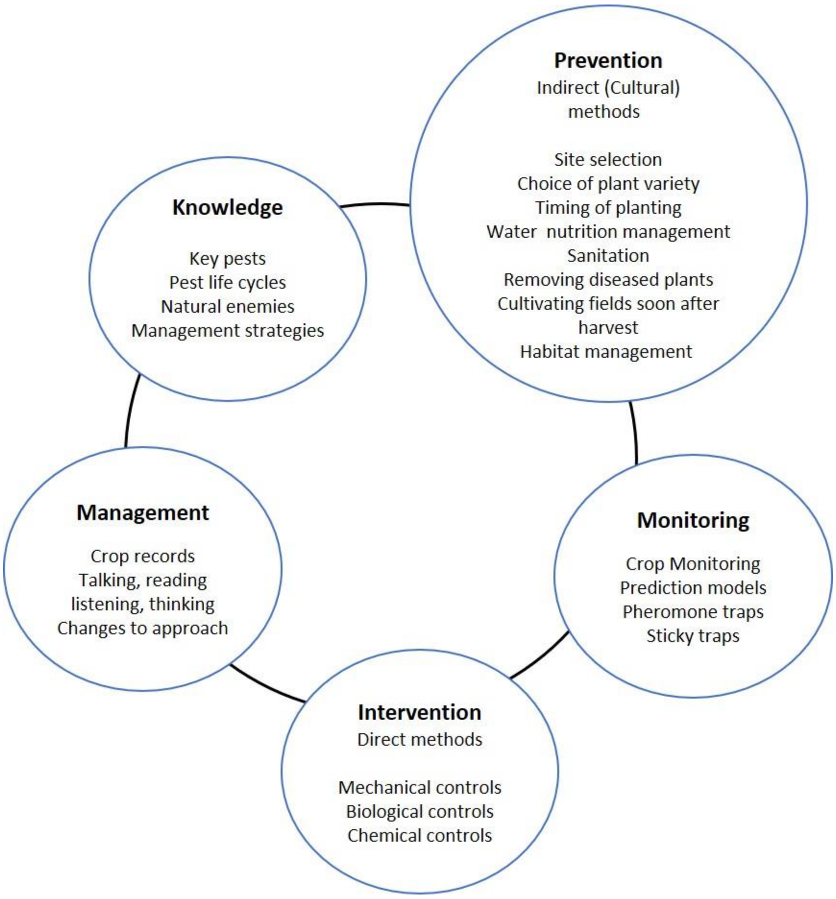

Figure 1. Integrated Pest Management Cycle

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

[3] Integrated Pest Management (FAO, undated) (https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/, accessed 2024-03-14).

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

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.[5] 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 directly attacked and destroyed. Physical controls are used mostly in weed control.[6] Horticultural oils, diatomaceous earth, insecticidal soap, vacuums, and water sprays have been used to control insects and mites.[7] Hand picking of pests, sticky boards or tapes in greenhouses and traps or attractants are also forms of physical control.[8]

[5] UC IPM (undated) cited above; Hillock D (2017) Cultural control practices (Available at https://extension.okstate.edu/fact-sheets/earth-kind-gardening-series-cultural-control-practices.html).

[6] Alberta (undated) Physical control of pests (https://www.alberta.ca/physical-control-of-pests, accessed 2024-02-20).

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

[8] Hoffmann and Frodsham (1993a) Integrated pest management control tactics (https://biocontrol.entomology.cornell.edu/ipm.php#phys, accessed 2020-11-12).

Biological control[9]

Biological control uses natural enemies – predators, parasites, pathogens, and competitors – to control pests and reduce their damage.[10] 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, the conservation of natural enemies is a critical component. Conservation of natural enemies involves either, reducing factors which interfere with natural enemies or provide 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 wider landscape.

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 borders with flowering plants are 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.

The 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 and 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, that can sometimes be achieved with importation or conservation methods.

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 in bait stations rather than sprays or targeted application of the pesticide rather than spraying an entire area.[11]

2.1 Economic viability of alternative approaches

IPM, organic and regenerative farming, and agroecology are gaining momentum as more sustainable approaches to agriculture. The use of an IPM approach reduces the quantity and frequency of pesticide use, and increases the quantity and quality of crops harvested. It can expand the market and export potential of the crops in question, and increase farmers' income. 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 (CropLife, 2014). Other authors have also documented economic benefits (for example, Pretty and Bharucha, 2015; Cuyno et al., 2001; Del Fava et al., 2017; Watts and Williamson, 2015; Willer et al., 2021), although some have raised concerns about its economic viability (Onstad and Crain, 2019).

Organic farming is promoted as an alternative to the use of toxic pesticides including methoxychlor. A review of 63 articles covering a range of crops and countries found that, economically, organic generally outperformed conventional systems (Durham and Mizik 2021). Studies in India have shown improved returns and better longer-

[9] 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).

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

[11] UC IPM (undated) cited above.

term economic positions relative to chemical approaches for crops such as cotton, rice, red gram and groundnut crops, (Eyhorn, 2007; Sudheer, 2013). The economic risk associated with the transition to organic farming during the initial two to three years of conversion can make the adoption of organic farming challenging for some farmers, however (Eyhorn, 2007).

2.2 IPM in cotton[12]

This section describes the main elements of an IPM strategy at the different stages of the crop cycle for cotton.

2.2.1 Preplant to planting

Select a variety of cotton that is most suitable for local conditions. Consider crop rotation if field had severe problems in the previous year with root-knot nematode, *Verticillium* wilt, *Fusarium* wilt, or seedling diseases. If root-knot nematodes are also a problem, precision tillage and ripping in locations with a history of soil compaction can be useful. Interplanting trap-crops of alfalfa, cowpea, or lima bean if lygus bug management. Seed treatment may help reduce damage from aphids, seed corn maggot, seedling diseases thrips and wireworms. Also survey for and manage weeds.

2.2.2 Crop emergence to seedling growth

Begin tracking plant growth as soon as crop emerges and monitor for spider mites, aphids, and thrips. Monitor nearby crops, fence rows, and weedy areas for false chinch bugs. Maintain a weed management program and manage *Fusarium* is necessary.

2.2.3 Squaring to first bloom

Continue to monitor plant growth. Monitor for pests such as armyworms, cabbage loopers, spider mites, aphids, whitefly and treat according to cotton pest management guidelines including the use of natural predators. Monitor lygus bug activity and manage alternate lygus bug hosts such as weeds, alfalfa, and safflower. Continue with weed management activities and sample for *Fusarium* if necessary. Adjust nitrogen application amount and first irrigation timing to limit rank or excessive growth.

2.2.4 First bloom to first open boll

Continue to monitor plant growth and adjust nitrogen, irrigation and application of plant growth regulators if needed. Monitor for pests, including armyworms, spider mites, aphids, whitefly and lygus bug activity, and treat as necessary. Start sampling for bollworms.

2.2.5 First open boll to harvest

Continue to monitor plant growth and to manage weeds. Monitor aphids and whitefly, including regrowth after defoliation and treat if necessary. Also continue to monitor and treat for lygus bugs as needed. Schedule defoliation to allow for timely harvest and minimum regrowth. If there is evidence of *Verticillium* wilt choose a time between crop maturity and harvest to sample stems for discoloration. While soil is still moist from final irrigation, sample plant roots for nematode infestation and treat if numbers warrant.

2.2.6 Harvest to postharvest

Maintain maximum time between harvest and planting whitefly host crops and promptly destroy stalks to prevent regrowth and limit additional whitefly buildup. Observe host-free periods to prevent the establishment of pink bollworms.

2.3 IPM in corn/maize[13]

This section describes the main elements of an IPM strategy at the different stages of the crop cycle for corn or maize (excluding sweet corn).

2.3.1 Preplant

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[12] This section is based on Barlow et al. (Undated) University of California Pest Management Guidelines: Cotton (https://ipm.ucanr.edu/agriculture/cotton/, accessed 2024-03-10).

[13] This section is based on Goodell et al (undated) University of California Pest Management Guidelines: Corn (https://ipm.ucanr.edu/agriculture/corn/, accessed 2024-03-10).

When you select the field consider soil type, cropping and pest history, and any plant back restrictions from a previous crop. Sample soil for nutrient, salinity, and pH analysis to determine field suitability and nutrient needs. Consider crop rotation to prevent build-up of soilborne pathogens, such as *Fusarium* and *Pythium* stalk rot, and problem weeds. If the previous crop is still in the field, survey for weeds and manage them as required. Pre-irrigate and cultivate to germinate and destroy weed seedlings. Pheromone traps can be used for community-level monitoring of pests such as the armyworm to identify the need for intervention.

The use of technologies such as corn-legume or push-pull[14] intercropping, and tolerant corn cultivars can reduce the risk of stemborer, armyworm and *Striga* weed infestations. The use of classical and conservation biological control that promote parasitoids can reduce populations of stemborers and fall armyworm. Maize or corn lethal necrosis can be managed with tolerant and disease-free cultivars, intercropping and the application of biopesticides to manage thrips and aphids.[15]

Push-pull habitat management strategy, an intercropping technology that integrates corn cultivation with foraged grasses and legumes for control of cereal stemborers, fall armyworm and *Striga* weed, improves soil fertility and increases fodder production. The technology has been adopted by over 300,000 farmers in Eastern Africa with significant increases in crop yield. This has led to a significant reduction in the use of synthetic pesticides and herbicides.[16]

Clean equipment and tractors between fields to prevent the spread of soilborne diseases and weed seeds. Prepare the field and consider reduced tillage options. Ensure good drainage and apply fertilizer based on soil test results. Consider herbicide resistance and insect resistance and select an appropriate hybrid based on yield and pest history.

2.3.2 Planting to 5th leaf

Consider a soil or seed treatment if wireworms have been a problem in the past or if conditions are conducive for seed corn maggots. Avoid planting in overly wet or overly soft seedbeds. Soon after planting, monitor the field to identify germinated weeds and manage them as needed. If nutsedge, johnsongrass, or bermudagrass are present, cultivate with sweeps or knives before corn is 20 cm tall. If using glyphosate resistance technology, follow directions carefully and rotate with other herbicides and mechanical methods to avoid resistant weeds.

Look for pests and damage as the corn emerges. Pests include aphids, armyworms, corn leafhopper, corn leafminer, cucumber beetles, flea beetles, grasshoppers, seed corn maggot, stem (stalk) borers, thrips, and wireworms, as well as diseases such as seed rot and damping-off.

2.3.3 6th leaf to tassel appearance

Assess plant nutrition status and apply nutrients as required. Survey and manage weeds. Look for spider mites and inspect for damage, and if needed apply pest control. If aphids appear on the tassels, treatment may be needed to prevent the spread of viruses. Look for corn leafhopper and monitor for *Pythium* stalk rot. Other pests or damage to monitor for include armyworms, corn leafminer, cucumber beetles, grasshoppers, and thrips.

2.3.4 Early silk through maturity

Look out for and control armyworms, cucumber beetles, and corn earworm. If necessary, treat spider mite colonies with spiromesifen at least 30 days before harvest. Monitor for diseases and incorporate mitigation measures for the next planting season (e.g. crop rotation, plant variety). Check for possible disease of concern – Charcoal rot; *Fusarium* stalk rot and *Pythium* stalk rot *Fusarium* ear rot, head smut or common smut – and manage accordingly. If more than ten percent of stalks have fallen over due to *Pythium* or *Fusarium* stalk rot, schedule an early harvest. Right before harvest, sample ears from different quadrants of the field. Check for damage (no ears/poorly filled ears, curved ears, red leaves) and plan for next year.

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[14] Push-pull technology is an intercropping strategy for controlling agricultural pests. It uses "push" plants that repel pests and "pull" plants to trap them. For more information see: Cook SM, Khan ZR, Pickett JA (2007) The Use of push-pull strategies in integrated pest management. Annual Review of Entomology (52) (Available at https://doi.org/10.1146/annurev.ento.52.110405.091407).

[15] Prasanna BM (2021) Maize lethal necrosis (MLN): A technical manual for disease management. CIMMYT (available at https://mln.cimmyt.org/wp-content/uploads/sites/39/2021/10/MLN-Disease-Management_Technical-Manual-CIMMYT.pdf).

[16] Khan Z, Midega C, Pittchar J, Pickett J, Bruce T (2011) Push—pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa: UK government's Foresight Food and Farming Futures project. International Journal of Agricultural Sustainability (9/1): 162–170 (https://doi.org/10.3763/ijas.2010.0558).

2.3.5 Harvest and postharvest

To prevent mold growth during storage, harvest at the appropriate moisture level. Methods to mitigate disease and pests (e.g. seed corn maggot, *Fusarium* stalk rot, *Pythium* stalk rot, corn leafhopper, and corn stunt) in the next season include disking under crop residue and volunteer corn. Plan next season's crop rotation.

2.4 IPM in greenhouses[17]

Pest management in greenhouse environments is complex especially when diverse number of crops, each with their own pest issues are grown together. The enclosed nature of greenhouses is conducive to the swift spread of a pest problem, but at the same time provides an environment where biological control can be effectively used as a low-risk management approach.[18] Successful management of pests requires the use of multiple tactics. These include starting with healthy plants, a clean greenhouse, and use of physical barriers and biological controls. While beneficial insects most often come to mind, beneficial organisms also include predatory mites and nematodes, antagonistic/entomopathogenic bacteria, fungi, and viruses. Horticultural oils, horticultural soaps, and insect growth regulators are also other pest control measures that can be used.

Insect growth regulators (IGR) are synthetic mimics of insect hormones. They disrupt the life cycle of insects, causing death or sterility. They only act on insects that are still developing and will not affect the adults. Examples of IGRs include: diflubenzuron and tebufenozide which are used to control caterpillars; kinoprene and pyriproxyfen to control fungus gnats, whiteflies, and scales; and cyromazine that control leafminer larvae.

Botanical pesticides include **neem**-related products such as **azadiractin**, and pyrethrum-based pesticides. Potassium and sodium bicarbonate are often used in combination with oil sprays when applied as preventive sprays against diseases. For example, baking soda/oil mixture can help control black spot and powdery mildew of roses, powdery mildew of phlox and zinnias, and most foliar garden vegetable diseases.

Box 2: Common Greenhouse Pests and Biological Control Agents[19]

Pest	Biological control agent	Comment
Aphids	*Aphelinus abdominalus* *Aphidius ervi*	Parasitic wasps; females parasitize and feed upon aphids for several weeks
	Aphidoletes aphidimyza	Aphid gall midge, resembles a fungus gnat; young feed exclusively on aphids
	Ladybird Beetles (Ladybugs)	Young and adults feed on aphids
	Chrysoperla carnea	Green lacewings; larvae are voracious predators; *C. carnea* recommended for dry areas
	Chrysoperla rufilabris	Green lacewings; larvae are voracious predators; *C. rufilabris* for humid areas
	Beauveria bassiana	Pathogenic fungi
Fungus Gnats and Shore Flies	*Atheta coriaria*	Voracious rove beetle predator
	Bacillus thuringiensis	Bacterium, controls larvae in soil
	Beauveria bassiana	Pathogenic fungi
	Steinernema feltiae	Parasitic nematode
	Hypoaspis miles	Predatory mite

[17] This section is primarily derived from Schnelle M and Rebek E (2017) Integrated Pest Management in Commercial Greenhouses. Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, OK (Available at https://extension.okstate.edu/fact-sheets/ipm-in-the-greenhouse-series-integrated-pest-management-in-commercial-greenhouses-an-overview-of-principles-and-practices.html).

[18] Agriculture and Agri-food Canada (2017) Pesticide Risk Reduction Strategy for Greenhouse Floriculture (https://agriculture.canada.ca/en/science/agriculture-and-agri-food-research-centres/pest-management-centre/pesticide-risk-reduction-pest-management-centre/pesticide-risk-reduction-strategies/pesticide-risk-reduction-strategy-greenhouse-floriculture, accessed 2021-02-17).

[19] Adapted from Schnelle and Rebek (2017) cited above.

Mealybugs	*Cryptolaemus montrouzieri*	Small ladybird beetle (Mealybug Destroyer), both adults and larvae attack mealybugs and scales
Spider Mitea	*Phytoseiulus persimilis*	Predator mite
	Stethorus punctillum	Small ladybird beetle that feeds specifically on mites
	Ladybird Beetles (Ladybugs)	Young and adults feed on spider mites
Thrips	*Amblyseius cucumeris*	Predatory mite
	Amblyseius degenerans	Works better in flowers than *A. cucumenis*; effective in low humidity
	Ladybird Beetles (Ladybugs)	Young and adults feed on thrips
	Orius insidiosus	Pirate bugs; nymphs and adults feed on thrips
	Beauveria bassiana	Pathogenic fungi
Whiteflies	*Encarsia formosa*	Parasitic wasp, eggs develop in body of young whiteflies
	Delphastus pusillus	Ladybird beetle
	Ladybird Beetles (Ladybugs)	Useful to "knock down" an infestation
	Eretmocerus californicus	Parasitic wasp
	Chrysoperla carnea	Green lacewings; larvae are voracious predators; *C. carnea* recommended for dry areas,
	Chrysoperla rufilabris	Green lacewings; larvae are voracious predators; *C. rufilabris* for humid areas
	Beauveria bassiana	Pathogenic fungi
Fungal Diseases in Soil	*Gliocladium virens*	Incorporation into growing media controls disease-causing soil fungi
	Trichoderma viride	Incorporation into growing media controls (for foliar use) disease-causing soil fungi
	Streptomyces fungus	Suppresses soil *Botrytis*
Fungal Diseases on Leaves	*Pseudomonas fluorescens*	Controls fungal diseases on certain plants
	Trichoderma harzianum	Suppresses powdery mildew and *Botrytis*
	Streptomyces fungus	Suppresses soil *Botrytis*

2.5 Approaches to control certain pests

This section highlights a few examples of alternative pest control approaches developed at International Centre of Insect Physiology and Ecology (icipe) in Kenya.

Diamondback moth: The parasitoid wasp, *Diadegma semiclausum* has been used successfully as a biological control agent for the diamondback moth in Cameroon, Ethiopia, Kenya and Tanzania. As a result, gross margins from the production crucifers increased by 81% due to mitigation of pest damage and a 75% reduction in insecticide sprays. The benefit-cost ratio for the investment in research is estimated at 24:1 over 25 years in Kenya.[20]

Fruit fly: icipe has developed an IPM strategy for fruit flies which include the following components: population monitoring, protein bait, male annihilation, field sanitation, and biological control (using biopesticides, parasitoids, and weaver ants). Over 5000 mango and citrus growers in Benin, Cameroon, Kenya, Mozambique and Tanzania are

[20] Macharia I, Löhr B, De Groote H (2005) Assessing the potential impact of biological control of Plutella xylostella (diamondback moth) in cabbage production in Kenya. Crop Protection (24/11): 981-989.

using these methods. As a result of using this approach, the rejection rate of mango fruit exports was reduced from 37% in 2003 to 4% in 2011.[21]

Lepidopteran and sucking pests: Ecofriendly netting is a very effective way to protect vegetables against lepidopteran pests, and may also delay the infestation of sucking pests. For example, Agronets produced by the Tanzanian company A to Z Textile Mills can protect nurseries and small-scale vegetables from infestation by sucking pest and have been shown to reduce the use of chemical insecticides by 70 to 100% on cabbages and tomatoes.[22]

Potato cyst nematode: Wrap-and-plant technology has been used to manage potato cyst nematodes in East Africa. A biodegradable lignocellulosic banana-paper matrix is used as a seed wrap to protect potato plants against the potato cyst nematode *Globodera rostochiensis* (PCN). Wrapping seed potatoes within the lignocellulose banana-paper matrix substantially reduced *G. rostochiensis* field inoculum and increased potato yields by up to five-fold in Kenya, relative to farmer practice, whether or not impregnated with ultra-low doses of the nematicide **abamectin**.[23]

Ticks: icipe developed a biological control strategy for use in conjunction with conventional approaches like acaricides to manage ticks on livestock of smallholder farming systems. This strategy uses fungal pathogens such as *M. anisopliae* isolate ICIPE 7, which is currenly being registered for tick control in Kenya.[24]

Tsetse fly: icipe has developed eco-friendly traps which attract tsetse flies. They consist of blue and black cloth shaped to attracts the flies and funnel them into a net. The use of volatile odour baits, such as cattle urine and acetone, increases their effectiveness. They have been used successfully across Africa for the control of savanna species of tsetse, eliminating the use of synthetic pesticides.[25]

2.6 Integrated vector management (IVM) for vector-borne diseases[26]

Methoxychlor was used in vector control including as an alternative to DDT. Prevention and control of vector-borne diseases is best achieved with a comprehensive, IVM programme. Such a programme applies the principles of IPM. The components of IVM are education, surveillance, source reduction, and pest control. A central element is surveillance of both vector populations and arbovirus activity levels to determine the interventions are needed to reduce the risk of human disease. Surveillance involves monitoring the conditions and habitats that are conducive to the build-up of vector populations, monitoring the abundance of vectors and the level of arboviral transmission activity. Data from surveillance activities are then used to inform the needed interventions which include in order of priority, education to reduce exposure to the virus, source reduction through habitat modification, control of the larval stages of the vector, and if needed control of the adult pest.

DDT is currently listed in Annex B to the Stockholm Convention with its production and/or use restricted for disease vector control purposes when no equally effective and efficient alternative is available, and in accordance with related World Health Organization (WHO) recommendations and guidelines. The POPs Review Committee identified the following pesticides as alternatives to DDT: alpha-**cypermethrin**, bendiocarb, **cyfluthrin**, lambda-cyhalothrin, **deltamethrin**, etofenprox, fenitrothion, malathion, primiphos-methyl, propoxur (pesticides in bold are included in

[21] Saliou N, Murithii B, Omuse ER, et al. (2022) "Insight on fruit fly IPM technology uptake and barriers to scaling in Africa" Sustainability (14/5): 2954 (https://doi.org/10.3390/su14052954).

[22] Parrot L, Assogba Komlan F, Vidogbena F, Adegbidi A, Baird V, Martin T, ... and, Ngouajio M (2014) Eco-friendly nets to improve vegetable production and quality in sub-Saharan Africa. In XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014) 1105: 221-228.

[23] Ochola J, Cortada L, Mwaura O, et al. (2022) Wrap-and-plant technology to manage sustainably potato cyst nematodes in East Africa. Nature Sustainability (5/5): 425-433.

[24] Akutse KS, Subramanian S, Maniania N,et al. (2020) Biopesticide research and product development in Africa for sustainable agriculture and food security–Experiences from the International Centre of Insect Physiology and Ecology (icipe). Frontiers in Sustainable Food Systems, 4: 563016.

[25] Masiga DK, Igweta L, Saini R, et al. (2014) Building endogenous capacity for the management of neglected tropical diseases in Africa: the pioneering role of ICIPE. PLoS Neglected Tropical Diseases (8/5): e2687;

Gamba DO, Olet PA, Maichomo MW, et al. (2021) Role of Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC) in control of African animal trypanosomiasis (AAT)/Nagana. In Combating and Controlling Nagana and Tick-Borne Diseases in Livestock, IGI Global: 73-94.

[26] This section is primarily derived from US CDC (2022) Prevention and control: integrated vector management (https://www.cdc.gov/mosquitoes/guidelines/west-nile/prevention-control/index.html, accessed 2024-03-20). See also WHO (2012) Handbook for integrated vector management (https://iris.who.int/bitstream/handle/10665/44768/9789241502801_eng.pdf).

Section 4 on alternatives to methoxychlor).[27] Section 4 also lists four active ingredients identified as potential alternatives are used in the control of vector-borne diseases: chlorfenapyr, DEET, fenvalerate, and permethrin. UZIMAX, a novel plant-based biopesticide developed developed by icipe, is estimated to kill up to 100% of *Anopheles* larvae within 48 hours of application and poses no risks to human health and the environment.[28]

Community-based interventions have been effective. For example, an icipe project in Kenya trained Community Resource Persons (CORPs) – local community members and children – in the proper use of mosquito nets, environmental management for disease vector control, mosquito proofing of houses, and promotion of use of eco-friendly biopesticides such as ***Bacillus thuringiensis*** *(Bt)* and plant-based vector-control products. In one of the project sites, malaria prevalence was reduced from 50 to 4%.[29]

2.7 Sources of information on IPM

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

- European Union Farmer's Toolbox for Integrated Pest Management https://datam.jrc.ec.europa.eu/datam/mashup/IPM/index.html
- 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

3. Biological control systems and botanical preparations

3.1 Cultural methods

As described in Box 1 above, 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. The approach used varies depending on the crop and pest to be controlled. Refer to IPM guides (such as those listed in 2.7 above) related to the specific crop and pest of concern.

3.2 Mechanical Treatments[30]

Mechanical treatments include the use of horticultural oils, diatomaceous earth, insecticidal soap, vacuums and water sprays.

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, although it may also affect some beneficial organisms such as ladybirds. The sharp edges of the ground diatoms scratch the waxy or oily outer layer of soft-bodied insects, which eventually die from dehydration; thus, it is described as a 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. It is less effective against pests in humid weather.

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[27] UNEP (2012) Assessment of alternatives to DDT (UNEP/POPS/POPRC.8/INF/30, https://chm.pops.int/Portals/0/download.aspx?d=UNEP-POPS-POPRC.8-INF-30.English.pdf).

[28] Ochola JB, Mutero CM, Marubu RM, et al. (2022). Mosquitoes larvicidal activity of *Ocimum kilimandscharicum* oil formulation under laboratory and field-simulated conditions. Insects, 13(2), 203 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8877965/).

Diiro GM, Kassie M, Muriithi BW, et al. (2020) Are individuals willing to pay for community-based eco-friendly malaria vector control strategies? A case of mosquito larviciding using plant-based biopesticides in Kenya. Sustainability (12): 8552 (https://doi.org/10.3390/su1220855).

[29] Kibe LW, Mbogo CM, Keating J, et al. (2006) Community based vector control in Malindi, Kenya. African Health Sciences (6/4)): 240 – 246.

[30] This section is primarily derived from: Hillock D and Bolin P (2017) Mechanical Pest Controls (http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2291/HLA-6432web.pdf).

Insecticidal soaps and detergents are effective against most small, soft-bodied arthropods such as such as aphids, young scales, whiteflies, psyllids, mealybugs, and spider mites. A few large insects such as boxelder bugs and Japanese beetles are susceptible to these products. However, predatory mites are 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 aphids and spider mites from foliage and stems of sturdy plants. It needs be repeated frequently since many of the insects are likely to return and may not be effective if pest populations are high. Frequent applications of water may increase of disease or lead root damage if the soil is too wet.

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 specialised, 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.[31] Predators include the larvivorous fish *Tilapia nilotica* and *Gambusa affinis* that have been used to reduce populations of mosquitoes and other insect pests.[32]

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.

Unless otherwise indicated the information of registration status has been obtained from the following sources and was valid at the time of writing:

- Australia: The Australian Pesticides and Veterinary Medicines Authority (APVMA) PubCRIS database
- Brazil: Agrofit – Sistema de agrotóxicos fitossanitários [Database of plant protection products registered in Brazil]
- Canada: Pest Management Regulatory Agency (PMRA) Product Label Search
- EU: European Chemicals Agency (ECHA) Information on chemicals database
- India: Insecticides/Pesticides registered under section 9(3) of the Insecticides Act, 1968 for use in the country as on 01.06.2023
- UK: Pesticides Register of Great Britain and Northern Ireland, and
- US: US Environmental Protection Agency (EPA) Pesticide Product and Label System.[34]

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[31] Hoffmann and Frodsham (1993b) Natural enemies of vegetable insect pests (https://biocontrol.entomology.cornell.edu/predators.php, accessed 2024-02-26).

[32] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1).

[33] US EPA (undated) What are biopesticides? (https://www.epa.gov/ingredients-used-pesticide-products/what-are-biopesticides, accessed 2024-02-26).

[34] These databases are available at: APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris);

Agrofit. Sistema de agrotóxicos fitossanitários (https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons);

Canada. Pesticide Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php);

European Chemicals Agency (https://echa.europa.eu/information-on-chemicals);

Government of India (2023) Insecticides / Pesticides registered under section 9(3) of the Insecticides Act, 1968 for use in the country as on 01.06.2023 (http://www.ppqs.gov.in/divisions/cib-rc/registered-products);

Pesticides Register of Great Britain and Northern Ireland (https://secure.pesticides.gov.uk/pestreg/prodsearch.asp); and

US EPA Pesticide Product and Label System (https://ordspub.epa.gov/ords/pesticides/f?p=PPLS:1).

Box 3: Examples of biochemical agents	
Pathogens	
***Bacillus cereus* (CAS No. 68038-62-0)**	
Description of the alternative	Various species of gram-positive bacteria commonly found in soil and food and which show fungicidal activity.[35]
Pest controlled / crop	*Bacillus cereus* Ar56 is a broad-spectrum of fungal pathogens including *Pseudomonas syringae* and bacterial wilt on tomatoes. *B. cereus c.* B4 can be used to control seedling rot; late and early blight, and *Alternaria solani* on tomatoes. *B. cereus* CIL can be used to control leaf blight on lilies. *B. cereus* DGA34 can be used to control to control damping-off, bacterial wilt, root rot on rice. *B. cereus* UW85 can be used to control damping-off bacterial wilt; root rot on certain crops including alfalfa, cucumbers, peanuts, and tobacco.[36]
Risk	Food poisoning caused by *B. cereus* is an acute intoxication that occurs when this microorganism produces toxins, causing two types of gastrointestinal illness: an emetic (vomiting) syndrome or a diarrhoeal syndrome. *B. cereus* is considered a relatively common cause of gastroenteritis worldwide.[37]
***Bacillus thuringiensis, subspecies israelensis* (Bti) (CAS No. 68038-71-1)**	
Description of the alternative	*Bacillus thuringiensis* (Bt) is bacterium found naturally in soils. Bt is genetically indistinguishable from *Bacillus cereus* (Bc). However, Bt has the ability to produce parasporal crystalline inclusions, which are toxic for certain invertebrates, especially species of insect larvae belonging to the insect orders Coleoptera, Diptera and Lepidoptera.[38] *Bacillus thuringiensis* subspecies *israelensis* (Bti) is registered or approved for use in Australia, Canada, EU, India, UK, and US.
Pest controlled / crop	Bti has been used as a biological pest control agent to combat mosquitoes and black flies since 1982. It is applied to surface water to control larvae. It is also used to control fungus gnat larvae on ornamental plants.[39]
Risk	Bti biodegrades readily through exposure to sunlight and microorganisms. Bti does is of low toxicity to non-target organisms. It is classified as having low toxicity to mammals, birds and honeybees. It is also of low toxicity to fish but shows moderate toxicity to invertebrates. It is a skin and eye irritant and a skin sensitiser. Bti poses little

[35] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/atoz.htm#B, accessed 2024-03-20).

[36] BPDB: Bio-Pesticides DataBase cited above.

[37] BC Centre for Disease Control (http://www.bccdc.ca/health-info/diseases-conditions/bacillus-cereus, accessed 2024-03-20).

[38] WHO (2009) *Bacillus thuringiensis israelensis* (Bti) in drinking-water – background document for development of WHO guidelines for drinking-water quality. World Health Organization, Geneva (https://cdn.who.int/media/docs/default-source/wash-documents/wash-chemicals/bacillus-thuringiensis-background.pdf).

[39] Health Canada (2011) Bti – *Bacillus thuringiensis* subspecies *israelensis* (Available at https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/fact-sheets-other-resources/bacillus-thuringiensis-subspecies-israelensis.html)

	threat to human health – the acidic stomachs of humans and animals do not activate Bti toxins. It is a WHO Classification III (Slightly hazardous) substance.[40,41] According to the EU hazard classification & labelling notifications this substance causes serious eye irritation (H319), may cause an allergic skin reaction (H317), may cause allergy or asthma symptoms or breathing difficulties if inhaled (H334) and may cause respiratory irritation (H335).[42]
***Beauveria bassiana* (CAS No. 63428-82-0)**	
Description of the alternative	*Beauveria bassiana* is a contact mycoinsecticide (an insecticide which contains fungi) used to control a wide range of pest insects on many agricultural and horticultural crops. Different strains of *B. bassiana* (e.g. 147, 203, 447, ANT-03, ATCC 74040, ESC 170, GHA, HF23, IMI389521, NPP111B005, PPRI 5339, and R444) which target specific pests are available.[43,44] Products containing certain strains of *B. bassiana* are approved for use or registered in Australia, Brazil, Canada, EU, India, UK and US.
Pest controlled / crop	*B. bassiana* is used to control insects and mites. It is effective against beetle and, caterpillar larvae, and adult aphids, thrips, whiteflies, chinch bugs, plant bugs, stink bugs, and beetles. Formulations of *B. bassiana* can be used in controlled environments (e.g., greenhouses, shade houses, and nurseries) and outdoors on labelled crops and plants such as turf, fruits, and vegetables.[45]
Risk	Products containing *B. bassiana* may cause eye irritation and can be harmful if inhaled, swallowed, or absorbed through the skin. *B. bassiana* is potentially toxic to bees, other nontarget insects and fish.[46]
***Metarhizium anisopliae* (CAS No. 67892-13-1)**	
Description of the alternative	*Metarhizium anisopliae* is pathogenic fungus that occurs naturally in soils world-wide.[47] *Metarhizium brunneum* strain Ma 43 was formerly *Metarhizium anisopliae* var *anisopliae* BIPESCO 5/F52. Certain strains of *Metarhizium anisopliae* and/or *Metarhizium brunneum* are approved or registered for use in Australia, Brazil, Canada, EU, India, and US.
Pest controlled / crop	*M. anisopliae* strain F52 affects many insects including aphids, thrips, whitefly, scarabs, weevils, mites, ticks. and gnats. It is used in various non-food sites, such as greenhouses, nurseries, residential lawns, sports fields, golf courses, and landscape perimeters. It has also been used on various crops (grapes, maize/corn, vegetables), ornamentals, trees, shrubs, fruit, perennials and annuals in nurseries or greenhouses.[48,49]

[40] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/Reports/1944.htm, accessed 2024-03-20).

[41] Health Canada (2011) cited above.

[42] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.132.858, accessed 2024-03-20).

[43] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/atoz.htm#B, accessed 2024-03-20).

[44] US EPA Pesticide Product and Label System (https://ordspub.epa.gov/ords/pesticides/f?p=PPLS:1, accessed 2024-03-20).

[45] Swoboda M (2022) *Beauveria bassiana* (https://cals.cornell.edu/new-york-state-integrated-pest-management/outreach-education/fact-sheets/beauveria-bassiana, accessed 2024-03-20).

[46] Swoboda M (2022) cited above.

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

[48] European Commission (2014) Review report for the active substance *Metarhizium anisopliae* var. *anisopliae* BIPESCO 5/F52 (Available at https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/backend/api/active_substance/download/623).

[49] US EPA (2011) cited above.

	M. anisopliae strain IMI 330189 is effective against grasshoppers and locusts. *M. anisopliae* strain FI-1045 is used to control the greyback canegrub on sugar cane soils. *M. anisopliae* strain ICIPE 30 is effective against harvester termites. *M. anisopliae* strain ICIPE 69 is effective against fruit flies, mealybugs and thrips. It is registered and commercialised in Ghana, Ethiopia, Kenya and South Africa through a Public–Private Partnership and is available as Mazao Campaign®. *M. anisopliae* strain ICIPE 78 is used for control of mites on various crops and Fall armyworm on maize. It registered and commercialised in Ghana, Ethiopia, Kenya and South Africa through a Public–Private Partnership and is available as Mazao Achieve®. *M. anisopliae* strain IMI 330189 is effective against grasshoppers and locusts. *M. brunneun* strain Cb15-III is used to control wireworms in various crops.[50]
Risk	*M. anisopliae* strain F52 is of low toxicity to birds, mammals, or terrestrial and aquatic plants. It has the potential to cause harm to aquatic vertebrate and invertebrates. It is not harmful to earthworms or beneficial insects such as lady beetles, green lacewings, parasitic wasps, and honey bees. Ingesting, inhaling, or touching products containing *M. anisopliae* strain F52 is not harmful to humans.[51]

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 repellents. Biochemical pesticides are important to IPM programs.[52] Some formulations may be registered as pesticides.

Box 4: 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.[53]
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.).[54]
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.[55]

[50] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/atoz.htm#M, accessed 2024-03-20).

[51] US EPA (2011) cited above.

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

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

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

[55] Baker and Grant (2018) Garlic & garlic oil profile (Available at 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.[56]

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.[57]

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.[58]

Rosemary oil (CAS No. 8000-25-7) is primarily a mixture of monoterpenes (alpha-pinene, 1,8 cineole, and camphene). Pesticidal uses of rosemary oil include insect repellent of clothes moths, fruit flies, lice, mosquitoes, and other insects and as anti-microbial agent. 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.[59]

Tea tree oil (CAS No. 68647-73-4) Tea tree oil (TTO) is a complex mixture of chemicals with fungicidal and antimicrobial properties. It has been found effective in controlling powdery mildew in potatoes, carrots, herbs, cucumbers, tomatoes, peppers, watermelon, grapes, and ornamentals.[60] It has also been shown to be effective in the management of equine lice and female ticks (*Rhipicephalus microplus*) in cattle. TTO has repellent activity against mosquitos.[61]

Thyme oil (CAS No. 8007-46-3): Thymol, the main active constituent of thyme and thyme oil, has anti-microbial, anti-fungal, and insecticidal properties. It has been used in the control of various insects (ants, aphids, armyworms, billbugs, chinch bugs, clothes moths, earwigs, fleas, grasshoppers, ground beetles, leafhoppers, mealybugs, mosquitos, and wireworms) and other arthropods (centipedes, millipedes, scorpions, spiders, and ticks). It has been applied in ponds, fountains, and aquaria to repel arthropods repellent and to control mosquito larvae.[62]

Other biopesticides

Abamectin (CAS No. 71751-41-2)

Description of the alternative	The biological pesticide 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

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

[57] 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).

[58] Borden MA et al. (2018) cited above.

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

[60] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/Reports/3309.htm, accessed 2024-03-20).

[61] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1).

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

	mite pests which results in their death. It can be used as an insecticide, nematicide, or miticide and is suitable for use in organic farming and for IPM.[63,64] Abamectin is approved or registered for use in Australia, Brazil, Canada, EU, India, UK and US.
Pest controlled / crop	Abamectin was introduced in 1985 and is used to control various pests such as phytophagous psyllids, mites, leafminers, cockroaches, ants including fire ants, pear psyllam and nematodes.[65] It is used on food crops such as vegetables (e.g. eggplant, curcubits, beans) fruits (e.g. citrus, pears, tomatoes, watermelon). It is also used on cotton, trees, turfgrass, nursery and ornamental plants.[66]
Risk	Abamectin is not persistent in the environment. It is highly toxic to mammals, birds, honeybees and other bees. It is moderately toxic to earthworms. In humans, abamectin is a neurotoxicant and exposure may lead to tremors, ataxia and mydriasis, liver, absent or decreased pupil reflex. There is some evidence teratogenicity and potential effects on reproduction.[67] Because abamectin is classified as WHO class 1b (highly hazardous) it is regarded as a Highly Hazardous Pesticide (HHP) by the FAO.[68] EU harmonised classification and labelling codes are: Fatal if swallowed (H300), fatal if inhaled (H330), suspected of damaging the unborn child (H361d), causes damage to organs through prolonged or repeated exposure (nervous system) (H372), very toxic to aquatic life (H400), and very toxic to aquatic life with long-lasting effect (H410).[69]
Neem oil (CAS No. 8002-65-1) / Azadirachtin (CAS No. 11141-17-6) **Related products:** Azadirachtin A (108168-76-9), Azadirachtin B (95507-03-2), Dihydroazadirachtin (108189-58-8); Margosa extract (84696-25-3, 8002-65-1) Neem seeds extract (11141-17-6), Clarified hydrophobic neem oil (947173-77-5).	
Description of the alternative	**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.[70] Some neem-based products make use of concentrated azadirachtin. **Azadirachtin** is an extract of the fruit from the neem tree. It interferes with the moulting of immature arthropods and reproduction in the adult. It also acts as repellent which deters pests from feeding and laying eggs on treated plants.[71] When the natural neem oil is removed from the seeds and treated with alcohol, virtually all

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

[64] BPDB: Bio-Pesticides DataBase (https://sitem.herts.ac.uk/aeru/bpdb/Reports/8.htm, accessed 2024-02-28).

[65] BPDB cited above.

[66] BPDB cited above.

[67] BPDB cited above.

[68] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[69] EU Pesticides Database (https://ec.europa.eu/food/plant/pesticides/eu-pesticides-db_en, accessed 2024-02-28).

[70] Borden MA et al. (2018) Natural products for managing landscape and garden pests in Florida (https://edis.ifas.ufl.edu/in197, accessed 2024-03-11).

[71] 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 2024-02-28).

	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.[72] Azadirachtin and/or neem (margosa) extracts are registered or approved for use in Australia, Brazil, Canada, EU, India,[73] UK, and US.
Pest controlled / crop	Neem extracts are contact pesticides and work best against soft-bodied pests, such as aphids, whiteflies, spider mites, and mealybug and scale nymphs.[74] Azadirachtin can be used to control a wide range of pests, including caterpillars, sawflies, flea beetles, weevils, aphids, and leafhoppers. Azadirachtin works well against the immature stages of chewing pests by making the juvenile unable to moult. Azadirachtin has various modes of action. It can act as a feeding deterrent, deterrent to egg-laying, repellent, direct toxin, or insect growth regulator.[75] In the US products are available of the market to control insects and mites 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. 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. It is authorised for use in the EU and the UK for the control of spider mites in protected settings. 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.[76] In Canada, it is registered for tree injection to manage a variety of tree pests in forest, woodlots, and urban and residential landscapes.
Risk	Neem products have low mammalian toxicity and do not cause skin irritation in most formulations.[77] Azadirachtin degrades naturally and is not harmful non-target organisms. However, it should not be applied when honeybees are foraging. It should not be applied directly to water, and care must be taken not to contaminate water.[78] According to the EU Hazard classification & labelling notifications azadirachtin poses the following hazards: May cause an allergic skin reaction (H317), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410). Identified hazards vary among products that contain margosa extracts and may also include: May cause an allergic skin reaction (H317), suspected of damaging the unborn child (H361d), and harmful or very toxic to aquatic life with long-lasting effects (H412, H410).[79]

3.4 Additional information on non-chemical alternatives

Information on alternative methods is available in the *Evaluation of non-chemical alternatives to endosulfan* (UNEP/POPS/POPRC.8/INF/14/Rev.1). OISAT is an online information service for non-chemical pest management in the tropics: http://www.oisat.org/. The Cornell University Cooperative Extension (https://nysipm.cornell.edu/) has many resources including the Biological Control Site (https://biocontrol.entomology.cornell.edu/index.php).

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

[73] See also product catalogues, for example: https://www.indiamart.com/agrilife/bio-pesticides.html; https://www.jaipurbiofertilizers.com/bio-insecticides.html (accessed 2024-02-28).

[74] Borden MA et al. (2018) cited above.

[75] Borden MA et al. (2018) cited above.

[76] See product catalogues such as: https://www.indiamart.com/agrilife/bio-pesticides.html; https://www.jaipurbiofertilizers.com/bio-insecticides.html (accessed 2024-02-28).

[77] Borden MA et al. (2018) Natural products for managing landscape and garden pests in Florida (https://edis.ifas.ufl.edu/in197, accessed 2024-03-11).

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

[79] European Chemicals Agency (https://echa.europa.eu/substance-information/-/substanceinfo/100.115.924, accessed 2024-02-28).

4. Chemical alternatives

The chemical alternatives identified in the risk management evaluation (UNEP/POPS/POPRC.17/13/Add.1) fall into three broad classes: pyrethroids, avermectins, and neonicotinoids. Box 5 provides summary information on their use and environmental and health effects. While the table includes information on potential risks, these are not expected to occur when the pesticides are used according to label directions.

Unless otherwise indicated the information of registration status has been obtained from the following sources and was accurate at the time of writing:

- Australia: The Australian Pesticides and Veterinary Medicines Authority (APVMA) PubCRIS database
- Brazil: Agrofit – Sistema de agrotóxicos fitossanitários [Database of plant protection products registered in Brazil)
- Canada: Pest Management Regulatory Agency (PMRA) Product Label Search
- EU: European Chemicals Agency (ECHA) Information on chemicals database
- India: Insecticides/Pesticides registered under section 9(3) of the Insecticides Act, 1968 for use in the country as on 01.06.2023
- UK: Pesticides Register of Great Britain and Northern Ireland, and
- US: US Environmental Protection Agency (EPA) Pesticide Product and Label System.[80]

The list of active ingredients registered in Madagascar that have been used as alternatives to methoxychlor which was received during the review of the initial draft is provided for information in the Appendix.

Box 5 Alternatives to Methoxychlor	
Acetamiprid (CAS No. 135410-20-7)	
Description of the alternative	Acetamiprid is a neonicotinoid insecticide used to control sucking and chewing pests. It is registered in Australia, Brazil, Canada, EU, India, UK, and US.
Pest controlled / crop	Acetamiprid is used to control a variety of pests such as aphids, thrips, mirids, spider mites, whiteflies, European pine sawflies, leaf miners, leaf hoppers, vine weevil, and ants. It is used on a variety of crops including leafy vegetables, fruiting vegetables (aubergine, pepper, tomato), potato, sugar beet, fruit (including apples, citrus, cherry, pears, plum, and grapes), oilseed rape, cotton, ornamental plants and flowers.[81,82]
Risk	Acetamiprid is an irritant. It is moderately toxic to mammals, highly toxic to birds and earthworms and moderately toxic to many aquatic organisms. Acetamiprid is highly soluble in water but not expected to leach into groundwater. It is not persistent in soil, though under certain conditions it may persist in aquatic ecosystems. It has a high potential for bioaccumulation.[83] There is evidence of developmental neurotoxicity in

[80] These databases are available at:

APVMA PubCRIS database (https://portal.apvma.gov.au/pubcris);

Agrofit. Sistema de agrotóxicos fitossanitários (https://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons);

Canada. Pesticide Label (https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php);

European Chemicals Agency (https://echa.europa.eu/information-on-chemicals);

Government of India (2023) Insecticides / Pesticides registered under section 9(3) of the Insecticides Act, 1968 for use in the country as on 01.06.2023 (http://www.ppqs.gov.in/divisions/cib-rc/registered-products);

Pesticides Register of Great Britain and Northern Ireland (https://secure.pesticides.gov.uk/pestreg/prodsearch.asp); and

US EPA Pesticide Product and Label System (https://ordspub.epa.gov/ords/pesticides/f?p=PPLS:1).

[81] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/11.htm, accessed 2024-02-28).

[82] US EPA (2002) Fact Sheet for Acetamiprid (http://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-099050_15-Mar-02.pdf).

[83] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/11.htm, accessed 2024-02-28).

	experimental animals, as well as increase sensitivity of the young to the adverse effects of exposure to acetamiprid.[84] The GHS hazard classifications for acetamiprid include: Toxic if swallowed (H301), harmful if swallowed (H302), fatal if inhaled (H330), harmful if inhaled (H332), suspected of damaging the unborn child (H361d), very toxic to aquatic life (H400), and very toxic or harmful to aquatic life with long lasting effects (H410; H412).[85] Only moderately or slightly hazardous pesticides, such as acetamiprid, are recommended by the FAO for sustainable farming practices which contribute to the UN Sustainable Development Goal Target 2.4 (sustainable agriculture).[86]
Azadirachtin (CAS No. 11141-17-6) see Neem under Biochemical formulations	
Bifenthrin (CAS No. 82657-04-3)	
Description of the alternative	Bifenthrin is a broad-spectrum non-systemic pyrethroid insecticide/miticide. It alters nerve function, which causes paralysis in target insect pests (also called 'knockdown') which eventually results in death.[87] Bifenthrin is registered for use in Australia, Brazil, India, and US, but no longer registered/approved for use in Canada, EU, and UK. The POPRC, in its analysis of substitutes for endosulfan, found that bifenthrin, could potentially be a POP.[88]
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.[89] First registered in the US in 1989, bifenthrin is used on various field crops, orchards/vineyards, ornamental plants (outdoor nurseries and greenhouses), Christmas tree farms and pine seed orchards, turf (sod farms, lawns, golf courses), and outdoor (commercial and residential) perimeter treatments. It is also available as a termiticide, dog shampoo, and seed treatment for various food/feed crops. It is used as an indoor/outdoor surface treatment for residential, institutional, public, commercial, industrial, and livestock/poultry premises.[90] In Australia, bifenthrin is registered to control selected mites and other pests on a variety of crops (e.g.: banana, barley, canola, clover, cotton, ornamentals, peas and beans, tomatoes, and wheat). It is also registered for use in buildings, on structures, turf and lawns to control various pests including ants, armyworm, certain beetles, biting midge, cockroaches, flea, flies, mosquito, paper nest wasp, spiders, ticks, webworm, certain weevils, and termites.

[84] Health Canada (2010) Proposed Registration Decision PRD2010-02: Acetamiprid (https://publications.gc.ca/collections/collection_2011/sc-hc/H113-9-2010-2-eng.pdf); and Health Canada (2010) Registration Decision RD2010-06: Acetamiprid (https://publications.gc.ca/collections/collection_2011/sc-hc/H113-25-2010-6-eng.pdf).

[85] PubChem (https://pubchem.ncbi.nlm.nih.gov/compound/Acetamiprid, accessed 2024-02-28).

[86] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[87] US EPA (2020a) Bifenthrin: Interim registration review decision case number 7402 (Available at https://www.regulations.gov/document?D=EPA-HQ-OPP-2010-0384-0299).

[88] UNEP (2022) cited above.

[89] US EPA (2020a) cited above.

[90] US EPA (2020b) Bifenthrin: Revised Draft Human Health Risk Assessment for Registration Review (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2016-0352-0008).

	In India, products are available to control broad range of foliar pests in various crops including cereals, citrus, cotton, fruit, grapes, ornamentals and vegetables. It is also available as a termicide.[91]
Risk	In the environment, bifenthrin is a persistent pyrethroid, stable to hydrolysis and slow to biodegrade, with a log KOW of > 1 x 106, which indicates a potential to bioaccumulate.[92] Bifenthrin is low in toxicity to birds but highly toxic to fish and small aquatic organisms and very highly toxic to bees.[93] As a Type I pyrethroid, exposure to bifenthrin affects the nervous system. There is evidence of urinary bladder tumors in mice, which has led the US Environmental Protection Agency to classify bifenthrin as "possible human carcinogen".[94] The EU harmonised classification and labelling codes for bifenthrin are: Fatal if swallowed (H300), may cause an allergic skin reaction (H317), toxic if inhaled (H331), suspected of causing cancer (H351), causes damage to organs through prolonged or repeated exposure – nervous system (H372), very toxic to aquatic life (H400), and very toxic to aquatic life with long-lasting effects (H410).[95]
Chlorfenapyr (CAS No. 122453-73-0)	
Description of the alternative	Chlorfenapyr is a broad-spectrum pyrrole pro-insecticide used to control many insects and mites, including those resistant to carbamate, organophosphate and pyrethroid compounds.[96] Chlorfenapyr is registered Australia, Brazil, Canada, India and the US. It is approved as a biocide for wood preservation in the European Economic Area and/or Switzerland, and under review for the control of insects, ants, other pests.
Pest controlled / crop	Chlorfenapyr is used to control mites, caterpillars, foliar nematodes, fungus gnats and thrips in greenhouse grown ornamentals (non-food), juvenile fruit and nut trees (including citrus), vines, brambles, bushberries, and fruiting vegetables. It can also be used for the control many nuisance pests, pests found in stored products and occasional invaders that infest structures, such as, ants, beetles, bark scorpions, bed bugs, boxelder bugs, centipedes, cockroaches, European earwigs, house crickets, house flies, mosquitoes, paper wasps, pillbugs, spiders and silverfish. It is also available as a termicide for pre-construction applications and post-construction soil treatment.[97]
Risk	Chlorfenapyr has a low aqueous solubility, low volatility and, based on its chemical properties, would not normally be expected to leach to groundwater. It is not usually persistent in soil or water systems. It is moderately toxic to mammals (oral route) and highly toxic to birds, fish and aquatic invertebrates.[98] Because of concerns about

[91] See product labels, for example: https://dir.indiamart.com/impcat/bifenthrin.html, https://www.dhanuka.com/details/markar, https://www.unitedinsecticides.in/insecticides.htm, accessed 2024-02-29.

[92] US EPA (2020b) cited above.

[93] Johnson M, Luukinen B, Gervais J, Buh, K, Stone, D (2010) Bifenthrin General Fact Sheet. National Pesticide Information Center, Oregon State University Extension Services (Available at http://npic.orst.edu/factsheets/bifgen.html).

[94] US EPA (2020b) cited above.

[95] European Chemicals Agency C&L Inventory (https://echa.europa.eu/information-on-chemicals/cl-inventory-database, accessed 2024-02-28).

[96] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/136.htm, accessed 2024-03-01).

[97] Pesticide Product Label System (https://ordspub.epa.gov/ords/pesticides/f?p=PPLS:1, accessed 2024-03-01).

[98] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/136.htm, accessed 2024-03-01).

	persistence and bird reproductive effects, the US EPA did not register the outdoor use of chlorfenapyr on cotton.[99] In its review of the registration of chlorfenapyr, Canada's Pest Management Regulatory Agency noted the potential increased sensitivity of the young to the toxic effects of this substance and established an acute reference dose (ARfD) for females aged 13-49 and children up to 12 years and acceptable daily intake (ADI) for all populations based on mortality, reduced motor activity, effects on learning and memory task in young animals in a rat developmental neurotoxicity study.[100] According to the EU harmonised classification and labelling this substance is classified as harmful if swallowed (H302), toxic if inhaled (H331), very toxic to aquatic life (H400), very toxic to aquatic life with long lasting effects (H410).[101]
Clothianidin (CAS No. 210880-92-5)	
Description of the alternative	Clothianidin is a systemic, neonicotinoid insecticide that acts on the central nervous system of insects.[102] Clothianidin is registered or approved for use in Australia, Brazil, Canada, EU, India, and US.
Pest controlled / crop	In the US, clothianidin is used control a variety of insect pests such as piercing sucking pests (e.g., aphids, mealybugs, sharpshooters, Asian citrus and pear psyllids and stinkbugs), coleopteran pests (e.g. corn rootworm, billbugs, white grubs, and plum curculio), and certain sporadic pests (e.g. maggots and symphylans). Clothianidin is used on a variety of vegetable crops, tree fruits, tree nuts, and field crops. It is also applied to poultry litter manure in chicken houses to control darkling beetles and other poultry houses pests. Non-agricultural applications include turf and ornamental plants. Products are available for indoor and outdoor residential, commercial, and industrial uses. The main use of clothianidin in the US is as a seed treatment for corn, cotton, soybean, and wheat.[103]
Risk	Clothianidin is very persistent in soil and water with a high potential for leaching to groundwater. Its bioaccumulation potential is low.[104,105] It is practically non-toxic to fish, however, the level of sensitivity varies greatly among aquatic invertebrates from practically non-toxic to water fleas (*Daphnia magna*) to very highly toxic to other aquatic insects. Use of clothianidin poses potential acute and chronic risks to aquatic invertebrates. Clothianidin is highly toxic to bees and other pollinators. The acute toxicity of clothianidin to birds is rated as moderate, but ingestion of treated seeds presents chronic risks to some birds. Clothianidin poses a low risk to plants.

[99] US EPA (2001) Pesticides fact sheet for chlorfenapyr. (https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-129093_01-Jan-01.pdf).

[100] Health Canada (2013) Proposed Registration Decision PRD2013-01 Chlorfenapyr; and Registration Decision RD2013-16 Chlorfenapyr (https://publications.gc.ca/collections/collection_2013/sc-hc/H113-9-2013-1-eng.pdf; and https://publications.gc.ca/collections/collection_2013/sc-hc/H113-25-2013-16-eng.pdf).

[101] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.116.332, accessed 2024-03-01).

[102] US EPA (2020) Clothianidin and thiamethoxam proposed interim registration review decision case numbers 7620 and 7614 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2011-0865-1190).

[103] US EPA (2020) cited above.

[104] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/171.htm, accessed 2024-03-05).

[105] US EPA (2020) cited above.

	Clothianidin is classified as having moderate acute oral toxicity to mammals, and as "not likely" carcinogenic to humans. Reproductive effects have been observed in Norway rats after chronic exposure.[106,107,108] According to EU harmonised classification and labelling clothianidin is harmful if swallowed (H302), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410). In addition, company data in REACH registrations identify the following risks to humans: Suspected of damaging fertility (H361f), causes or may cause damage to organs (H370/H371), and may cause damage to organs through prolonged or repeated exposure (H373).[109] While clothianidin is toxic and persistent, it does not meet the bioaccumulation criterion and therefore is not classified as a PBT substance.[110]
Cyfluthrin (CAS No. 68359-37-5)	
Description of the alternative	Cyfluthrin and *beta*-cyfluthrin are non-systemic pyrethroid insecticides (i.e., they are effective against target pests only through direct contact or ingestion by individual insects). These insecticides work by altering nerve function initially, causing paralysis in target insect pests (also called 'knockdown'), and eventually resulting in death.[111] Cyfluthrin is registered or approved for use in Australia, Brazil, Canada, EU, India, and US. Cyfluthrin is also authorised for use in veterinary medicinal products sheep and cattle in the EU.[112]
Pest controlled / crop	Cyfluthrin is used on a wide variety of food/feed crops, including as seed treatment. It is used in a variety of commercial settings (e.g., food handling establishments) or residential settings (e.g., apartments). In agriculture, cyfluthrin is applied by aerial, ground, chemigation, and hand-held equipment. Hand-held equipment is used to apply products containing cyfluthrin and *beta*-cyfluthrin in and around commercial and residential settings.[113] In Brazil, cyfluthrin is approved as a wood preservative.[114]
Risk	Cyfluthrin and beta-cyfluthrin have similar toxicological profiles, with beta-cyfluthrin being more potent than cyfluthrin. Cyfluthrin is highly toxic to fish and invertebrates; toxicity varies with insects being the most sensitive and crustacean the least sensitive. Cyfluthrin has low toxicity to algae.

[106] US EPA (2023) Imidacloprid, thiamethoxam and clothianidin: Draft predictions of likelihood of jeopardy and adverse modification for federally listed endangered and threatened species and designated critical habitats (Available at https://www.epa.gov/system/files/documents/2023-05/ESA-JAM-Analysis.pdf).

[107] US EPA (2003) Pesticide fact sheet for clothianidin (Available at https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-044309_30-May-03.pdf).

[108] Health Canada Pest Management Regulatory Agency (2021) Special Review Decision: Clothianidin Risk to Aquatic Invertebrates Final Decision Document (Available at https://publications.gc.ca/site/eng/9.898264/publication.html).

[109] European Chemicals Agency (https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/134858, accessed 2024-03-05).

[110] Germany (2014) Clothianidin: Assessment Report Regulation (EU) No 528/2012 concerning the making available on the market and use of biocidal products (Available at https://echa.europa.eu/documents/10162/2d76b3b2-0909-8a0e-82ce-77e346a40683).

[111] US EPA (2020) Cyfluthrin and beta-cyfluthrin interim registration review decision Case Number 7405 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2010-0684-0133).

[112] European Food Safety Authority (2021) Review of the existing maximum residue levels for beta-cyfluthrin and cyfluthrin according to Article 12 of Regulation (EC) No 396/2005 (https://efsa.onlinelibrary.wiley.com/doi/10.2903/j.efsa.2021.6837).

[113] US EPA (2020) cited above.

[114] IBAMA. Lista de produtos preservativos de madeira registrados no IBAMA [Products for wood preservation registered at IBAMA] (https://www.gov.br/ibama/pt-br/assuntos/quimicos-e-biologicos/preservativos-de-madeiras/arquivos/2024/20240424_produtos_preservativos_de_madeiras_registrados_abril_2024.pdf).

	In humans, cyfluthrin is considered very acutely toxic when ingested and acutely toxic when inhaled. It is not acutely toxic by dermal route. The nervous system is the main target organ. Cyfluthrin is not genotoxic, teratogenic or carcinogenic.[115,116] When setting its exposure limits, the Pest Management Regulatory Agency of Canada applied an uncertainty factor of 3 due to insufficient data on the potential sensitivity of the young, including developmental effects.[117] According to the EU harmonised classification and labelling the following hazard codes apply to cyfluthrin: Fatal if swallowed (H300), fatal if inhaled (H330), may cause harm to breast-fed children (H362), causes damage to organs – nervous system (H370), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[118] According to WHO classification, cyfluthrin is classified as highly hazardous (1b).[119] Cyfluthrin is not persistent organic pollutant since it is neither persistent nor bioaccumulative and does not show a potential for long-range transport.[120]
Cypermethrin (CAS No. 52315-07-8)	
Description of the alternative	A pyrethroid insecticide used to control a broad spectrum of pests especially Lepidoptera. It is a non-systemic pesticide with contact and stomach action.[121] The pyrethroid insecticide, cypermethrin, is a racemic mixture of eight isomers. Zeta- and alpha-cypermethrin are enrichments of the more insecticidally potent isomers. Cypermethrin, alpha-cypermethrin (CAS no. 67375-30-8), and zeta-cypermethrin are separate active ingredients with chemical characteristics uses, and toxicity [122] Cypermethrin is registered or approved for use in Australia, Brazil, Canada, EU, India, UK and US. While in its analysis of substitutes for endosulfan, the POPRC found that cypermethrin could be a POP,[123] in 2017, the European Chemicals Agency concluded that cypermethrin did not meet the criteria as a BPT substance or a POP.[124]
Pest controlled / crop	Products containing cypermethrin are broad spectrum insecticides used in agricultural, industrial, commercial, and residential settings. It is used as a foliar application on food

[115] Germany (2016) Cyfluthrin Product-type 18 (insecticides, acaricides and products to control other arthropods): Assessment report under Regulation (EU) No 528/2012 concerning the making available on the market and use of biocidal products (Available at https://www.echa.europa.eu/documents/10162/965f85c8-07b0-dad7-83dc-ce32039307db).

[116] US EPA (2017) Cyfluthrin and beta-cyfluthrin: Draft human health risk assessment for registration review (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2010-0684-0102).

[117] Health Canada (2016) Proposed Re-evaluation Decision PRVD2016-17 Cyfluthrin; and Health Canada (2018) Re-evaluation Decision RVD2018-35 Cyfluthrin and Its Associated End-use Products (https://publications.gc.ca/collections/collection_2016/sc-hc/H113-27-2016-17-eng.pdf; and https://publications.gc.ca/collections/collection_2018/sc-hc/h113-28/H113-28-2018-35-eng.pdf)

[118] European Chemicals Agency (https://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/134858, accessed 2024-03-05).

[119] WHO (2020) The WHO recommended classification of pesticides by hazard and guidelines to classification, 2019 edition (Available at https://iris.who.int/bitstream/handle/10665/332193/9789240005662-eng.pdf).

[120] Germany (2016) cited above.

[121] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/197.htm, accessed 2024-03-07).

[122] US EPA (2008) Reregistration eligibility decision for cypermethrin (EPA OPP-2005-0293, available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/P100BE6X.PDF?Dockey=P100BE6X.PDF).

[123] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[124] European Chemical Agency Biocidal Products Committee (2017) Opinion on the application for approval of the active substance: Cypermethrin Product type: PT 18 (ECHA/BPC/153/2017) (Available at: http://echa.europa.eu/regulations/biocidal-products-regulation/approval-of-activesubstances/).

	and feed crops including canola, cereals (e.g. wheat, barley, oats, and rye), cotton, fruits (e.g. apples and pears) pecans, peanuts, vegetables (e.g. broccoli and other Brassicas, peas and beans, potatoes, and sweet corn), and fodder and sugar beets. Pests controlled include summer aphids, flea and blossom beetles, caterpillars; pod midge weevils, and yellow cereal fly.[125,126] Cypermethrin is also used to control pests on livestock and horses. It is used as a soil residual termiticide and to control insect pests such as ants in and on structures, impervious surfaces (in perimeter and crack and crevice treatments) and lawns. Cypermethrin can also be applied indoors to control ants, cockroaches, fleas, and other insects.[127,128]
Risk	Cypermethrin is moderately persistent in the environment with a moderate bioaccumulation potential in fish. It is very highly acutely toxic to freshwater and estuarine/marine fish and invertebrates after acute exposure. Chronic exposures can also result in adverse impacts to aquatic life. Cypermethrin shows low toxicity to birds but may pose a risk to some small mammals. It is highly toxic to honey bees, and very toxic to earthworms; however, it is not expected to be toxic to aquatic or terrestrial plants.[129] Cypermethrin is considered to have moderate acute toxicity by the oral and inhalation route and low acute toxicity by the dermal route in humans. It is a local irritant for the airways but is not a skin sensitiser or irritant. The primary target organ for cypermethrin is the nervous system. There is evidence of damage to the liver and kidney in animal experiments.[130] There is also evidence of potential reproductive effects in males, tumorigenicity in mice and rats and genotoxicity.[131] Cypermethrin may interact with the androgen (anti-androgenic) pathway in mammals and fish.[132] According to EU classification, labelling and packaging notifications the following hazard statements apply to cypermethrin: Is toxic if swallowed (H302), is harmful in contact with skin (H312), may cause an allergic skin reaction (H317), causes skin irritation (H315), is toxic if inhaled (H331), may cause respiratory irritation (H335), is suspected of damaging fertility or the unborn child (H361), may cause damage to organs – nervous system (H373), is very toxic to aquatic life (H400); and is very toxic to aquatic life with long lasting effects (H410).[133] Cypermethrin is listed as a candidate for substitution under Regulation (EC) No 1107/2009 due to potential adverse impacts on non-target organisms, in particular aquatic organisms and non-target arthropods,

[125] PPDB as cited above.

[126] US EPA (2008) as cited above.

[127] PPDB as cited above.

[128] US EPA (2008) as cited above.

[129] US EPA (2008) as cited above.

[130] European Food Safety Authority (2018) Peer review of the pesticide risk assessment of the active substance cypermethrin (Available at https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2018.5402).

[131] Health Canada (2016) Proposed Re-Evaluation Decision PRVD2016-18 – Cypermethrin. (Available at https://publications.gc.ca/collections/collection_2016/sc-hc/H113-27-2016-18-eng.pdf); and

Health Canada (2018) Re-evaluation Decision RVD2018-22 – Cypermethrin and its associated end-use products (https://www.canada.ca/content/dam/hc-sc/documents/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-decision/2018/rdv2018-22/rvd2018-22-eng.pdf).

[132] US Environmental Protection Agency (2023) Status of Endocrine Disruptor Screening Program (EDSP) List°1 screening conclusions (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2023-0474-0001).

[133] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.052.567, accessed 2024-03-07).

	including bees. Authorisations are limited to professional users and require implementation of appropriate mitigation measures.[134] Cypermethrin does not meet the criteria as a PBT substance or POP.[135]
DEET (CAS No. 134-62-3)	
Description of the alternative	DEET (N,N-diethyl-m-toluamide) is a broad-spectrum insect repellent.[136] It is approved or registered for use as an insect repellent in Australia, Canada, EU, India,[137] UK,[138] and US.
Pest controlled / crop	DEET is effective against biting flies, biting midges, black flies, chiggers, deer flies, fleas, gnats, horse flies, mosquitoes, sand flies, stable flies, and ticks. DEET is used as repellent on human skin, hair, clothing, footwear, shoes and headgear (hats) and on animals such as horses.[139]
Risk	DEET is considered to have moderate toxicity to mammals, fish and aquatic invertebrates.[140] DEET is of low risk to humans and the environment, although there are some concerns regarding neurotoxic effects on children.[141] It is an irritant. According to the EU hazard classification & labelling notifications, DEET is harmful if swallowed (H302), causes skin irritation (H315), and causes serious eye irritation (H319). Some products may cause respiratory irritation (H335), and are classified as harmful to aquatic life with long lasting effects (H412).[142] DEET is neither a PBT substance nor a POP.[143]
Deltamethrin (CAS No. 52918-63-5)	
Description of the alternative	A fast-acting pyrethroid insecticide used to control a wide range of sucking and chewing pests by altering nerve function, causing paralysis in target insect pests (also called "knockdown"), eventually resulting in death.[144,145] Deltamethrin is registered or approved for use in Australia, Brazil, Canada, EU, India, UK, and US.

[134] Consolidated text: Commission Implementing Regulation (EU) No 540/2011 of 25 May 2011 implementing Regulation (EC) No 1107/2009 (https://eur-lex.europa.eu/legal-content/EN/AUTO/?uri=CELEX:02011R0540-20231216, accessed 2024-03-09).

[136] US EPA (2014) DEET (N,N-diethyl-meta-toluamide) interim registration review decision case number 0002 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2012-0162-0012).

[137] Products containing DEET are available on the market, for example: https://trueindianreview.in/best-mosquito-repellent/ https://www.1mg.com/otc/odomos-naturals-non-sticky-mosquito-repellent-cream-otc504786 (accessed 2024-05-25)

[138] UK authorised biocidal products (updated May 2024), downloaded from https://www.hse.gov.uk/biocides/uk-authorised-biocidal-products.htm.

[139] US EPA (2014) cited above.

[140] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/1190.htm, accessed 2024-03-16).

[141] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[142] European Chemicals Agency Database (https://www.echa.europa.eu/web/guest/substance-information/-/substanceinfo/100.004.682, accessed 2024-03-16).

[143] US EPA (2014) cited above.

[144] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/205.htm, accessed 2024-03-07).

[145] US EPA (2020) Deltamethrin interim registration review decision (Available at: https://www.epa.gov/sites/default/files/2020-10/documents/deltamethrin-reg-review-id.pdf).

	The POPRC, in its analysis of substitutes for endosulfan, found that deltamethrin could be a POP.[146]
Pest controlled / crop	Deltamethrin is used to control a broad spectrum of pests (including cockroaches, mosquitos, bed bugs, mites, ants, weevils, and beetles) in both agricultural and non-agricultural settings. In agriculture, deltamethrin is used on various crops including cotton, maize, sweetcorn, sorghum, wheat, vegetables (e.g. artichoke, cauliflower, lettuce, tomato), root crops (e.g. potato, sugar beet), fruits, and tree nut crops. It is also used for indoor and outdoor perimeter treatments to control pests such as cockroaches, silverfish, mosquitos, bedbugs, and other flying and crawling insects in residential, commercial and industrial settings. Deltamethrin is also registered for use as a pet collar to control fleas and ticks.[147,148] In Brazil, cyfluthrin is approved as a wood preservative.[149]
Risk	Data indicates that deltamethrin is moderately to highly persistent in terrestrial environments has the potential to persist in aquatic environments. It shows moderate bioaccumulation potential in fish. Deltamethrin shows low to no toxicity to birds but is highly toxic to non-target terrestrial invertebrates, including honey bees. Deltamethrin technical is very highly toxic to freshwater fish and highly toxic to freshwater invertebrates. It is highly toxic to estuarine/marine fish and very highly toxic to estuarine/marine invertebrates. No phytotoxic effects have been observed in terrestrial plants.[150] The target organ system for deltamethrin is the nervous system. There is no evidence of mutagenicity and the US EPA classifies deltamethrin as “not likely to be carcinogenic to humans”. Deltamethrin is categorised as moderately toxic for acute oral and inhalation exposure, and minimally toxic for acute dermal exposure. It is rated as minimally irritating to the eye and non-irritating to the skin, and is not a skin sensitiser.[151] According to EU harmonised classification and labelling this substance is toxic if swallowed (H301), is toxic if inhaled (H331), is very toxic to aquatic life (H400), and is very toxic to aquatic life with long lasting effects (H410).[152]
Dinotefuran (CAS No. 165252-70-0)	
Description of the alternative	Dinotefuran is a neonicotinoid systemic pesticide with contact and stomach action that affects an insect’s nervous system.[153]

[146] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[147] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/205.htm, accessed 2024-03-07).

[148] PPDB as cited above.

[149] IBAMA. Lista de produtos preservativos de madeira registrados no IBAMA [Products for wood preservation registered at IBAMA] (https://www.gov.br/ibama/pt-br/assuntos/quimicos-e-biologicos/preservativos-de-madeiras/arquivos/2024/20240424_produtos_preservativos_de_madeiras_registrados_abril_2024.pdf).

[150] US EPA (2010) Environmental fate and ecological risk assessment problem formulation in support of registration review for deltamethrin (Available at https://downloads.regulations.gov/EPA-HQ-OPP-2009-0637-0003/content.pdf).

[151] US EPA (2010) Deltamethrin registration review human health assessment scoping document (Available at https://downloads.regulations.gov/EPA-HQ-OPP-2009-0637-0004/content.doc).

[152] European Chemicals Agency Database, as cited above.

[153] US EPA (2020) Dinotefuran: proposed interim registration review decision case number 7441 (Available at https://www.epa.gov/sites/production/files/2020-01/documents/dinotefuran_pid_signed_1.22.2020.pdf).

	Dinotefuran is approved or registered for use in Australia, Brazil, Canada, EU, India, and US.
Pest controlled / crop	Dinotefuran is used to control a variety of insects, including aphids, whiteflies, thrips, leafhoppers, stinkbugs, mole crickets, white grubs, beetles and lacebugs. It is applied on field crops, fruits, and vegetables (e.g. cucurbit vegetables, fruiting vegetables, brassica vegetables and leafy vegetables), as well as Christmas tree plantations in soil and foliar applications or tree/trunk injection. It is also used in gardens, lawns, and ornamental plantings and in residential and commercial building, including food handling establishments and animal and pet premises.[154]
Risk	The acute toxicity of dinotefuran is classified as practically non-toxic to moderately toxic to birds and practically non-toxic to mammals. The acute toxicity of dinotefuran adult bees is high. The potential risk of dinotefuran to fish and amphibians is considered low; chronic exposure to may pose a risk to estuarine/marine invertebrates. The use of dinotefuran is not expected to be a risk to aquatic or terrestrial or plants.[155] The acute oral, dermal, or inhalation toxicity of dinotefuran is low. While it does not irritate the eye, it may cause some skin irritation; it is not a dermal sensitizer. There is no evidence of mutagenicity and the US EPA classifies dinotefuran as “not likely to be carcinogenic to humans”.[156] The European Chemicals Agency (2014) concluded that dinofuran did not have endocrine disrupting properties.[157] In its 2019 review, the Pest Management Regulatory Agency of Canada noted potential adverse effects at high doses on the thyroid, and on male and female reproductive organs in experimental animals.[158] According to the EU hazard classification and labelling scheme, dinotefuran poses the following hazards: This substance is very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[159] Dinotefuran does not meet the criteria for being PBT substance.[160] While dinotefuran very persistent and toxic it does not demonstrate the potential for long range transport and therefore does not meet the criteria for being a persistent organic pollutant.[161]
Doramectin (CAS No. 117704-25-3)	
Description of the alternative	Doramectin is a broad-spectrum veterinary drug of the avermectin class, which induces rapid, non-spastic paralysis in nematodes and arthropods. It is used for the treatment and control of internal parasitosis.[162]

[154] US EPA (2020) as cited above.

[155] US EPA (2020) as cited above.

[156] US EPA (2020) as cited above.

[157] European Chemicals Agency Biocidal Products Committee (2014) Opinion on the application for approval of the active substance: Dinotefuran, Product type:18 ECHA/BPC/006/2014 (Available at https://echa.europa.eu/documents/10162/eaee10a8-c67f-4cd8-84ff-50ad59c0aa50).

[158] Health Canada (2019) Proposed Registration Decision PRD2019-01 Dinotefuran and Related End-Use Products (https://publications.gc.ca/collections/collection_2019/sc-hc/h113-9/H113-9-2019-1-eng.pdf); and Health Canada (2019) Registration Decision RD2019-09 Dinotefuran and Related End-use Products (https://www.canada.ca/content/dam/hc-sc/documents/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/registration-decision/2019/dinotefuran/rd2019-09-eng.pdf)

[159] European Chemicals Agency Database as cited above.

[160] UK (2014) Dinotefuran: assessment report Regulation (EU) No 528/2012 concerning the making available on the market and use of biocidal products (Available at https://echa.europa.eu/documents/10162/e7b3136e-ddd2-9ac1-272c-3cd7949757f9).

[161] European Chemicals Agency (2014) as cited above.

[162] VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1814.htm, accessed 2024-03-08).

	It is approved as a veterinary drug in Australia, Canada,[163] EU,[164] India,[165] UK,[166] and US.[167]
Pest controlled / crop	Doramectin is used to manage gastrointestinal roundworms, lungworms, eyeworms, grubs, sucking lice and mange mites in cattle sheep and pigs.[168]
Risk	Doramectin is highly toxic to fish and aquatic invertebrates. It has also been shown to be toxic to dung fauna.[169] According to the EU hazard classification & labelling classification doramectin poses the following hazards: Toxic if inhaled (H331), harmful if swallowed (H302), suspected of damaging fertility or the unborn child (H361), may cause harm to breast-fed children (H362), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[170]
Eprinomectin (CAS No. 123997-26-2)	
Description of the alternative	Eprinomectin is a semi-synthetic compound of the avermectin family used for the treatment of internal and external parasites.[171] Approved for veterinary purposes in Australia, Canada,[172] EU,[173] UK,[174] and US.[175]
Pest controlled / crop	Uses of eprinomectin include the treatment and control of gastrointestinal roundworms, lungworms, warbles, sucking and biting lice, chorioptic and sarcoptic mange mites, and other parasitic infections in beef and dairy cattle, sheep; goats; cats and deer.[176]
Risk	According to EU hazard classification and labelling notifications this substance is toxic if swallowed (H301), is suspected of damaging fertility or the unborn child (H361), may cause harm to breast-fed children (H362) and may cause damage to organs through prolonged or repeated exposure (H373). Affected organs include the brain, central

[163] Canada Drug Product Database (https://health-products.canada.ca/dpd-bdpp/, accessed 2024-03-08).

[164] EU Veterinary medicines information website (https://medicines.health.europa.eu/veterinary/en, accessed 2024-03-08).

[165] Government of India List of veterinary drugs approved by CDSCO (https://cdsco.gov.in/opencms/resources/UploadCDSCOWeb/2018/Bio_sop/Final%20List%20of%20Veterinary%20approved%20drugs.pdf, accessed 2024-03-08).

[166] UK Product Information Database (https://www.vmd.defra.gov.uk/ProductInformationDatabase, accessed 2024-03-08).

[167] US FDA Electronic Animal Drug Product Listing Directory (https://www.fda.gov/industry/structured-product-labeling-resources/electronic-animal-drug-product-listing-directory, accessed 2024-03-08).

[168] VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1814.htm, accessed 2024-03-08).

[169] US Dept. of Agriculture (2018) Final Environmental Assessment: Cattle Fever Tick Eradication on Laguna Atascosa and Lower Rio Grande Valley National Wildlife Refuges. (Available at https://aphis.prod.usda.gov/sites/default/files/final-ea-cft-eradication-on-south-texas-refuges_4.pdf)

[170] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.123.125, accessed 2024-03-08)

[171] VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1527.htm, accessed 2024-03-09)

[172] Canada Drug Product Database (https://health-products.canada.ca/dpd-bdpp/, accessed 2024-03-09).

[173] EU Veterinary medicines information website (https://medicines.health.europa.eu/veterinary/en, accessed 2024-03-09).

[174] UK Product Information Database (https://www.vmd.defra.gov.uk/ProductInformationDatabase, accessed 2024-03-09).

[175] US FDA Electronic Animal Drug Product Listing Directory (https://www.fda.gov/industry/structured-product-labeling-resources/electronic-animal-drug-product-listing-directory, accessed 2024-03-09).

[176] VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1527.htm, accessed 2024-03-09).

	nervous system, kidney, liver and ovaries. It is also very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[177]
Esfenvalerate (CAS No. 66230-04-4)	
Description of the alternative	A pyrethroid insecticide especially effective against Coleoptera (beetles and weevils), Diptera (flies) and Hemiptera (bugs, aphids and cicadas).[178] Esfenvalerate is the enriched SS isomer of naturally occurring compound fenvalerate. It is a more powerful insecticide than fenvalerate that can be used at a lower applications rate. It also has a lower chronic toxicity.[179] Esfenvalerate is registered or approved for use in Australia, Brazil, UK, and US. The POPRC, in its analysis of substitutes for endosulfan, found that esfenvalerate could be a POP.[180]
Pest controlled / crop	Pest controlled include aphids; barley yellow dwarf virus vectors, carpenter ants, cockroaches, crickets, cucumber beetles, earwigs, fleas, millipedes, silverfish, sowbugs, scorpions, and ticks. It is used on various crops including cereals such as barley and wheat, cucurbits, lawns, peas and beans, potatoes and ornamental plants. It is also used in structures such as schools, industrial sites, and public buildings.[181]
Risk	Esfenvalerate is non-mobile and moderately persistent in soil. It is not expected to leach to groundwater. It is highly toxic to mammals, earthworms, honeybees and aquatic life.[182] Esfenvalerate poses risks to invertebrates, pollinators, mammals, birds, and fish, with the major concern being impacts on aquatic and terrestrial invertebrates.[183] Esfenvalerate targets the nervous system. Based on animal studies it is considered to have moderate acute toxicity by ingestion and inhalation, and mild acute toxicity from skin exposure. It is not readily absorbed through the skin. Esfenvalerate is not a skin sensitizer but is mildly irritating to the eye and skin. Prenatal development studies in rats and rabbits did not show adverse effects on foetuses. There is no evidence of immunotoxicity and the US EPA has concluded there is "no evidence of carcinogenicity to humans".[184] According to the EU harmonised classification and labelling esfenvalerate is toxic if swallowed (H301), is toxic if inhaled (H331), and may cause an allergic skin reaction (H317), causes damage to organs – nervous system (370), is very toxic to aquatic life (H400), and is very toxic to aquatic life with long lasting effects (H410). Esfenvalerate is listed as a candidate for substitution under Regulation (EC) No 1107/2009 due to its risk

[177] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.106.561, accessed 20204-03-09).

[178] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/269.htm, accessed 2024-03-09).

[179] Toxin and Toxin Target Database (T3DB) (http://www.t3db.ca/toxins/T3D1036, accessed 2024-03-09).

[180] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[181] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/269.htm, accessed 2024-03-09).

[182] PPDB as cited above.

[183] US EPA 2020 Esfenvalerate – Interim registration review decision, Case number 7406 (Available at https://downloads.regulations.gov/EPA-HQ-OPP-2009-0301-0137/content.pdf).

[184] US EPA (2017) Esfenvalerate. Draft human health risk assessment for registration review (https://downloads.regulations.gov/EPA-HQ-OPP-2009-0301-0074/content.pdf).

	to aquatic organisms including the risk for bioaccumulation through the food chain, the risk to honeybees and non-target arthropods and the protection of groundwater.[185]
Fenvalerate (51630-58-1)	
Description of the alternative	Fenvalerate is a broad-spectrum pyrethroid insecticide and acaricide used to control a range of pests especially those with resistance to organochlorine, organophosphate and carbamate insecticides.[186] It consists of four isomers all being present at equal amounts in the technical material.[187] It is registered for use in Australia, and India. The POPRC, in its analysis of substitutes for endosulfan, found that fenvalerate could be a POP.[188]
Pest controlled / crop	Fenvalerate controls a various insects including butterflies, moths, skippers, flies, cockroaches, crickets, grasshoppers, bugs, aphids, cicadas, beetles, blackfly, mosquitoes and termites. It has been used on cotton, soyabeans, vegetables, fruit (e.g., apples, pears, peaches, grapes) and nuts.[189]
Risk	Fenvalerate has low solubility in water and low volatility. It is considered moderately persistent in soil and water, but unlikely to leach to groundwater.[190] Fenvalerate poses a risk to wildlife. It has a low toxicity to mammals, but is extremely toxic to fish and highly toxic to bees.[191] Fenvalerate is an irritant with moderate oral toxicity.[192] It is neurotoxic. It is not considered a carcinogen or a teratogen.[193] According to the EU hazard classification and labelling scheme fenvalerate poses the following hazards: Toxic if swallowed (H301), skin and eye irritant (H315, H319), harmful if inhaled (H332), may cause respiratory irritation (H335), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[194]
Fluvalinate (CAS No. 69409-94-5); Tau-fluvalinate (CAS No. 102851-06-9)	
Description of the alternative	Fluvalinate is a pyrethroid insecticide and acaricide also available for veterinary use. It is considered obsolete.[195] Originally introduced as the racemic mixture, it has been

[185] Consolidated text: Commission Implementing Regulation (EU) No 540/2011 of 25 May 2011 implementing Regulation (EC) No 1107/2009 (https://eur-lex.europa.eu/legal-content/EN/AUTO/?uri=CELEX:02011R0540-20231216, accessed 2024-03-09).

[186] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/314.htm, accessed 2024-03-10)

[187] FAO/WHO Joint Meeting on Pesticide Residues (2012) Fenvalerate (Available at https://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/JMPR/Report12/Fenvalerate.pdf).

[188] UNEP (2022) Risk management evaluation on methoxychlor (UNEP/POPS/POPRC.17/13/Add.1, available at https://chm.pops.int/TheConvention/POPsReviewCommittee/Meetings/POPRC17/Meetingdocuments/tabid/8918/Default.aspx).

[189] PPDB as cited above.

[190] PPDB as cited above.

[191] US EPA (1987) Pesticide fact sheet: Fenvalerate (Available at https://nepis.epa.gov/Exe/ZyPDF.cgi/91024KX6.PDF?Dockey=91024KX6.PDF).

[192] PPDB as cited above.

[193] FAO/WHO Joint Meeting on Pesticide Residues (2012) Fenvalerate (Available at https://www.fao.org/fileadmin/templates/agphome/documents/Pests_Pesticides/JMPR/Report12/Fenvalerate.pdf).

[194] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.052.098, accessed 2024-03-10).

[195] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/1720.htm, accessed 2024-03-10)

	replaced by tau-fluvalinate derived from one isomer (the R-form).[196] Pyrethroids alter nerve function, which causes paralysis ('knockdown') in target insect pests, eventually resulting in death.[197] Tau-fluvalinate is registered/authorised for use in, Australia, Canada, EU, UK, and US.
Pest controlled / crop	Tau-fluvalinate is an insecticide used to control a broad range of foliar pests. Also used to control Varroa mite in beehives. It is used to control pests on cereals including wheat, potatoes, fruit trees (such as cherries, peaches, plums, nectarines, tamarillos, avocados) and lawns.[198] It is also used on non-food seed crops (carrots, brassica, cole crops), ornamental plants, building surfaces/perimeters, and ant mounds.[199]
Risk	Tau-fluvalinate is highly toxic to fish and aquatic invertebrates.[200] It is also highly toxic to honey bees.[201] Tau-fluvalinate is practically non-toxic to birds and does not pose a risk to terrestrial or aquatic plants. Tau- fluvalinate is a neurotoxic substance. It is not a mutagen or a carcinogen. It is moderately toxic by ingestion and slightly toxic by skin exposure. It is slightly irritating the eye but not a skin irritant or sentitiser.[202] It has endocrine disruption properties.[203] According to the EU hazard classification & labelling, tau-fluvalinate poses the following hazards: Harmful if swallowed (H302), causes skin irritation (H315), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[204]
Imidacloprid (CAS No. 138261-41-3)	
Description of the alternative	Imidacloprid is a neonicotinoid insecticide. It is a xylem and phloem-mobile systemic compound that is readily taken up by the roots of the plants and translocated through the plant via transpiration.[205] It is registered or approved for use in Australia, Brazil, Canada, India, EU, and US.
Pest controlled / crop	Imidacloprid is used to control a variety of sucking and piercing insect pests such as thrips, aphids, and whiteflies. It is also used to control soil insects such as beetles, grubs, and wireworms. Imidacloprid is applied to a variety of agricultural crops such as root and tuber vegetables, fruiting vegetables, oilseed crops, citrus fruit, leafy green vegetables, cucurbit vegetables and tropical and subtropical fruits. Imidacloprid is also used to control pests in turf ornamental plants, forestry, Christmas tree plantations, pet spot-on and collar products, baits and pellets, and in farm/residential/commercial areas.[206]

[196] Cage et al. (undated) UKPID Monograph: Tau-fluvalinate (https://inchem.org/documents/ukpids/ukpids/ukpid81.htm, accessed 2024-03-10)

[197] US EPA (2020) Tau-fluvalinate – interim registration review decision case number 2295 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2010-0915-0050).

[198] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/608.htm, accessed 2024-03-10).

[199] US EPA (2016b) Tau-fluvalinate: Draft human health risk assessment for registration review and for establishment of a tolerance with no U.S. registrations for residues in wine grapes (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2010-0915-0030).

[200] PPDB as cited above.

[201] US EPA (2016a) Ecological Risk Management Rationale for Pyrethroids in Registration Review (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2010-0915-0017).

[202] US EPA (2016b) as cited above.

[203] PPDB as cited above.

[204] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.127.965, accessed 2024-03-10).

[205] US EPA (2020) Imidacloprid proposed interim registration review decision case number 7605 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2008-0844-1619).

[206] US EPA (2020) cited above.

Risk	Imidacloprid is highly soluble, non-volatile and persistent in soil. It is moderately mobile. It has a low risk of bioaccumulating. It is highly toxic to birds and honeybees. Moderately toxic to mammals and earthworms. It is non-toxic to fish.[207] The US EPA has determined that, overall, acute risks to avian and mammalian species from foliar and soil treatments of imidacloprid is low. Exposures from treated seed results in the highest acute and chronic risks to terrestrial organisms. Imidacloprid poses ecological risks, particularly to pollinators and aquatic invertebrates. Imidacloprid is rated as highly toxic to birds from acute oral exposure, with smaller birds being at higher risk. Imidacloprid is very highly toxic to adult honeybees. The use of imidacloprid poses acute risks to freshwater invertebrates and chronic risks to both freshwater and saltwater invertebrates. When used as directed, imidacloprid poses a low risk to fish or aquatic phase amphibians. The risk of adverse effects to terrestrial and aquatic plants is low.[208] Ingestion is the route of exposure of concern, with imidacloprid rated as having high acute oral toxicity in mammals. The primary target system for mammals after ingestion is the nervous system. The risk of acute toxicity after exposure to skin or lung is low. Imidacloprid is not a carcinogen.[209] According to EU harmonised classification and labelling scheme, imidacloprid poses the following hazards: Toxic if swallowed (H301), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[210] Imidacloprid is a candidate for substitution under Regulation (EC) No 1107/2009.[211] Imidacloprid is not considered a PBT substance because it does not meet the bioaccumulation criterion.[212]
Ivermectin (CAS No. 70288-86-7)	
Description of the alternative	Ivermectin as an insecticide, acaricide or vermicide commonly used for the treatment of certain internal and external parasites in animals, including humans. It is a member of the avermectin class of broad-spectrum antiparasitic agents.[213]

[207] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/397.htm, accessed 2024-03-10).

[208] US EPA (2020) Imidacloprid proposed interim registration review decision case number 7605 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2008-0844-1619).

[209] US EPA (2020) cited above.

[210] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.102.643, accessed 2024-03-10).

[211] European Chemicals Agency. Biocidal active substances (https://echa.europa.eu/information-on-chemicals/biocidal-active-substances/-/disas/factsheet/37/PT18, accessed 2024-03-10).

[212] Germany (2011) Imidacloprid: Assessment report Directive 98/8/EC concerning the placing of biocidal products on the market, revised (Available at https://echa.europa.eu/documents/10162/225b9c58-e24c-6491-cc8d-7d85564f3912).

[213] VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1455.htm, accessed 2024-03-10).

	Products containing ivermectin are registered or approved for use in Australia, Canada,[214] EU,[215] India,[216] UK,[217] and US.[218]
Pest controlled / crop	Traditionally used against worms (except tapeworms) but more recently found to be effective against many species of mites and lice.[219] It used to treat cattle, pigs, sheep and horses. Some products are approved for use in humans.
Risk	Ivermectin is non-mobile and persistent in soil. It is rated as highly acutely toxic to mammals, moderately toxic to birds (acute and chronic exposures), moderately toxic to earthworms, moderately toxic to freshwater fish, highly toxic to freshwater invertebrates. Chronic exposures to ivermectin reduces growth in algae.[220] Ivermectin is an eye irritant.[221] According to EU hazard classification & labelling classification notifications ivermectin has the following potential hazards: Fatal if swallowed (H300), toxic in contact with skin (H311), causes damage to organs – central nervous system (H370, H372, H373), suspected of damaging fertility or the unborn child (H361), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[222]
Moxidectin (CAS No. 113507-06-5)	
Description of the alternative	Moxidectin semi-synthetic, broad spectrum veterinary drug of the avermectin class of compounds used as an insecticide, repellent, acaricide, antiparasitic, endectocide and ectocide.[223] Moxidectin is registered or approved for use in Australia, Canada,[224] EU, [225] India,[226] UK,[227] and US.[228]

214 Canada Drug Product Database (https://health-products.canada.ca/dpd-bdpp/?lang=eng, accessed 2024-03-10).

215 Veterinary Medicines information website (https://medicines.health.europa.eu/veterinary/en, accessed 2024-03-10).

216 Government of India Central Drugs Standard Control Organization https://cdsco.gov.in/opencms/resources/UploadCDSCOWeb/2018/Bio_sop/Final%20List%20of%20Veterinary%20approved%20drugs.pdf, accessed 2024-03-10).

217 UK Product Information Database (https://www.vmd.defra.gov.uk/ProductInformationDatabase, accessed 2024-03-10).

218 US FDA Electronic Animal Drug Product Listing Directory (https://www.fda.gov/industry/structured-product-labeling-resources/electronic-animal-drug-product-listing-directory, accessed 2024-03-10).

219 VSDB as cited above.

220 VSDB as cited above.

221 VSDB as cited above.

222 European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.067.738, accessed 2024-03-11).

223 VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1752.htm, accessed 2024-03-11)

224 Canada Drug Product Database (https://health-products.canada.ca/dpd-bdpp/?lang=eng, accessed 2024-03-11).

225 EU Veterinary Medicines (https://medicines.health.europa.eu/veterinary/en/search-medicines, accessed 2024-03-11).

226 Government of India Central Drugs Standard Control Organization https://cdsco.gov.in/opencms/resources/UploadCDSCOWeb/2018/Bio_sop/Final%20List%20of%20Veterinary%20approved%20drugs.pdf, accessed 2024-03-10).

227 UK Product Information Database (https://www.vmd.defra.gov.uk/ProductInformationDatabase, accessed 2024-03-10).

228 US FDA Electronic Animal Drug Product Listing Directory (https://www.fda.gov/industry/structured-product-labeling-resources/electronic-animal-drug-product-listing-directory, accessed 2024-03-10)

Pest controlled / crop	Moxidectin is used to prevent and control infections of heartworm and intestinal worms in dogs, cats, horses, cattle and sheep.[229] In humans, medicines containing moxidectin are used to treat river blindness.[230]
Risk	Moxidectin is non-mobile and moderately persistent in soil. It is moderately toxic to birds and earthworms. It is rated as having high toxicity to freshwater fish and invertebrates. It impacts growth in algae.[231] It is a skin and eye irritant with moderate acute toxicity to mammals.[232] According to EU hazard classification & labelling notifications, moxidectin poses the following hazards: Toxic if swallowed (H301), causes serious eye irritation (H319), is harmful if inhaled (H332), suspected of damaging the unborn child (H361), causes damage to organs through prolonged or repeated exposure - central nervous system (H372), very toxic to aquatic life (H400), and is very toxic to aquatic life with long lasting effects (H410).[233]
Nitenpyram (CAS No. 150824-47-8)	
Description of the alternative	Nitenpyram is a systemic neonicotinoid insecticide used mainly to kill external parasites and sucking insects.[234,235] Currently approved for use as a veterinary drug in Australia, Canada,[236] EU,[237] UK,[238] US.[239]
Pest controlled / crop	Nitenpyram is mainly used to treat adult flea infestations in mammals such as dogs and cats. It is also used to treat maggot infestations on reptiles.[240] Agricultural uses of nitenpyram include the control of aphids, thrips, whitefly on rice and glasshouse crops.[241]
Risk	Nitenpyram is non-persistent and mobile in soil with a low risk of bioconcentration. It is rated as having moderate acute toxicity to mammals, birds, earthworms and freshwater fish. It shows low acute toxicity to freshwater invertebrates and algae.[242] It is highly toxic to honey bees.[243, 244]

229 VSDB cited above.

230 Moxidectin (https://www.drugs.com/cons/moxidectin.html, accessed 2024-03-11).

231 VSDB cited above.

232 VSDB cited above.

233 European Chemicals Agency Databse (https://echa.europa.eu/substance-information/-/substanceinfo/100.163.046, accessed 2024-03-11).

234 VSDB: Veterinary Substances DataBase (https://sitem.herts.ac.uk/aeru/vsdb/Reports/1612.htm, accessed 2024-03-13).

235 IUPAC Pesticides Properties DataBase (https://sitem.herts.ac.uk/aeru/iupac/Reports/1612.htm, accessed 2024-03-13).

236 Canada Drug Product Database (https://health-products.canada.ca/dpd-bdpp/, accessed 2024-03-13).

237 EU Veterinary Medicines (https://medicines.health.europa.eu/veterinary/en/search-medicines, accessed 2024-03-13).

238 UK Product Information Database (https://www.vmd.defra.gov.uk/ProductInformationDatabase/, accessed 2024-03-13).

239 US FDA Approved Animal Drug Products (https://animaldrugsatfda.fda.gov/adafda/views/#/search, accessed 2024-03-13).

240 VSDB cited above.

241 IUPAC cited above.

242 VSDB cited above.

243 IUPAC cited above.

244 PAN International (2021) List of Highly Hazardous Pesticides (Available at https://pan-international.org/resources/).

	Hazards identified in the EU hazard classification and labelling notifications for nitenpyram include: Harmful if swallowed (H302), causes serious eye irritation, (H319) causes skin irritation (H315) and may cause respiratory irritation (H335).[245] Some products are also classified as very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[246]
Permethrin (CAS No. 52645-53-1)	
Description of the alternative	Permethrin is a broad-spectrum synthetic pyrethroid contact insecticide use to control pests in crops as well as animal ectoparasites.[247] Products are approved or registered for use in Australia, Brazil, Canada, EU, India, and US.
Pest controlled / crop	Permethrin is used to control ants, aphids, fleas; mosquitoes, cockroaches, and ticks. It is used on grains and oilseeds, legumes, potatoes, fruits, vegetables, horticultural crops, mushroom houses, ginseng, greenhouse and field-grown ornamentals as well as tobacco and cotton. It is also used on livestock, companion animals, forestry and woodlots, feedlots, termite treatment, pet premises, kennels, indoors and outdoors of homes, agricultural, commercial and institutional buildings, military clothing, mosquito netting and soil around honeybee hives. Permethrin is used as a pharmaceutical for the treatment of head lice and scabies.[248,249,250]
Risk	Permethrin is not readily biodegradable. It is highly toxic to both freshwater and estuarine aquatic organisms and has the potential to cause chronic risks to estuarine and/or freshwater organisms. Permethrin is highly toxic to honeybees, as well as other beneficial insects. Permethrin may be hazardous to small mammals following acute exposure. It is of low toxicity to birds, terrestrial soil-dwelling organisms such as earthworms and plants.[251,252,253] Permethrin alters nerve function. It is moderately toxic to humans, is an irritant and may be a CNS toxicant.[254] In its re-evaluation of permethrin and its associated end products, the Pest Management Regulatory Agency of Canada identified potential evidence of increased sensitivity of the young to the neurotoxic effects of permethrin, as well as evidence of impacts on the immune system. Evidence of tumorigenicity in mice and rats suggest a potential for causing cancer in humans. There is also evidence of adverse effects on the reproductive system.[255] While initial screening found that

[245] European Chemicals Agency Database (https://echa.europa.eu/substance-information/-/substanceinfo/100.162.838, accessed 2024-03-13).

[246] IUPAC cited above.

[247] IUPAC Pesticides Properties DataBase (https://sitem.herts.ac.uk/aeru/iupac/Reports/515.htm, accessed 2024-03-14).

[248] Health Canada (2019) Re-evaluation Decision RVD2019-11, Permethrin and its associated end-use products (https://www.canada.ca/en/health-canada/services/consumer-product-safety/reports-publications/pesticides-pest-management/decisions-updates/reevaluation-decision/2019/permethrin.html, accessed 2024-03-14).

[249] IUPAC cited above.

[250] US EPA (2009) Permethrin facts (Available at https://www3.epa.gov/pesticides/chem_search/reg_actions/reregistration/fs_PC-109701_1-Aug-09.pdf).

[251] US EPA (2006) Reregistration eligibility decision (RED) fact sheet https://archive.epa.gov/pesticides/reregistration/web/html/permethrin_fs.html, accessed 2024-03-14)

[252] EFSA (2014) Assessment Report Permethrin – Product-Type 18 (Available at https://dissemination.echa.europa.eu/Biocides/ActiveSubstances/1342-18/1342-18_Assessment_Report.pdf).

[253] Ireland (2014) Evaluation of active substances assessment report: Permethrin – product-type 18 (Available at https://dissemination.echa.europa.eu/Biocides/ActiveSubstances/1342-18/1342-18_Assessment_Report.pdf).

[254] IUPAC Pesticides Properties DataBase (https://sitem.herts.ac.uk/aeru/iupac/Reports/515.htm, accessed 2024-03-14).

[255] Health Canada (2017) Proposed Re-evaluation Decision PRVD2017-18 Permethrin and its associated end-use products (https://publications.gc.ca/collections/collection_2017/sc-hc/H113-27/H113-27-2017-18-eng.pdf); and

	permethrin has potential to interact with the androgen hormone system in mammals, the US Environmental Protection Agency did not recommend additional testing as it was not expected to impact the human health risk assessment.[256] According to the EU harmonised classification and labelling notifications permethrin poses the following hazards: Harmful if swallowed (H302), may cause an allergic skin reaction (H317), harmful if inhaled (H332), very toxic to aquatic life (H400), and is very toxic to aquatic life with long lasting effects (H410).[257] Permethrin and its individual constituent isomers are not PBT candidates. While they fulfill the persistence and toxicity criteria, they do not meet the criteria for bioaccumulation.[258]
Tefluthrin (CAS No. 79538-32-2)	
Description of the alternative	Tefluthrin is a pyrethroids insecticide that alter nerve function, causing paralysis in target insect pests (also called 'knockdown'), eventually resulting in death.[259] Registered or approved for use in Australia, Canada, EU, UK, and US.
Pest controlled / crop	Tefluthrin is a pyrethroid insecticide having a neurotoxic mode of action activity against a variety of soil-borne insects such as cutworms, corn rootworms, seed-corn maggots, seed-corn beetles, lesser cornstalk borers white grubs and wire worms. It is also used to control other pests including springtails, symphylids, millipedes, pygmy beetle, fire ants, rootworms, wireworms, and white grubs. Tefluthrin is used on field corn, seed corn, sweet corn, and popcorn as well as a seed treatment for corn and sugar beet.[260,261]
Risk	Tefluthrin is considered moderately persistent in soil. In mammals it is characterised as having high acute toxicity and moderate chronic toxicity. In birds it is rated as having moderate acute toxicity and high chronic toxicity. In earthworms, tefluthrin shows high acute and moderate chronic toxicity. Tefluthrin is highly toxic to bees as well as fish and aquatic invertebrates.[262,263] In mammalian toxicity studies tefluthrin is irritating to the eyes and very toxic by inhalation and if swallowed. The main target organs are the nervous system and the thyroid.[264] In its re-evaluation of tefluthrin the Pest Management Regulatory Agency of Canada noted evidence of adverse effects on the reproductive organs of experimental animals as well as evidence of uterine cancer in rats.[265]

Health Canada (2019) cited above.

[256] US Environmental Protection Agency (2023) Status of Endocrine Disruptor Screening Program (EDSP) List°1 screening conclusions (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2023-0474-0001).

[258] Ireland (2014) cited above.

[259] US EPA (2020) Tefluthrin Interim Registration Review Decision (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2012-0501-0075).

[260] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/617.htm, accessed 2024-03-14)

[261] PPDB: cited above.

[262] PPDB cited above.

[263] European Food Safety Authority (2010) Conclusion on the peer review of the pesticide risk assessment of the active substance tefluthrin EFSA Journal 2010;8(12):1709. (https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2010.1709).

[264] European Food Safety Authority (2010) Conclusion on the peer review of the pesticide risk assessment of the active substance tefluthrin EFSA Journal 2010;8(12):1709. (https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2010.1709).

[265] Health Canada (2010) Proposed Re-evaluation Decision PRVD2010-01: Tefluthrin (https://publications.gc.ca/collections/collection_2010/arla-pmra/H113-27-2010-1-eng.pdf); and

	When used as a seed treatment, use of tefluthrin poses a low risk to bees and other non-target arthropods including earthworms.[266] According to EU Hazard classification and labelling notifications tefluthrin is fatal if swallowed (H300), fatal in contact with skin (H310), fatal if inhaled (H330), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[267]
Thiacloprid (CAS No. 111988-49-9)	
Description of the alternative	A neonicotinoid insecticide with contact and stomach action and some systemic properties.[268] Thiacloprid is currently registered or approved for use in Australia, Brazil, and India.
Pest controlled / crop	Thiacloprid is used to control sucking and chewing insects on apples cotton, stone fruits, pome fruits (apples and pears) and other crops.[269,270]
Risk	Thiacloprid is not persistent in soil and its bioconcentration potential is low.[271] In its review the US EPA concluded that the use of thiacloprid posed a potential chronic risk to birds, as well as acute and chronic risk to mammals and marine and estuarine invertebrates. Thiacloprid is practically non-toxic to honeybees on contact, practically non-toxic to birds on acute exposure, and slightly toxic to birds in sub-acute dietary studies. It is moderately acutely toxic to mammals, slightly toxic to fish, very toxic to aquatic invertebrates.[272] Thiacloprid is an eye and skin irritant. There is evidence of endocrine disruption, reproductive/developmental effects, and neurotoxicity.[273] Liver is the primary target organ for thiacloprid. The US EPA has classified thiacloprid as likely to be a human carcinogen.[274] According to EU hazard classification & labelling notifications, thiacloprid is toxic if swallowed (H301), harmful if inhaled (H332), may cause drowsiness or dizziness (H336), may damage fertility and/or the unborn child (H360), is suspected of causing cancer (H351), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410).[275] As thiacloprid is neither persistent nor bioaccumulative, it is not considered a PBT substance.[276]
Thiamethoxam (CAS No. 153719-23-4)	

Health Canada (2010) Re-evaluation Decision RVD2010-07: Tefluthrin (https://publications.gc.ca/collections/collection_2011/sc-hc/H113-28-2010-7-eng.pdf).

[266] European Food Safety Authority (2010) cited above.

[267] https://echa.europa.eu/substance-information/-/substanceinfo/100.124.968

[268] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/630.htm, accessed 2024-03-14)

[269] PPDB cited above.

[270] US EPA (2012a) EFED Registration Review Problem Formulation for Thiacloprid (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2012-0218-0010).

[271] PPDB cited above.

[272] US EPA (2012a) cited above.

[273] PPDB cited above.

[274] US EPA (2012b) Thiacloprid: Human health assessment scoping document in support of registration review (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2012-0218-0003).

[275] https://echa.europa.eu/substance-information/-/substanceinfo/100.129.728

[276] UK (2008) Thiacloprid: Assessment report Directive 98/8/EC concerning the placing of biocidal products on the market (Available at https://dissemination.echa.europa.eu/Biocides/ActiveSubstances/0053-08/0053-08_Assessment_Report.pdf).

Description of the alternative	Thiamethoxam is a broad-spectrum neonicotinoid insecticide, with systemic and some contact and stomach action, used to control a wide range of common pests.[277] Registered in Australia, Brazil, Canada, EU, and US.
Pest controlled / crop	The target pests for thiamethoxam include insect pests, such as aphids, whiteflies, thrips, caterpillars, beetles, flies, stinkbugs, lacewings, leafhoppers, mealybugs, wireworms, ground beetles, fire and carpenter ants, craneflies and mole crickets.[278,279] Thiamethoxam is used on many crops including corn, cotton, soybeans, vegetables (e.g. brassicas, cucurbits, fruiting vegetables, globe artichoke, leafy vegetables, mint, and root and tuberous vegetables), pome fruit, stone fruit, berries, tree nuts, legumes, cereal grains, oilseed crops, and herbs. Thiamethoxam is also used in non-agricultural settings such as turf, poultry houses, and ornamental plants.[280,281]
Risk	Based on physicochemical properties thiamethoxam is not expected to bioaccumulate.[282] Risks to mammals and birds are classified as low to moderate, with exposures from treated seeds posing the highest acute and chronic risks. Acute oral exposure to thiamethoxam is characterized as slightly toxic to birds. Subacute dietary exposure is considered practically non-toxic. The risk is highest for small birds. No risks of concern have been identified in terrestrial plants. Thiamethoxam is highly toxic to adult honeybees and it can also pose a risk to larvae through oral and contact exposure.[283,284] The toxicity of thiamethoxam is rated as low in temperate freshwater fish and moderate in tropical fish. While susceptibility varies, thiamethoxam is very highly toxic to certain aquatic invertebrates.[285,286] Thiamethoxam poses a low risk to semi-aquatic, aquatic plants and algae.[287,288] Thiamethoxam is rated as having moderate acute and chronic toxicity for humans, with potential reproductive, developmental and neurotoxic effects. It is classified as "not likely to be carcinogenic to humans". [289,290] According to EU hazard classification and labelling notifications this substance is harmful if swallowed, is suspected of damaging fertility and the unborn child (H361), very toxic to aquatic life (H400), and very toxic to aquatic life with long lasting effects (H410). [291] As thiamethoxam is neither bioaccumulative nor toxic, it is not considered a PBT substance.[292]

[277] PPDB: Pesticide Properties DataBase (https://sitem.herts.ac.uk/aeru/ppdb/en/Reports/631.htm, accessed 2024-03-15)

[278] US EPA (2020) Clothianidin and thiamethoxam: Proposed interim registration review decision – case numbers 7620 and 7614 (Available at https://www.regulations.gov/document/EPA-HQ-OPP-2011-0865-1190).

[279] PPDB cited above.

[280] US EPA (2020) cited above.

[281] PPDB cited above.

[282] US EPA (2020) cited above.

[283] US EPA (2020) cited above.

[284] PPDB cited above.

[285] US EPA (2020) cited above.

[286] PPDB cited above.

[287] US EPA (2020) cited above.

[288] PPDB cited above.

[289] US EPA (2020) cited above.

[290] PPDB cited above.

[291] https://echa.europa.eu/substance-information/-/substanceinfo/100.102.703

[292] Spain (2008) Thiamethoxam: Assessment report Directive 98/8/EC concerning the placing of biocidal

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Baker BP, Grant JA (2018d) Thyme & thyme oil profile. New York State Integrated Pest Management, Cornell University, Geneva, NY (Available https://hdl.handle.net/1813/56143).

Baker BP, Grant JA, Malakar-Kuenen R (2018a) Cinnamon & Cinnamon Oil Profile New York State Integrated Pest Management, Cornell University, Geneva, NY (Available at https://hdl.handle.net/1813/56120)

Baker BP, Grant JA, Malakar-Kuenen R (2018b) Cloves & clove oil profile. New York State Integrated Pest Management, Cornell University, Geneva, NY (Available at https://hdl.handle.net/1813/56120).

Baker BP, Grant JA, Malakar-Kuenen R (2018c) Peppermint & peppermint oil profile. New York State Integrated Pest Management, Cornell University, Geneva, NY (Available at https://hdl.handle.net/1813/56135).

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Appendix

List of potential pesticide alternatives to methoxychlor registered and used in Madagascar as of April 2024.

Active Substance	CAS Number
Biopesticides	
Bacillus thuringiensis israelensis (Bti)	68038-71-1
Metarhizium anisopliae	67892-13-1
Biochemical pesticides	
Abamectin	71751-41-2
Azadirachtin	11141-17-6
Chemical pesticides	
Acetamiprid	135410-20-7
Chlorfenapyr	122453-73-0
Cyfluthrin	68359-37-5
Cypermethrin	52315-07-8
Deltamethrin	52918-63-5
Esfenvalerate	66230-04-4
Fenvalerate	51630-58-1
Imidacloprid	138261-41-3
Tefluthrin	79538-32-2
Thiacloprid	111988-49-9
Thiamethoxam	153719-23-4

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