**Supplementary Material**

**Updated assessment of potential biopesticide options for managing fall armyworm (*Spodoptera frugiperda*) in Africa**

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# Detailed description of the process for compiling the biopesticide profiles

**Efficacy assessment.** A review of literatures that evidence efficacy of biopesticide AI against FAW, *Spodoptera* spp. or Lepidoptera in general was conducted. Likewise, it was noted whether the evidence of efficacy is from Africa, Asia, FAW’s native range or the laboratory. Based on these assessments, each AI was assigned a code to summarise the findings of the efficacy assessments as given in Table 2. We compared how the evidence for efficacy has changed from the previous assessment.

**Hazard assessment.** For each AI, any associated hazards to human health and the environment were identified and assessed if the risks posed were unacceptable. The human health hazards were deemed to be unacceptable if an AI met any of the Highly Hazardous Pesticide criteria (FAO and WHO (World Health Organization), 2017). A full list of Globally Harmonized System of Classification and Labelling of Chemicals (GHS (UN (United Nations), 2019)) hazard statements compiled for each identified AI based on GHS hazard statements published the European Chemicals Agency (ECHA) Classification and Labelling Inventory (ECHA, 2020d) and the most recent US EPA regulatory documents (such as Reregistration Eligibility Decision documents). Once all GHS hazard statements associated with each biopesticide AI were compiled, each biopesticide AI was assigned an overall hazard category using an approach adapted from the guidance set out in Annex 3 of the *Guidelines on Good Labelling Practice for Pesticides* (FAO, 2015). To the extent possible, we also collected data on precautionary statements and PPE requirements for each AI. Finally, it was noted whether or not an AI was permitted for use in organic agriculture by the European Commission (EC, 2013) and whether it was listed as WHO acute toxicity class U (unlikely to cause acute hazard under conditions of normal use) in the *WHO recommended classification of pesticides by hazard and guidelines to classification, 2019 editio*n (WHO, 2019). We noted whether each AI was included in the *Pesticide Action Network list of HHPs* (PAN (Pesticide Action Network), 2019) since this list covers environmental hazards such toxicity to bees, the potential to bioaccumulate and persistence in water, soil and sediment. We determined whether any of the AI’s hazard assessments had changed.

**Assessment of agronomic sustainability.** Through a review of the literature and product labels, it was determined whether there was any evidence indicating that the biopesticide AI would compromise agronomic sustainability. In particular, evidence for the development of resistance to the AI by FAW or other Lepidoptera was collected. Likewise, hazard data was reviewed to assess whether the AI posed an unacceptable risk to pollinators, natural enemies or other beneficial organisms. We specifically looked for information on compatibility with other recommended or widely used controls and potential impacts on beneficial organisms. Finally, for the biopesticides that are living organisms, or may be locally produced from living organisms, it was determined whether the organisms had been classified as an invasive species in any country in Africa. If there was an indication that the AI might compromise agronomic sustainability, it was then determined whether it would be possible to put in place mitigation measures to adequately manage the risk. The findings of this assessment were used to assign a code to indicate whether or not the available evidence indicates that the AI is agronomically sustainable (Table 3). We compared the current findings to those of the previous study.

**Practicality.** Information available, primarily from product labels and regulatory documents, was reviewed in order to assess whether or not the biopesticide would be practical for smallholder farmers to use and if any special application equipment, personal protective equipment, or storage conditions were required. Also, information such as the frequency and number of applications required, for example, were used to gauge whether the use of the biopesticide in a manner consistent with the product label instructions might pose prohibitively high time or labour requirements. It was noted whether or not the AI would be more appropriate for area-wide management (as opposed to use by individual smallholder farmers). The current findings were comparied to those of the previous study.

**Availability.** As stated above, the registration status of the identified biopesticide AI was assessed for 19 selected countries in Africa where FAW is present. Furthermore, we determined whether a biopesticide is already being recommended for use in IPM schemes based on a review extension materials produced by national governments published on the Plantwise Knowledge Bank (CABI (CAB International), 2020) and the FAO (2018a, 2018b); and data on the provision of biopesticides through input support schemes. Furthermore, we referred to findings from farmer surveys to gain an understanding of availability at the local level.

**Cost effectiveness.** We reviewed the literature for information on the costs of products containing the AI and their cost effectiveness.

**Decision matrix.** A decision matrix for biopesticides that could be used to target FAW was adapted from the FAO Pesticide Registration Toolkit (FAO, 2020b) and the Plantwise plant doctor training module on how to give good recommendations (Taylor, 2019). This decision matrix, provided in Supplementary Table 2, poses five key questions against which each AI should be evaluated, based on the five main information categories listed above, and describes criteria for how to proceed. The answers to these five questions served as the basis for recommendations for next steps for each AI following the decision matrix. For AI for which no evidence of efficacy against FAW was found, no follow-up action was recommended. Likewise, no follow-up action was recommended for AI which were classified as HHPs, could compromise agronomic sustainability or would be prohibitively impractical for smallholder farmers to use. Follow-up action was recommended for AI that passed these key criteria. If evidence of efficacy against FAW is available from field trials in FAW’s native range, field trials were recommended to confirm the efficacy of the AI against FAW under field conditions in Africa. If evidence of efficacy was only available for other *Spodoptera* or Lepidopteran species or if data was only available from laboratorystudies, bioassays and field assessments were recommended as the next step.

**Analyses.** For each information category, the counts of AI were compared for 2018 and 2020. For the purposes of the comparisons, all the chemical components of the synthetic FAW pheromone are grouped together as they are used in combination. For Mexico and the US, products were counted by their registration numbers (as opposed to brand names since products with the same registration number may be marketed under multiple names).

# Supplementary Table 1 Decision matrix for biopesticides which target fall armyworm (FAW); adapted from the FAO *Pesticide Registration Toolkit* (FAO, 2017) and the Plantwise plant doctor training module on how to give good recommendations (Taylor, 2015).

|  |  |  |
| --- | --- | --- |
| Is the biopesticide effective against FAW? | * Is evidence available that the biopesticide is effective against FAW? Is the control measure known to work reliably under normal farm conditions?
 | * If **yes**, then proceed to the next point.
* If **no** evidence is available that the biopesticide controls FAW, it should be rejected.
 |
| Is the biopesticide sufficiently safe? | * Are the risks posed by the biopesticide to human health and the environment acceptable?
 | * If **yes**, then proceed to the next point.
* If **no**,
	+ Biopesticides which meet any of the highly hazardous pesticides (HHP) criteria are considered to pose an unacceptable hazard and should be rejected.
	+ Where there are other serious human health (e.g. endocrine disruption) or environmental hazards (e.g. bioaccumulation, aquatic toxicity) mitigation measures should be put in place to reduce risk. For example, the biopesticide should only be adopted for use if appropriate personal protection equipment (PPE) is available.
 |
| Is the biopesticide sustainable? | * Does evidence indicate that the biopesticide will not compromise agronomic sustainability? Is the risk of the development of pest resistance low? Does it pose low risk to pollinators, natural enemies and other beneficial organisms? Is the biopesticide compatible with other crop protection measures that are applied in the production system?
 | * If **yes**, then proceed to the next point.
* If **no**,
	+ Assess whether mitigation measures can be put in place to reduce risk.
	+ If not, the biopesticide should be rejected.
 |
| Is the biopesticide practical? | * Given the local circumstances, is the biopesticide practical for farmers to use? For example, do products require access to water for spraying water-based formulations? Is use realistic given farmers’ time and labour constraints? Are there appropriate application equipment and storage facilities available? Is the biopesticide appropriate for use by small scale farmers (or is it only effective when used for areawide management)?
 | * If **yes**, then proceed to the next point.
* If **no**,
	+ Assess whether the practicalities can be overcome, e.g. by adjusting the production system.
	+ If the impracticalities cannot be overcome the biopesticide should be rejected.
 |
| Is the biopesticide locally available? | * Can the biopesticide be sourced locally?
 | * If **yes**, then consider including the biopesticide in integrated pest management (IPM schemes.
* If **no**,
	+ For particularly compelling biopesticides with strong evidence of efficacy, consider exploring the possibility of registration.
	+ For biopesticides registered for use but not locally available, liaise with manufacturers/distributers.
 |

# Supplementary Table 2 National lists of registered pesticides and biopesticides for the 30 study countries. Where online links for the latest list are unavaible, links to previous version have been provided. Identification of which AI are considered biopesticides and for which pests they are registered was based on the information in each countries’ list of registered pesticides. This information was not always available in the lists of registered pesticides, though it is likely that it would be available elsewhere, e.g. on product labels. As with the previous study, plant-incorporated-protectants such as genetically modified maize incorporating genes of *Bacillus thuringiensis* Berliner (*Bt*) and the use of classical biological control were excluded from the study.

| Country | References for the national lists of registered pesticides | Biopesticides flagged in list (Y /N) | Pests for which prodcuts are registered identified in list (Y / N) | Notes |
| --- | --- | --- | --- | --- |
| Argentina | Servicio Nacional de Sanidad y Calidad Agroalimentaria - Argentina. *Registro Nacional de Terapéutica Vegetal.* <http://www.senasa.gov.ar/informacion/prod-vet-fito-y-fertilizantes/prod-fitosanitarios-y-fertili/registro-nacional-de-terapeutica-vegetal>. Published February 2020. Accessed 18 May 2020.Servicio Nacional de Sanidad y Calidad Agroalimentaria - Argentina. *LMR de principios activos por cultivo.* Published February 2020. Accessed 18 May 2020.  | N | N |  |
| Benin | Comité Sahélien des Pesticides. Liste globale des pesticides autorisés par le Comité Sahélien des Pesticides, Version de Novembre 2019. <http://insah.cilss.int/index.php/csp/>. Accessed May 2020. | N | Y | This is the list of pesticides which are authorised for Comité Permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS) member countries. The national list of pesticides for Benin would be a subset of these pesticides.  |
| Bolivia | COSAVE, Comité Directivo. 2016. Lista Productos fitosanitario biologicos – ACB. Resolución 220/86-16D. <http://www.cosave.org/sites/default/files/erpfs/Anexo%20Resol.%20220%20-%20Lista%20Productos%20fitosanitario%20biologicos%20-%20ACB..pdf> Accessed 10 August 2020.Servicio Nacional de Sanidad Agropecuaria e Inocuidad Alimentaria. 2018. Agroquimicos – Productos alimenticios.  | N | Y |  |
| Brazil | Ministério da Agricultura, Pecuária e Abastecimento - Coordenação-Geral de Agrotóxicos e Afins/DFIA/SDA - Brazil. *AGROFIT.* <http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons>. Accessed May 2020. | Y | Y |  |
| Burkina Faso | Comité Sahélien des Pesticides. Liste globale des pesticides autorisés par le Comité Sahélien des Pesticides, Version de Novembre 2019. <http://insah.cilss.int/index.php/csp/>. Accessed May 2020. | N | Y | This is the list of pesticides which are authorised for CILSS member countries.  |
| Cameroon | Ministere de l'Agriculture et du Developpement Rural - Direction de la Réglementation et du Contôle des Qualités des Intrants et des Produits Agricoles. Liste des pesticides homologues au Cameroun au 18 Avril 2019 - Liste réservée au Grand Public. <http://drcq-minader.org/docs/Liste_Pesticides_Homologues_042019.pdf>. Accessed May 2020. | N | Y |  |
| Chile | Servicio Agrícola y Ganadero. Lista de Plaguicidas Autorizados. <http://www.sag.cl/ambitos-de-accion/plaguicidas-y-fertilizantes/78/registros>. Accessed May 2020. | Y | Y |  |
| Colombia | Instituto Colombiano Agropecuario – ICA. *Registros plaguicidas registrados - 26 de Febrero 2020*. <http://www.ica.gov.co/Areas/Agricola/Servicios/Regulacion-y-Control-de-Plaguicidas-Quimicos.aspx>. Accessed May 2020.Instituto Colombiano Agropecuario – ICA. *Productos bioinsumos registrados - Diciembre 2019.* <https://www.ica.gov.co/areas/agricola/servicios/fertilizantes-y-bio-insumos-agricolas/listado-de-bioinsumos/2009/productos-bioinsumos-mayo-13-de-2008.aspx>. Accessed May 2020. | Y | Y |  |
| DR Congo | Ministere de L'Agriculture, Peche et Elevage - Direction de Production et Protection des Vegetaux. Liste Actualisee des Pesticides Homologues et Autorises en RDC. 2016<http://www.au-ibar.org/component/jdownloads/finish/134-reports/2759-la-gestion-des-pesticides-en-r-d-congo><http://documents.worldbank.org/curated/en/280961468032356665/text/SFG1825-EA-FRENCH-P143307-PUBLIC-Disclosed-2-10-2016.txt> | N | N |  |
| Costa Rica | Servicio Fitosanitario del Estado. Plaguicidas sintéticos formulados aprobados por el Decreto N° 33495-MAG-S-MINAE-MEICal 11/12/2019. <http://www.sfe.go.cr/DocsStatusRegistro/Formulados_aprobados_bajo_Decreto_33495.pdf>. Accessed May 2020. Servicio Fitosanitario del Estado. Plaguicidas sintéticos formulados aprobados por el Decreto N° 39461-MAG perfeccionamiento activo al 11/12/2019. <http://www.sfe.go.cr/DocsStatusRegistro/Formulados_aprobados_bajo_Decreto_39461_Perfeccionamiento_activo.pdf>. Accessed May 2020.Servicio Fitosanitario del Estado. *Productos botánicos registrados en Costa Rica al 11/12/2019*. <http://www.sfe.go.cr/DocsStatusRegistro/Botanicos_aprobados.pdf>. Accessed May 2020. | Y | N |  |
| Ecuador | AGROCALIDAD - Agencia Ecuatoriana de Aseguramiento de la Calidad del Agro. *Plaguicidas registrados.* <https://web.agrocalidad.gob.ec/AgrocalidadNuevo/wp-content/uploads/2020/PLAGUICIDAS%20Y%20PRODUCTOS%20AFINES%20DE%20USO%20AGRICOLA.xls>. Accessed May 2020. | N | Y | With the exception of pheromones, biopesticides are not flagged. |
| Ethiopia | Ministry of Agriculture of Ethiopia. List of registered pesticides. <http://www.moa.gov.et/list-of-registered-pesticides>. Published June 2019. Accessed May 2020.  | N | Y |  |
| Ghana | Environmental Protection Agency. (2019). Revised Register of Pesticides as at October 2019 under Part II of the Environmental Protection Agency Act, 1994 (Act 490). Accra, Ghana.<https://waapp.org.gh/waappmedia/manuals/46-revised-register-of-pesticides/file>  | N | Y |  |
| Kenya | Kenyan Pesticide Control Products Board. *Registered conventional pest control products for use on crops.* <http://www.pcpb.go.ke/crops/>. Accessed May 2020.Kenyan Pesticide Control Products Board. *Registered biopesticides for use in crop production.* <http://www.pcpb.go.ke/biopesticides-on-crops/>. Accessed May 2020. | Y | Y |  |
| Malawi | Pesticides Control Board. April 2020. List of Pesticides Registered In Malawi.<https://gazettes.africa/archive/mw/2019/mw-government-gazette-dated-2019-03-22-no-11.pdf> | Y/N | Y | Some botanicals and biologicals are flagged, though some AI which are generally regarded as biopesticides are not listed as such, e.g. *Metarhizium anisopliae*. |
| Mali | Comité Sahélien des Pesticides. Liste globale des pesticides autorisés par le Comité Sahélien des Pesticides, Version de Novembre 2019. <http://insah.cilss.int/index.php/csp/>. Accessed May 2020. | N | Y | This is the list of pesticides which are authorised for CILSS member countries.  |
| Mexico | Comisión Federal para la Protección contra Riesgos Sanitarios. *Consulta de Registros Sanitarios de Plaguicidas, Nutrientes Vegetales y LMR.* <http://siipris03.cofepris.gob.mx/Resoluciones/Consultas/ConWebRegPlaguicida.asp>.Accessed May 2020. | N | N |  |
| Mozambique | Ministério da Agricultura, Direcção Nacional de Serviços Agrários. 2019. *Lista Dos Pesticidas Registados Em Moçambique*., Departamento de Sanidade Vegetal, Repartição de Registo e Controle De Agroquímicos.<https://ewsdata.rightsindevelopment.org/files/documents/31/WB-P164431_WY9NtW1.pdf>  | N | N |  |
| Nigeria | National Agency for Food & Drug Administration and Control. Directorate of Registration & Regulatory Affairs – Lagos. 2018. *Approved pesticides*.  | N | N |  |
| Panama | *Listado de insumos fitosanitarios registrados*. <https://www.mida.gob.pa/direcciones/direcciones_nacionales/direcci-n-nacional-de-sanidad-vegetal/agroqu-micos/listado-de-insumos-fitosanitarios-registrados.html>. Accessed May 2020.  | Y | N |  |
| Peru | Sistema Integrado de Gestión de Insumos Agrícolas – SIGIA. Reporte de Productos Plaguicidas Registrados. <https://servicios.senasa.gob.pe/SIGIAWeb/sigia_consulta_producto.html>. Accessed May 2020. | Y | N |  |
| Rwanda | Minister of Agriculture and Animal Resources. 2016. Ministerial Order No 002/11.30 OF 14/07/2016 Determining Regulations Governing Agrochemicals. Official Gazette nᵒ 30 of 25/07/2016. | N | N |  |
| Sierra Leone | 2012 List of AI recommended by Ministry of Agriculture, Forestry and Food Security<http://documents1.worldbank.org/curated/en/647541526656882513/pdf/Pest-management-plan-for-Sierra-Leone.pdf>  | N | N |  |
| South Africa | Agri-Intel. <https://www.agri-intel.com/label-information>. Accessed May 2020.  | N | Y |  |
| Tanzania | Tropical Pesticides Research Institute - Registrar of Pesticides. February 2020. *Registered Pesticides for use in the United Republic of Tanzania.*Tropical Pesticides Research Institute - Registrar of Pesticides. June 2020. Provisional list of registered pesticides 2020. Accessed 25 August 2020. <http://www.tpri.go.tz/registered-pesticides-intanzania>.  | Y/N | Y | With the exception of macrobials, biopesticides are not flagged. |
| Togo | Comite National De Gestion Des Pesticides - Commission Des Agréments Professionnels, Des Autorisations Et Des Licences. April 2020. Liste des produits phytopharmaceutiques homologues. | N | N |  |
| Tunisia | Centre Technique de l’Agriculture Biologique. La liste des produits phytosanitaires homologués et autorisés en agriculture biologique. <http://www.ctab.nat.tn/pdf/Pesticides_bio_tunisie_fr.pdf>. Accessed May 2020. Flehetna. Guide Phytosanitaire. Accessed June 2020. | Y | Y |  |
| Uganda | Ministry of Agriculture Animal Industry and Fisheries. 2018. Register of Agricultural Chemical Registered Under Section 4 of the Agricultural Chemicals (Control) Act, 2006. | Y/N | Y | With the exception of macrobials, biopesticides are not flagged. |
| USA | *Pesticide Product Information System (PPIS).* United States Environmental Protection Agency. <https://www.epa.gov/ingredients-used-pesticide-products/pesticide-product-information-system-ppis> Accessed April 2020.*Pesticides Chemical Search*. Office of Pesticide Programs. United States Environmental Protection Agency. <https://iaspub.epa.gov/apex/pesticides/f?p=CHEMICALSEARCH:1>: Accessed May 2020.United States Government Publishing Office. *Govinfo.* <https://www.govinfo.gov>. Accessed May 2020.*Biopesticide Active Ingredients*. United States Environmental Protection Agency. US <https://www.epa.gov/ingredients-used-pesticide-products/biopesticide-active-ingredients>. Accessed June 2020.  | Y | Y |  |
| Zambia | Zambia Environmental Management Agency. June 2018. List of pesticides.<http://documents1.worldbank.org/curated/en/492531468210284831/text/NonAsciiFileName0.txt>  | N | Y | Pests for which products are registered are broadly identified. |

# Supplementary Table 3 Hazard profiles for the biopesticide active ingredients (AI) registered for use against fall armyworm (FAW) in at least one of the 30 study countries

The table below lists the AI registered for use against FAW in at least one of 30 countries in its native range in the Americas, or in areas where it is invading in Africa. Some countries may allow for emergency use of AI, as a consequence, there may be instances when AI which are not fully registered for use against FAW are exceptionally authorized. AI and products subjected to such emergency use permits have not been captured in the present analysis.

The table also lists the substance group for each AI and the search terms that flagged the AI as being registered for use against FAW in one or more countries.

**Notes:**

1. Grouping the AI (active ingredients) into **hazard categories**, based on the GHS (Globally Harmonized System of Classification and Labelling of Chemicals) (UN (United Nations), 2019) hazard statements associated with each AI.

|  |  |
| --- | --- |
| **Hazard category** | **Basis for inclusion in the hazard category** |
| Highly hazardous pesticide (HHP) | AI that fit one or more HHP criteria |
| Danger | Not an HHP. One or more of the associated human health hazard statements used the signal word 'danger' and/ or the AI is WHO (World Health Organisation) acute toxicity class II (FAO, 2016).  |
| Warning | Not an HHP. None of the human health hazard statements uses the signal word 'danger'. One or more of the human health hazard statements uses the signal word 'warning' and / or the AI is WHO acute toxicity class III. |
| Low toxicity | No known human health hazard statements associated with the AI and the AI is WHO acute toxicity class U.  |
| Missing data | Data not available on one or more of the criteria used for identifying HHPs |

2 **HHP1 - Acute toxicity**

**Y** = Extremely actutely toxic (WHO 1a) or highly acutely toxic (WHO 1b); **N** = Not extremely or highly acutely toxic; **U** = Unlikely to present acute hazard (WHO (World Health Organization), 2019); **-** = no data

3 **HHP2 – Carcinogenicity, HHP3 – Mutagenicity, HHP4 - Reproductive toxin**

**Y** = GHS 1A or 1B for the respective criteria category; **N** = Not GHS 1A or 1B for the respective criteria

4 **HHP5 – Persistent Organic Pollutants (POPs) under Stickholm Convention, HHP6 – prior informed consent (PIC) required for international trade under Rotterdam Convention; HHP7 – Ozone depleting substances (ODS) listed under Montreal Convention**

**Y** = Listed in the respective international convention; **N** = Not listed in the respective international convention

5 Whether included in the *PAN International List of Highly Hazardous Pesticides* (PAN (Pesticide Action Network), 2019).

Y = Listed; N = Not listed

6 AI is permitted for use in in the EU (EC (European Commission), 2020).

**Y** = Permitted, **N** = Not permitted. **P** = Pending.

7 AI is permitted for use in organic agriculture in the EU.

**Y** = Permitted, **N** = Not permitted.

| **Active ingredient** **(in alphabetical order by substance group)** | **Substance group** | **Target pests** | **Hazard summary1** | **HHP1 - Acute toxicity2** | **HHP2 – Carcinogenicity3** | **HHP3 – Mutagenicity3** | **HHP4 - Reproductive toxin3** | **HHP5 – POPs4** | **HHP6 – PIC4** | **HHP7 – ODS4** | **Rotterdam notifications** | **PAN HHP List5** | **Registered for use in EU6** | **EU organic use7** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 2-phenylethyl propionate | Botanical | No longer registered for FAW | Missing data | N | - | N | - | N | N | N | N | N | N | N |
| Allyl isothiocyanate (Mustard oil) | Botanical | Used as a fungicide, herbicide, nematicide and insecticide against various insects including FAW and other *Spodoptera spp.* | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Azadirachtin (neem products) | Botanical | Various insects including Lepidopteran caterpillars such as FAW | Warning | U | N | N | N | N | N | N | N | N | Y | Y |
| Canola oil (Rape seed oil) | Botanical | Mainly used for control of sucking insects in greenhouses but also registered for some caterpillars such as FAW | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| Capsaicin | Botanical | Various insects including Lepidopteran caterpillars such FAW and other *Spodoptera spp.* | Danger | N | N | N | N | N | N | N | N | N | P | N |
| Cinnamaldehyde (cinnamon oil) | Botanical | Various plant pathogens and insects including Lepidoptera such as *Spodoptera spp.*  | Warning | N | N | N | N | N | N | N | N | N | P | N |
| Citric acid | Botanical | Wide range of insects including ants, aphids, beetles, mealybugs and mites; fungi | Danger | N | N | N | N | N | N | N | N | N | N | N |
| d-glucitol, octanoate | Botanical | Soft-bodied insects; no longer registered for FAW | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| D-limonene (Orange oil) | Botanical | Various plant pathogens and insects | Warning | U | N | N | N | N | N | N | N | N | N | N |
| *Dysphania ambrosioides (syn. Chenopodium ambrosioides)* | Botanical | Various insects including Lepidoptera | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Ethyl palmitate | Botanical | Spider mites, FAW | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| Eugenol | Botanical | Various plant pathogens and insects including armyworm | Warning | N | N | N | N | N | N | N | N | N | Y | N |
| Garlic extract | Botanical | Various insects, nematodes and mammals | Warning | N | N | N | N | N | N | N | N | N | Y | N |
| Maltodextrin | Botanical | Various insects such as spider mites, aphids, whiteflies and FAW | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| Matrine (*Sophora flavescens*) | Botanical | Various insects including Lepidoptera | Warning | N | N | N | N | N | N | N | N | N | N | N |
| Oxymatrine | Botanical | Various insects | Warning | N | N | N | N | N | N | N | N | N | N | N |
| Potassium salts of fatty acids (Potassium laurate) | Botanical | Used as an acaricides, algaecide, herbicide and insecticide. Registered targets include FAW | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| Pyrethrins | Botanical | Various insects including *Spodoptera spp.* | Warning | N | N | N | N | N | N | N | N | N | Y | N |
| Soybean oil | Botanical | Various insects including *Spodoptera spp.* | Warning | N | N | N | N | N | N | N | N | N | N | N |
| Sucrose octanoate | Botanical | No longer registered for FAW | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| Thyme oil | Botanical | Crawling and flying insects, including armyworm | Warning | N | N | N | N | N | N | N | N | N | P | N |
| Kaolin clay | Inorganic compound | Plant growth regulator, various insects including Lepidoptera such as FAW | HHP | U | Y | N | N | N | N | N | N | N | Y | N |
| Sulphur | Inorganic compound | Various insects including caterpillars | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| S-methoprene | Insect growth regulator | Various insects including *Spodoptera spp.* | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| *Steinernema carpocapsae* | Macrobials - entomopathogenic nematodes | Various soil insects, including armyworms | Low hazard | - | - | - | - | N | N | N | N | - | - | - |
| *Steinernema feltiae* | Macrobials - Entomopathogenic nematodes | Various soil insects | Low hazard | - | - | - | - | N | N | N | N | - | - | - |
| *Trichogramma* spp. | Macrobials - parasitoids | Various Lepidopteran species including FAW | Low hazard | - | - | - | - | N | N | N | N | N | - | - |
| Anagrapha falcifera nucleopolyhedrovirus (AfNPV) | Microbial | Lepidopteran caterpillars including FAW and various other *Spodoptera spp.* | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| *Aspergillus oryzae* | Microbial | FAW | Missing data | - | - | - | - | N | N | N | N | N | N | N |
| Autographa californica multiple nucleopolyhedrovirus (AcMNPV) | Microbial | Lepidoptera (more than 30 species from about 10 families) including FAW | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| *Bacillus thuringiensis* | Microbial | Various Lepidoptera including FAW | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| *Bacillus thuringiensis* subsp. *aizawai* | Microbial | Various Lepidoptera including *Spodoptera spp.* | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| *Bacillus thuringiensis* subsp. *kurstaki* | Microbial | Various Lepidoptera including FAW and other *Spodoptera spp.* | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| *Beauveria bassiana* | Microbial | Various soft bodied insects including Lepidopteran caterpillars such as FAW | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| *Chromobacterium subtsugae* strain praa4-1 cells | Microbial | Various insects including Lepidoptera such as FAW | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| Helicoverpa armigera nucleopolyhedrovirus (HaNPV)/ Helicoverpa zea single capsid nucleopolyhedrovirus (HzSNPV) | Microbial | *Helicoverpa armigera, Helicoverpa zea* and other Noctuidae | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| *Isaria fumosorosea* *(Paecilomyces fumosoroseus)* | Microbial | Various insects including Lepidoptera such as *Spodoptera spp.* | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| *Metarhizium anisopliae* | Microbial | Various insects including FAW | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| *Metarhizium rileyi* | Microbial | Various lepidopteran insects | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| *Spodoptera exigua multicapsid nucleopolyhedrovirus* (SeMNPV)  | Microbial | *Spodoptera exigua* | Low hazard | U | N | N | N | N | N | N | N | N | P | N |
| *Spodoptera exigua nucleopolyhedrovirus* (SeNPV) | Microbial | *Spodoptera exigua* | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| *Spodoptera frugiperda Multiple Nucleopolyhedrovirus* (SfMNPV) | Microbial | FAW, *Spodoptera exigua* | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| *Spodoptera littoralis nucleopolyhedrovirus* (SpliNPV) | Microbial | FAW, *Spodoptera littoralis* | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| Spinosad | Microbial extract / fermentation product / enzyme | Various insects including FAW | Warning | N | N | N | N | N | N | N | N | Y | Y | N |
| (Z)-11-Hexadecenal | Semiochemical | *Spodoptera frugiperda* | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| (Z)-11-Hexadecenyl acetate | Semiochemical | Beet armyworm, FAW | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| (Z)-7-Dodecenyl acetate | Semiochemical | *Spodoptera frugiperda* | Missing data | N | - | - | - | N | N | N | N | N | N | N |
| (Z)-9-Dodecenyl acetate | Semiochemical | *Spodoptera frugiperda* | Warning | U | N | N | N | N | N | N | N | N | N | N |
| (Z)-9-Tetradecenyl acetate | Semiochemical | *Spodoptera frugiperda* | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| (Z,E)-9,12-Tetradecadien-1-ol acetate | Semiochemical | *Spodoptera exigua* | Low hazard | U | N | N | N | N | N | N | N | N | N | N |
| (Z,E)-9,12-Tetradecadien-1-yl acetate | Semiochemical | Lepidoptera, *Spodoptera litura* | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| (Z,Z)-11,13-Hexadecadienal | Semiochemical | Moths | Missing data | N | - | - | - | N | N | N | N | N | N | N |
| Ethyl (z)-7-dodecenyl acetate | Semiochemical | FAW | Missing data | N | - | - | - | N | N | N | N | N | N | N |
| Ethyl (z)-9-tetradecenyl | Semiochemical | FAW | Missing data | N | - | - | - | N | N | N | N | N | N | N |
| Z-9-Tetradecen-1-yl acetate | Semiochemical | FAW | Warning | N | N | N | N | N | N | N | N | N | N | N |
| GS-omega/kappa-Hxtx-Hv1a | Spider venom toxin | Various insects including *Spodoptera spp.* | Warning | U | N | N | N | N | N | N | N | N | N | N |
| Borax | No longer categorized as a biopesticide | Various insects, mainly used in non-crop settings | HHP | N | N | N | **Y** | N | N | N | N | Y | N | N |
| Cryolite | No longer categorized as a biopesticide | Various leaf-eating insects including caterpillars such as *Spodoptera spp.*  | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Emamectin benzoate | No longer categorized as a biopesticide | Various insects including Lepdiptera such as FAW | Danger | N | N | N | N | N | N | N | N | Y | Y | N |
| Lufenuron | No longer categorized as a biopesticide | Biting and sucking insects, e.g. caterpillars and beetle larvae | Warning | N | N | N | N | N | N | N | N | Y | N | N |
| Methoxyfenozide | No longer categorized as a biopesticide | Lepidoptera eggs | Low hazard | U | N | N | N | N | N | N | N | N | Y | N |
| Silicon dioxide (diatomaceous earth) | No longer categorized as a biopesticide | Various insects including Lepidopteran caterpillars such as *Spodoptera spp.* | HHP | N | **Y** | N | N | N | N | N | N | N | Y | N |
| Spinetoram | No longer categorized as a biopesticide | Various insects including FAW | Warning | U | N | N | N | N | N | N | N | Y | Y | N |

# Supplementary Table 4 Registration status for the identified biopesticide active ingredients for fall armyworm (FAW) by country. The numbers for sex pheromones and macrobialsmay be incomplete as they only include those countries which require registration and where we have been able to identify FAW sex pheromone as the AI.

|   | **Active Ingredients registered for use in native range of FAW in the Americas** | **Active Ingredients registered for use in its countries where FAW is spreading in Africa** |
| --- | --- | --- |
| **Active ingredient** | Argentina | Bolivia | Brazil | Chile | Colombia | Costa Rica | Ecuador | Mexico | Panama | Peru | USA | Benin | Burkina Faso | Cameroon | DR Congo | Ethiopia | Ghana | Kenya | Malawi | Mali | Mozambique | Nigeria | Rwanda | Sierra Leone | South Africa | Tanzania | Togo | Tunisia | Uganda | Zambia |
| 2-phenylethyl propionate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Allyl isothiocyanate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| AfMNPV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Aspergillus oryzae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| AcMNPV | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Azadirachtin | 1 | 0 | 0 | 0 | 1 | 6 | 0 | 35 | 21 | 27 | 45 | 0 | 0 | 0 | 0 | 1 | 0 | 12 | 6 | 0 | 0 | 0 | 1 | 0 | 1 | 8 | 0 | 8 | 1 | 0 |
| *Bacillus thuringiensis* | 8 | 3 | 11 | 1 | 1 | 0 | 3 | 64 | 5 | 50 | 51 | 3 | 3 | 2 | 0 | 0 | **1** | 10 | 1 | 3 | 0 | 2 | 1 | 0 | 4 | 3 | 0 | 7 | 0 | 0 |
| *Bacillus thuringiensis subsp. aizawai* | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Bacillus thuringiensis subsp. kurstaki* | 7 | 0 | 0 | 1 | 3 | 0 | 1 | 4 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Beauveria bassiana* | 2 | 0 | 0 | 1 | 2 | 0 | 0 | 23 | 16 | 11 | 5 | 0 | 0 | 0 | 0 | 0 | **1** | 4 | 0 | 0 | 0 | 1 | 1 | 0 | 2 | 2 | 0 | 0 | 1 | 0 |
| Borax | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Canola oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Capsaicin | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 2 | 9 | 1 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Chromobacterium subtsugae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cinnamaldehyde | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 27 | 1 | 6 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Citric acid | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Cryolite | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| d-glucitol, octanoate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D-limonene | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Dysphania ambrosioides* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Emamectin benzoate | 7 | 70 | 0 | 0 | 0 | 0 | 16 | 13 | 22 | 0 | 4 | 24 | 24 | 18 | 1 | 4 | 9 | 21 | 4 | 24 | 5 | 9 | 0 | 0 | 5 | 40 | 0 | 2 | 4 | 2 |
| Ethyl palmitate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Eugenol | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Garlic extract | 3 | 1 | 0 | 0 | 1 | 5 | 0 | 16 | 10 | 6 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 |
| GS-omega/kappa-Hxtx-Hv1a | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| HzSNPV | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| *Isaria fumosorosea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kaolin clay | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Lufenuron | 50 | 41 | 0 | 0 | 0 | 0 | 16 | 1 | 11 | 0 | 0 | 2 | 2 | 3 | 0 | 1 | 1 | 12 | 2 | 2 | 2 | 1 | 0 | 0 | 6 | 9 | 2 | 3 | 1 | 0 |
| Maltodextrin | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Matrine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 17 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Metarhizium anisopliae* | 0 | 1 | 1 | 0 | 3 | 0 | 0 | 10 | 11 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | **1** | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 0 |
| Methoxyfenozide | 7 | 9 | 0 | 0 | 0 | 0 | 1 | 2 | 4 | 0 | 9 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 1 | 0 | 0 |
| PRGV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oxymatrine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Potassium laurate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 2 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pyrethrins | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 27 | 3 | 0 | 271 | 0 | 0 | 0 | 0 | 0 | 3 | 16 | 5 | 0 | 1 | 1 | 1 | 0 | 1 | 7 | 0 | 1 | 3 | 0 |
| Sex pheromones | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 2 | 2 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 9 | 0 | 0 | 0 |
| (Z)-11-Hexadecenyl acetate | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| (Z)-7-Dodecenyl acetate | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| (Z)-9-Dodecenyl acetate | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| (Z)-9-Tetradecenyl acetate | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| (Z,E)-9,12-Tetradecadien-1-ol acetate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| (Z,Z)-11,13-Hexadecadienal | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Ethyl (z)-7-dodecenyl acetate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 |
| Ethyl (z)-9-tetradecenyl | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Z-9-Tetradecen-1-yl acetate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Silicon dioxide | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | 0 |
| S-Methoprene | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Soybean oil | 76 | 11 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | 2 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| Spinetoram | 3 | 3 | 0 | 0 | 0 | 0 | 4 | 2 | 4 | 0 | 10 | 3 | 3 | 0 | 0 | 1 | 1 | 3 | 1 | 3 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 1 |
| Spinosad | 6 | 4 | 0 | 0 | 0 | 0 | 1 | 7 | 11 | 0 | 18 | 4 | 4 | 0 | 0 | 2 | 2 | 4 | 1 | 4 | 0 | 1 | 1 | 0 | 7 | 3 | 1 | 2 | 0 | 1 |
| SeNPV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SfMNPV | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SpliNPV | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Steinernema spp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| Sucrose octanoate | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |   | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sulphur | 18 | 6 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 1 | 1 | 0 | 0 | 0 | 2 | 15 | 5 | 1 | 1 | 1 | 0 | 0 | 0 | 35 | 0 | 20 | 2 | 0 |
| Thyme oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| *Trichogramma spp.* | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

# Supplementary Table 5 Summary of the assessments of the biopesticide AI registered in 30 countries for use against FAW, its congeners and other Lepidoptera.

1 Explanation of codes used to summarise the findings of the efficacy assessments.

|  |  |
| --- | --- |
| **Code** | **Explanation of the letters in the code** |
| N | No evidence of efficacy |
| YFa+ | Evidence of efficacy against FAW |
| YSp+ | Evidence of efficacy against other Spodoptera |
| YLe+ | Evidence of efficacy against Lepidoptera |
| La | Data from the lab |
| Nr | Data from the field in FAW's native range |
| Af | Data from the field in Africa |
| As | Data from the field in Asia |

2 Explanation of codes used to summarise the findings of the assessment of agronomic sustainability.

|  |  |
| --- | --- |
| **Code** | **Explanation of the letters in the code** |
| Y | Evidence suggests agronomic sustainability |
| N | Evidence that the AI may not be agronomically sustainable |
| NM | Evidence of that the AI may compromise agronomic sustainability but risks may be addressed through mitigation measures |
| I | History of invasiveness |
| R | History of development of resistance among FAW or other Lepidoptera |
| P | Very toxic or very highly toxic to pollinators |
| A | Very toxic to aquatic organisms |

Colour coding of individual assessment factors:

|  |  |  |
| --- | --- | --- |
| Negative | Neutral | Positive |

Colour coding of recommendations:

|  |  |
| --- | --- |
| Negative | Positive / further work needed |

| Biopesticides registered for use against FAW and its congeners | 1. Effective1 | 2. Risks posed by the CPA to human health and the environment are acceptable (Y/N) | 3. Sustainable2 | 4. Practical (Y/N) | 5. Registered in Africa (Y/N) | 6. Cost effective? (Y/N) | Recommendation and next steps |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 2-phenylethyl propionate | N | Missing data | Y | Y | N | No data | Not recommended for further action |
| Allyl isothiocyanate | YSpLa | Y | NMAP | N | Y | No data | Not recommended for further action |
| AfNPV | N | Y | Y | Y | N | No data | Not recommended for further action |
| *Aspergillus oryzae* | YFaAf | Missing data | No data | No data | Y | No data | This AI has been tested in the field and is registered for use against FAW in Tanzania. Other countries may consider field tests and registration if merited.  |
| AcMNPV | YSpLa | Y | Y | Y | N | No data | Not recommended for further action |
| Azadirachtin (neem products) | YFaAf | Y | NMI | Y | Y | Y | This AI is recommended for use in IPM schemes. For countries where the risk of invasion is low, local production of neem could be undertaken. For countries where neem may become invasive, commercial products could be marketed for management of FAW. |
| *Bacillus thuringiensis* | YFaAf | Y | NMR | Y | Y | N | The literature on use of Bt to control *Spodoptera* spp is variable in its efficacy. As there are Bt products available in 10 African countries it is recommended to carry out field trials to see which products are most effective against FAW. |
| *Bacillus thuringiensis* subsp. *aizawai* | YFaLa, YSpLa | Y | NMR | Y | Y | No data |
| *Bacillus thuringiensis* subsp. *kurstaki* | YFaLa,YSpAf | Y | NMR | Y | Y | No data |
| *Beauveria bassiana* | YFaLa | Y | Y | Y | Y | No data | Potent isolates identified in lab need to be moved forward for field efficacy trials for assessment of FAW control. |
| Borax  | YFaLa | N | Y | Y | Y | No data | No longer categorized as a biopesticide by any of the governments. Not recommended for further action |
| Canola oil (rape seed oil) | YFaLa | Y | Y | Y | Y | No data | Recommended for bioassays and field trials if merited. |
| Capsaicin | YFaLa | Y | Y | Y | N | Y | Capsaicin is the active ingredient in chili peppers, so it is potentially a candidate for local production. Bioassays should be performed and field trials if merited. |
| *Chromobacterium subtsugae* | YSpNr | Y | Y | Y | N | Y | Not registered for use in any of the reviewed countries in Africa. Therefore, no further action is recommendedI. |
| Cinnamaldehyde | N | Y | Y | Y | N | No data | Not recommended for further action. |
| Citric acid | N | Y | NMA | No data | Y | No data | Not recommended for further action. |
| Cryolite | N | Y | NMA | Y | N | No data | No longer categorized as a biopesticide by any of the governments.  |
| D-glucitol, octanoate | N | Y | No data | Y | N | No data | Not registered for use against FAW in any of the reviewed countries. Not recommended for further action. |
| D-limonene | YFaLa | Y | Y | Y | Y | No data | Recommended for bioassays and field trials if merited. |
| *Dysphania ambrosioides* | YFaAf | Y | NMI | Y | N[[1]](#footnote-1) | No data | Because of its invasiveness, *Dysphania ambrosioides* is not recommended for local production. Additional laboratory and field tests would be needed before considering it for registration and inclusion in IPM schemes.  |
| Emamectin benzoate | YSpAf | Y | N | Y | Y | Not assessed | No longer categorized as a biopesticide by any of the governments. |
| Ethyl palmitate | YFaLa | Y | Y | Y | Y | N | Recommended for field trials. |
| Eugenol | YFaAf | Y | Y | Y | Y | No data | Recommended for bioassays and field trials to isolate the effect of eugenol versus that of the other constiuents of the plant extracts and to confirm efficacy against FAW. |
| Garlic extract | YFaAf | Y | Y | Y | N | Y | Recommended for field trials. |
| GS-omega/kappa-hxtx-hv1a | YFaAf | Y | Y | Y | N[[2]](#footnote-2) | No data | Recommended for bioassays and field trials if merited. |
| HzSNPV | YSpNr | Y | Y | N | N | No data | Given that *Helicoverpa zea* single nucleoolyhedrovirus virus has only been shown to be effective against *H. zea* and is not registered for use in any of the reviewed countries in Africa, it is not recommended for further action. |
| *Isaria fumosorosea*  | YSpLa | Y | Y | Y | N | Y | *Isaria fumosorosea* is not registered in any of the 19 countries, so further action is not recommended. |
| Kaolin clay | YSpAf | N | Y | Y | N | No data | Given that kaolin may be carcinogenous, it is not recommended for futher follow-up. |
| Lufenuron | YFaNr | Y | NMA | Y | Y | Not assessed | No longer categorized as a biopesticide by any of the governments.  |
| Maltodextrin | YFaAf | Y | NMP | Y | Y | N | Maltodextrin is recommended by the Government of Ghana for FAW. However, no information was found on specific availability in-country and information on non-target effects is lacking. |
| Matrine | N | Y | No data | No data | Y | No data | Not recommended for further action. |
| *Metarhizium anisopliae* | YFaNr | Y | Y | Y | Y | Y | Twelve countries have *Metarhizium* registered and it has been tested on FAW in the laboratory in Africa. Registration/Label extension trials in the field are underway in Kenya, Uganda and Tanzania and registration is nearing completion in some of these countries . |
| *Metarhizium relyi* | YFaNr/As | Y | Y | Y | N | No data | Not registered for use in any of the reviewed countries in Africa. Therefore, no further action is recommended |
| Methoxyfenozide | YFaNr | Y | Y | Y | Y | Not assessed | No longer categorized as a biopesticide by any of the governments.  |
| Oxymatrine | YLeAf | Y | No data | No data | Y | No data | Bioassays to determine its efficacy against FAW are recommended. These trials could also be used to assess its agronomic sustainability and the practicality of its use. |
| Potassium salts of fatty acids | N | Y | Y | Y | Y | No data | No further follow-up action recommended. |
| Pyrethrins | N | Y | NMAP | Y | Y | No data | No further follow-up action recommended. |
| Sex pheromones | YFaAf | Y | Y | N | Y | N | Develop for monitoring especially at a broader geographic range beyond individual farms rather than control. A pheromone-based mating disruption product is registered in Brazil and registration field trials are on-going in East Africa. |
| Silicon dioxide | YFaLa | Y | Y | Y | Y | Not assessed | No longer categorized as a biopesticide by any of the governments.  |
| S-methoprene | N | Y | NMA | Y | Y | No data | No further follow-up action recommended. |
| Soybean oil | N | Y | Y | N | Y | No data | No further follow-up action recommended. |
| Spinetoram | YFaNr | Y | NMP | Y | Y | Not assessed | No longer categorized as a biopesticide by any of the governments. |
| Spinosad | YFaNr | Y | NMPR | Y | Y | Y | Field trials to assess efficacy should be conducted in countries where registered. |
| SeNPV | YSpNr | Y | Y | Y | N | No data | Not registered in any of the 19 African countries, so no further action is recommended. |
| SfMNPV | YFaNr | Y | Y | Y | N | No data | Field trials underway and registration is nearing completion in some countries in Africa. |
| SpliNPV | YFaAf | Y | Y | Y | Y | No data | Field trial results are available from Ghana, which needs to be further validated through large scale trials leading to registration |
| *Steinernema carpocapsae* | YSpNr | Y | Y | N | Y | N | There are issues regarding efficacy, shelf-life and cost |
| *Steinernema feltiae* | YFaNr | Y | Y | N | Y | N | There are issues regarding efficacy, shelf-life and cost |
| Sucrose octanoate | YLeLa | Y | Y | Y | N | No data | Not registered for use against FAW, Spodoptera or Lepidoptera in any of the reviewed countries. Not recommended for further action. |
| Sulphur | N | Y | Y | Y | Y | No data | No evidence to merit further work. |
| Thyme oil | YLeLa | Y | Y | Y | Y | No data | No evidence to merit further work. |
| *Trichogramma* spp. | YFaAf | Y | Y | N | Y | Y | Field trials, ideally in combination with other measures, recommended |

# Supplementary data. Efficacy, agronomic sustainability, practicality and affordability of the biopesticide active ingredients registered for use against fall armyworm (or related species) in at least one of the 30 study countries (either currently or at the time of the previous assessment).

[2-phenylethyl propionate 28](#_Toc53595346)

[Allyl isothiocyanate (mustard oil) 28](#_Toc53595347)

[Anagrapha falcifera nucleopolyhedrovirus (AfNPV) 29](#_Toc53595348)

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[Autographa californica multiple nucleopolyhedrovirus (AcMNPV) 30](#_Toc53595350)

[Azadirachtin (neem products) 30](#_Toc53595351)

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[Helicoverpa armigera nucleopolyhedrovirus (HaNPV) / Helicoverpa zea single capsid nucleopolyhedrovirus (HzSNPV) 40](#_Toc53595369)

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[Spodoptera littoralis nucleopolyhedrovirus (SpliNPV) 51](#_Toc53595389)

[Steinernema carpocapsae, S. feltiae and other entomopathogenic nematodes 51](#_Toc53595390)

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2-phenylethyl propionate

2-Phenylethyl propionate is a naturally occurring chemical, which contributes to the flavour of foods such as guava (*Pisidium guajava*), cheeses, peanut and brandy (National Center for Biotechnology Information, 2017). It is also a component of peppermint oil (US EPA (United States Environmental Protection Agency), 2020a). Products containing 2-phenylethyl propionate act as attractants and are formulated in traps with other active ingredients to control indoor and outdoor pests (US EPA, 2020b).

1. *Efficacy:* The current and previous reviews of the literature failed to identify any references demonstrating the efficacy of 2-phenylethyl propionate against FAW or any other Lepidoptera in agricultural settings.
2. *Human health and environmental hazards:* According to the available data, the AI does not meet any of the HHP criteria (US EPA, 2010a; 2020a), but data is missing on carcinogenicity and reproductive toxicity. The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN (Pesticide Action Network), 2019). The EPA records show that effects associated with the use of 2-phenylethyl propionate include effects include nausea, vomiting, hives, rashes, and dermal and respiratory irritation (US EPA, 2020a). It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* The US EPA considers that exposure to non-target organisms will be low to nonexistant (US EPA, 2020a). In the previous assessment, it was noted that some products listed Hymenoptera such as wasps, hornets and yellow jackets as targets; this toxicity can be attributed to the co-formulants.
4. *Practicality:* No special requirements for PPE, application equipment, storage or disposal of products containing 2-phenylethyl propionate have been identified.
5. *Availability:* Previously, this AI was only registered for use against FAW in the USA. It is no longer registered for FAW in any of the assessed countries.
6. *Affordability:* A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Not recommended for further action.

Allyl isothiocyanate (mustard oil)

Allyl isothiocyanate is an organosulfur compound found in mustard oil and certain other cruciferous vegetables such as cabbage, kale and horseradish (US EPA, 2013a). It is used as a fungicide, herbicide, nematicide and insecticide against various insects including FAW and other *Spodoptera* spp.

1. *Efficacy:* The previous review identified laboratory evidence of efficacy of allyl isothiocyanate against other *Spodoptera* species. One new laboratory study (Konecka, Kaznowski, & Tomkowiak, 2019) found that mixing *B. thuringiensis* with mustard oil lead to higher than expected mortality of *S. exigua*.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria (ECHA (European Chemicals Agency), 2020j; US EPA, 2013a), so it is not classified as an HHP. Human health hazards associated with the AI include that it is toxic or harmful if swallowed (H301 and H302); toxic in contact with skin (H310 and H311); causes skin irritation (H315); causes serious eye irritation (H319); is fatal if inhaled (H330); and may cause respiratory irritation (H335) (ECHA, 2020j). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). It is not approved for use in organic agriculture in the EU (EC (European Commission), 2020). The AI is very toxic to aquatic organisms with long lasting effects (ECHA, 2020j). When using products containing allyl isothiocyanate, mitigation measures should be applied in order to safeguard human health and the aquatic oragnisms.
3. *Agronomic sustainability:* The previous assessment found that products containing allyl isothiocyanate kill and repel bees, thus it should not be applied prior to or during pollination.
4. *Practicality:* Applications of allyl isothiocyanate requires tractor mounted shank injection, followed by tarp overlay, (2) by drip injection, also covered by tarp overlay, or (3) by deep injection (US EPA, 2013a). These equipment requirements might not be practical for smallholder farmers.
5. *Availability:* This AI is registered in Panama, Tunisia and the USA. It is only registered against FAW in the US.
6. *Affordability:* No data available.

**Recommendation:** Given that allyl isothiocyanate is the active ingredient in mustard oil, the previous study identified it as a potential candidate for local production and it was recommended that bioassays should be performed. Since there is no new direct evidence of allyl isothiocyanate’s efficacy against FAW and the equipment requirements may not be practical for smallholder farmers, it is not recommended for further action.

*Anagrapha falcifera* nucleopolyhedrovirus (AfNPV)

This nucleopolyhedrovirus was originally isolated from the celery looper, *Anagrapha falcifera* [*Syngrapha falcifera*].

1. *Efficacy:* This nucleopolyhedrovirus (NPV) has a relatively broad host range for a baculovirus (Grewal, Webb, Beek, Dimock, & Georgis, 1998), and laboratory trials suggest that AfNPV is effective against neonate *S. frugiperda* (Pingel & Lewis, 1999). Evidence from the field is lacking.
2. *Human health and environmental hazards:* It is not an HHP or a cholinesterase inhibitor, and the risks to human health and the environment are low (University of Hertfordshire, 2018a). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). It is not approved for use in organic agriculture in the EU (EC, 2020). It can cause moderate eye irritation and is harmful if inhaled (CERTIS, 2004).
3. *Agronomic sustainability:* No negative impacts on fish, wildlife or other beneficial organisms has been observed or are anticipated (CERTIS, 2004)
4. *Practicality:* The product label examined for nucleopolyhedrovirus of *Anagrapha falcifera* recommends treating early instar larvae that are actively feeding, before extensive damage has occurred. Thorough spray coverage is essential for good insect control. Application rate: 100-200 ml/acre (3.4-6.8 fl ozs) using non-chlorinated water at a pH near 7.0 in the spray tank mix. Store below 32 oC (90 oF). Nucleopolyhedrovirus of *Anagrapha falcifera* can be frozen or stored in a fridge for extended shelf-life.
5. *Availability:* Of the 30 countries assessed, this AI is only registered in the USA. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** This AI is not recommended for further action.

*Aspergillus* *oryzae*

*Aspergillus oryzae* is an asexual, ascomycetous fungus which has been widely used for several centuries in the fermentation of food products for production of soy sauce, miso and other fermentation products (US EPA, 1997). Isolates of *A. oryzae* currently commercialized in Tanzania under the trade name “Vuruga” has been isolated from infected *Tuta absoluta* caterpillars.

1. *Efficacy:* Efficacy of atoxicogenic *A. oryzae* against corn earworm and fall armyworm has been tested in the lab as early as 1989. However toxicity of atoxicogenic strains of *A. oryzae* were less toxic than the wild-type *A. flavus* (Wicklow & Dowd, 1989). Recently two *Aspergillus* fungus isolates infective to larva and adults of *Tuta absoluta* were identified in Tanzania (Zekeya et al., 2019). The isolates were 100% similar to strains of *Aspergillus oryzae* from China and Korea. At 1 x 108 conidia/ml, these isolates inflicted up to 70% mortality of *Tuta absoluta*. Zekeya et al. (Zekeya, Mbega, & Ndossi, 2020) also reported the efficacy of *Aspergillus oryzae* (TZ/P/2018/000035). Detailed information on the efficacy of *A. oryzae* isolated in Tanzania against fall armyworm is not widely available. However field efficacy trials on the efficacy of *A. oryzae* against FAW are reported to be conducted in eight regions of Tanzania and a commercial product based on the pathogen, “Vuruga” has been registered for control of fall armyworm (FAO (Food and Agriculture Organization of the United Nations), 2020a).
2. *Human health and environmental hazards:* Data on human health hazards for the isolate that has been commercialized in Tanzania is not available in the public domain. However environmental and human health hazard assessments on other *A. oryzae* isolates commercially used in food industry reveals that when incubated less than 3 days, these fungus do not produce toxins. However when incubated longer than 3 days, the fungus produces various toxins, Kojic acid (toxic to chicken at 4 – 8 mg/kg feed), Cyclopiazonic acid and b-nitropropionic acid (EPA, 1997), with varied levels of toxicity to poultry, livestock and humans. Hence more detailed assessment of the human and environmental health hazards of the commercial *A. oryzae* isolate need to be undertaken
3. *Agronomic sustainability:* Data on agronomic sustainability not available.
4. *Practicality:*  More details on the practicality of the commercial product for FAW management is needed.
5. *Availability:* Of the 30 countries assessed, this AI is only registered in Tanzania.
6. *Affordability:* More details on the cost of the commercial product at the farm level is needed.

**Recommendation:** This AI has been tested in the field and is registered for use against FAW in Tanzania. More details on the human health hazards, environmental safety and field efficacy need to be made available. This could lead to other countries considering field tests and registration if merited.

*Autographa californica* multiple nucleopolyhedrovirus (AcMNPV)

Originally isolated from infected caterpillars of *Autographa biloba* (now named *Megalographa biloba* (bilobed looper)), the host range of this baculovirus includes more than 30 species from ten different families of Lepidoptera (US EPA, 2020c). Products containing AcMNPV are registered for various Lepidoptera, including FAW. The biology of AcMNPV is well-studied (Salem, Zhang, Xie, & Thiem, 2011) but it has only recently become available as a commercial product (registered in 2019 in Brazil and in 2020 in the US).

1. *Efficacy:* Three products containing AcMNPV (Lepigen, Surtivo Plus and Surtivo Ultra) are registered in the Brazil and the US for various Lepidoptera, including FAW (US EPA, 2020b). While AcMNPV is widely used in molecular studies and it infects FAW cell lines, we found no evidence of efficacy against FAW from the field.
2. *Human health and environmental hazards:* It is not an HHP and the risks to human health and the environment are expected to be low (US EPA, 2019a). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). It is not approved for use in organic agriculture in the EU (EC, 2020).
3. *Agronomic sustainability:* In its registration decision, the US EPA stated that adverse effects to birds, mammals, honey bees, non-lepidopteran insects, plants, and aquatic animals are not expected and adverse effects to other lepidopteran insects are expected to be minimal (US EPA, 2020c). To mitigate risks to non-target Lepidoptera, it is recommended not to apply products containing AcMNPV while nontarget Lepidoptera are actively visiting treatment areas and to minimize drift.
4. *Practicality:* The product labels examined for AcMNPV recommend treating early instar larvae that are actively feeding, before extensive damage has occurred (US EPA, 2019b, 2019d, 2019e). Products should not be stored at temperatures above 40oC (104 oF). AcMNPV can be frozen or stored in a fridge for extended shelf-life.
5. *Availability:* Of the 30 countries assessed, this AI is only registered in Brazil and the USA. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** Given that evidence of efficacy of *Autographa californica multiple nuclear polyhedrosis virus* against FAW is limited and this AI is not registered for use in any of the reviewed countries in Africa, any further action is not recommended .

Azadirachtin (neem products)

Azadirachtin, derived from the tree *Azadirachta indica*, is one of the most widely used botanical biopesticides. It is used by both commercial farmers and small scale farmers, and produced both commercially and by the farmers themselves. Azadirachtin acts as a repellent, a feeding and ovipositional deterrent, an ovacide and a mating disruptor.

1. *Efficacy:* The previous review found evidence from the lab and the field in the Americas for the efficacy of azadirachtin against FAW. More recently, field trials in Africa have found neem-based products to be efficient at controlling FAW and to have favourable cost benefit ratios, and the authors concluded that neem-based products can be recommended as part of IPM schemes for the management of FAW (D. Babendreier et al., 2020; Sisay, Tefera, Wakgari, Ayalew, & Mendesil, 2019). Likewise, in a recent comparison of several species of pesticidal plants, azadirachtin extracts had the second highest level of feeding deterrence (Phambala et al., 2020). A study in India which took place shortly after FAW was first detected in that country showed that neem-based products reduced levels of infestation by FAW (Naik, Sekhar, Naidu, & Reddy, 2020). Other studies have demonstrated that *Bacillus thuringiensis* works more efficiently against various Lepidopteran species (including some *Spodoptera* species)when it is mixed with azadirachtin (Konecka et al., 2019). In contrast, one laboratory study found that azadirachtin was not very effective (Chen et al., 2019).
2. *Human health and environmental hazards:* Azadirachtin does not meet any of the HHP criteria (ECHA, 2020c), so it is not considered to be an HHP. The only human health hazard statement associated with azadirachtin is that it may cause an allergic skin reaction (H317). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. Azadirachtin is approved for use in organic agriculture in the EU. It is very toxic to aquatic life and with long lasting effects (H400 and H410).
3. *Agronomic sustainability:* Although azadirachtin is toxic to aquatic organisms, it is considered to pose “negligible to non-existant” ecological risk (US EPA, 2008a). *A. indica,* the tree from which neem-based products are derived has been extensively introduced throughout tropical and subtropical regions, and it has become invasive in some of countries in Africa and the Caribbean. It has become a widespread weed in native forests in countries such as Ethiopia, Ghana and Kenya (CABI (CAB International), 2017). Thus, the potential for invasiveness should assessed when considering local production of neem extracts.
4. *Practicality:* Overall, products containing azadirachtin seem practical to use and they do not require specialized equipment or storage conditions.
5. *Availability:* Neem-based products have a long history of use in its native range of India, and it was first registered as a biochemical biopesticide in 1985 in the USA (US EPA, 2008a). Azadirachtin is registered in half of the assessed countries, and in many countries it is registered for FAW, *Spodoptera* or Lepidoptera in general. Azadirachtin is registered in eight of the 19 countries assessed in Africa: Ethiopia, Kenya, Malawi, Rwanda, South Africa, Tanzania, Tunisia and Uganda, and in Malawi, Rwanda and Tanzania several products are broadly registered for the control of Lepidoptera or insects in general.
6. *Affordability:* The abovementioned field study (D. Babendreier et al., 2020) found a favourable cost benefit ratio in Ghana. Numerous other studies have found favourable cost benefit rations for the use of azadirachtin in managing pests in other crops.

**Recommendation:** Recent field trials in Africa and Asia suggest that neem-based products can be effective tools for managing FAW, particularly when used in conjunction with other IPM practices. For countries where the risk of invasion by neem trees is low, local production of neem could be undertaken, based on either pods or leaves. For countries where neem may become invasive, commercial products could be marketed for management of FAW. The FAO lists neem extracts as an example of local solution which farmers can apply (FAO, 2018a).

*Bacillus thuringiensis*

*Bacillus thuringiensis* (*Bt*) is one of the most commonly registered biopesticides for use around the world (Holmes et al., 2018). *Bt* is a bacterium naturally found in soils worldwide and infects many insect pests, including caterpillars. The proteins produced by the bacteria are toxic to insects and and their action is very specific; each type of *Bt* strain targets a specific group of insects. *B. thuringiensis subsp. aizawai* and *B. thuringiensis subsp. kurstaki* infect lepidopteran larvae such as *Helicoverpa armigera*, *Helicoverpa zea*, *Spodoptera exigua*, *Spodoptera littoralis* and *Heliothis virescens*. For this reason the type of *Bt* to be used must be selected carefully to match and control the target insect pest. To be effective, the bacteria must be eaten by caterpillars and reach the gut of the insect before it will take effect.

1. *Efficacy:* This will depend on the subspecies and strain. *Bt aizawai* HD 68 and *Bt thuringiensis* 4412 showed 100% and 80% control, respectively against *Spodoptera frugiperda* (Polanczyk, Silva, & Fiuza, 2004). *Bacillus thuringiensis* subsp. *kurstaki* (product name DiPel strain ABTS – 351) is effective against *Spodoptera* spp., however other strains are better (Hernandez, 1988), including *Bacillus thuringiensis* var. *aizawai* (Jakka, Knight, & Jurat-Fuentes, 2014; Martínez et al., 2004). The XenTari product (*Bacillus thuringiensis* var. *aizawai*) is effective against strains of fall armyworm that are either susceptible or resistant to Bt maize varieties (Horikoshi et al., 2019) and in fall armyworm strains that were resistant to Bt maize varieties *B. thuringiensis subsp. aizawai* (products XenTari and Agree) performed better than *B. thuringiensis subsp. kurstaki* (products Dipel and Thuricide) (Souza et al., 2019).
2. *Human health and environmental hazards: B. thuringiensis* is not an HHP or a cholinesterase inhibitor (University of Hertfordshire, 2019a, 2019b). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). Because of the microbial nature of *Bt*, the US EPA requires labels of *Bt* products to call for workers mixing, loading and applying the pesticide to agricultural sites to wear appropriate respirators with NIOSH approval prefix N-95, P-95 or R-95 .
3. *Agronomic sustainability:* Due to toxicity to some aquatic invertebrates it should not be applied directly to water or to areas where surface water is present. Water must not be contaminated when disposing of water used to clean equipment.There are records of resistance to some *Spodoptera* species(Mota-Sanchez & Wise, 2020)*.*
4. *Practicality:* Existing spray equipment can be used with *Bt* products. Shelf life is extended by storing in a fridge or freezer.
5. *Availability: Bt* products are registered in 12 African coutries, and some of the products are registered specifically for the management of FAW.
6. *Affordability:* At least one study found that *Bt* was less cost effective than other tested AI (Jin et al., 2019). Some other studies have found favourable cost benefit ratios for the use of *Bt* against other pests in other crops.

**Recommendation:** The literature on the use of *Bt* to control *Spodoptera* spp is variable in its efficacy.As there are*Bt* products available in 10 African countries it would be worth carrying out lab/field trials to see which products are most effective against FAW.

*Beauveria bassiana*

*Beauveria bassiana* is an entomopathogenic fungus with a broad host range, and it is one of the biopesticides most commonly registered and used worldwide to control arthropod species (Holmes et al., 2018). It occurs naturally in the soil throughout the world and can be applied to the soil or as a foliar application. When an insect host comes into contact with *B. bassiana* spores, the spores stick to the insect’s skin (cuticle), allowing the fungus to infect and kill the insect.

1. *Efficacy: Beauveria bassiana* was shown to be effective against *Plutella xylostella* (diamondback moth) when applied to cabbages in Kenya (Waiganjo et al., 2011). Wraight, Ramos, Avery, Jaronski, & Vandenberg (2010) concluded that FAW was susceptible to *B. bassiana,* however, for effective control greater than 100 conidia/mm was required for all but one isolate. Lezama Gutierrez et al. (1996) also concluded that *Beauveria bassiana* had potential to control FAW. Ramos et al (2020) have recently shown that *B. bassiana* (commercial strain Bb-18) can establish as an endophyte of maize in the roots, shoots and leaves when used as a soil drench in Cuba, and in laboratory bioassays caused 100% and 87% mortality to 2nd and 4th instar fall armyworm, respectively. Ramanujam et al (2020) found that field trials using an indigenous strain of *B. bassiana* (ICAR-NBAIR Bb-45) was effective against fall armyworm in India. Akutse et al. (2019) found low infectivity of eggs and neonate *B. bassiana* strains as compared to *M. anisopliae.*  However, isolates of *B. bassiana* were highly infective to FAW adults and caused up to 100% mortality. They were also compatible with FAW pheromones highlighting the potential for development of “lure and infect” strategies (Akutse, Khamis, et al., 2020; Akutse, Subramanian, Maniania, Dubois, & Ekesi, 2020). Ramirez-Rodriguez & Sánchez-Peña (2016) reported the efficacy of endophytically colonized *B. bassiana* against 3rd instar FAW which resulted in up to 75% cummulative mortality. Similarly Ramos et al. (2020) reported up to 100% mortality of second instar FAW when bioassayed against endophytically colonized *B. bassiana* and *M. anisopliae*.
2. *Human health and environmental hazards: Beauveria bassiana* is not an HHP or a cholinesterase inhibitor (University of Hertfordshire, 2019d). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). Zimmermann (2007a) gave a very comprehensive review of safety of *Beauveria bassiana* and *B. brongniartii* which presented the following data: 1. identity of *Beauveria* spp.; 2. biological properties of *Beauveria* spp.; 3. analytical methods to determine and quantify residues; 4. fate and behaviour in the environment; 5. effects on non-target organisms; 6. effects on verebrates; and 7. effects on mammals and human health. He concluded that, based on current knowledge, both *Beauveria* species were considered to be safe. BontaniGard 22WP is listed as generally safe. While the US EPA has not found *B. bassiana* to be pathogenic or infective and no incidents of hypersensitivity have been observed (US EPA, 2000), all labels of products containing it call for the use of dust masks (NIOSH/MSHA approved respirator), overalls and gloves. Although *B. bassiana* is not considered to be an aquatic microorganism (US EPA, 2000), products containing oil are classified under Section 311 of the US Clean Water Act and/or under the Oil Pollution Act. Micro-organisms may have the potential to provoke sensitising reactions.
3. *Agronomic sustainability:* Products containing *B. bassiana*have the potential to be pathogenic to honey bees (US EPA, 2000). It should not be applied to areas where honey bees are actively foraging or around bee hives. This product may also be toxic to fish, so application to ponds, rivers or fish-populated areas should be avoided.
4. *Practicality:* No extraordinary equipment, storage or disposal requirements were listed on labels.
5. *Availability:* There are 11 products of *B. bassiana* registered in 6 African countries and a further 60 products registered in 7 countries in the Americas. Most of these products are allowed for use for management of FAW. *Beauveria bassiana* has also been registered for FAW management in China (AgroNews, 2020). This AI is registered in the EU, and there it is also allowed for use in organic agriculture.
6. *Affordability:* Cost effectiveness has been examined for some other pests. Kivett, Cloyd, & Bello (2015) found that cost savings of up to 34% (in US dollars) were possible when including *B. bassiana* and other entomopathogenic organisms in an insecticide rotation program for *Frankliniella occidentalis* in a greenhouse production system*.* We found no reference to information on cost effectiveness against FAW in Africa.

**Recommendation:** Field trials should be conducted with the commercial strains available in Africa, while effort to commercialize some of the potent strain in Africa should be strengthened.

Borax

Borax, also known as boric acid or sodium tetraborohydrate decahydrate, is a naturally-occurring mineral produced by the repeated evaporation of seasonal lakes which works by desiccating the soft body stage of arthropods. At the time of the previous assessment, one of the governments classified borax as a biopesticide; at present none of the governements classifiy borax as a biopesticide.

1. *Efficacy:* The review of the literature for both the previous study and the current assessment failed to identify any references that demonstrated the efficacy of borax against FAW or any other Lepidoptera in agricultural settings. The previous assessment found that certain microbial products, e.g. *Bacillus thuringiensis* and nuclear polyhedrosis virus, are more effective in formulation with boric acid.
2. *Human health and environmental hazards:* Borax is a GHS Category 1B reproductive toxin (EC, 2018), thus it is considered to be an HHP. In addition to its potential to affect fertility or cause harm to the unborn child, it also causes serious eye irritation. Borax is on PAN’s list of HHPs (PAN, 2019). Borax is not listed in the Rotterdam database of notifications; and it is not a candidate POP. It is not approved for use in the EU.
3. *Agronomic sustainability:* Not assessed.
4. *Practicality:* Not assessed.
5. *Availability:* Not assessed.
6. *Affordability:* Not assessed.

**Recommendation:** Given that borax is an HHP and it is no longer categorized as a biopesticide by any of the governments, no further action is recommended.

Canola oil (rape seed oil)

Canola oil is an edible vegetable oil extracted from rape plants of the family Brassicaceae (mustard family) that can be used to control insects on a wide variety of crops (US EPA, 2009b). Canola oil repels insects by altering the outer layer of the leaf surface or by acting as an insect irritant.

1. *Efficacy:* One product reviewed, which contained only canola oil as an active ingredient, was registered for use against fall armyworm. Several products containing canola oil and other botanicals such as capsicum, garlic and pyrethrins are registered for use against *Spodoptera spp.* in the USA. While products containing canola oil are permitted for use in a wide range of crops and are purported to target many different types of insects, documented studies on its efficacy in the literature is limited. The current review identified some laboratory studies which demonstrated that canola oil had an impact of *Spodoptera* species when applied in conjunction with other AI: FAW was found to be susceptible (mortality > 80% at 96 h) to a mixture of *Steinernema carpocapsae* (Weiser) and canola oil (Viteri, Linares, Cabrera, & Sarmiento, 2019) and a mixture of canola oil, neem extract and castor oil exhibited strong anti-feedant properties against *S. exigua* (Kim et al., 2015). We did not identify any research which demonstrated efficacy of canola oil against FAW when used on its own.
2. *Human health and environmental hazards:* There is no evidence that this AI is an HHP – canola is commonly used in foods and is “generally recognized as safe” by the US Food and Drug Administration (US EPA, 2010e). The US EPA states that no harmful health effects to humans or the environment are expected from the use of canola oil to repel insects because of its low toxicity and its rapid decomposition (US EPA, 2009b). The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Canola oil degrades rapidly in the environment. The US EPA has concluded that end-use products containing canola oil are of minimal risk and there are no concerns of adverse effects to non-target organisms (US EPA (United States Environmental Protection Agency), 2010d).
4. *Practicality:* Canola oil based products are applied either as a spray or through irrigation systems. For best results, pests must be contacted directly with spray. The products can be applied at any time up to the day of harvest. No extraordinary equipment, storage or disposal requirements were listed on the label. Products containing canola oil are marketed both for commercial production and for use in home gardens, suggesting that the products would be practical to use for smallholder farmers.
5. *Availability:* Of the 30 countries assessed, this AI is only registered in Ethiopia and the USA. In Ethiopia, it is not registered for use against FAW.
6. *Affordability:* A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Products containing canola oil are said to be repellents, which may not be the most effective approach for managing FAW in the field. Most evidence of efficacy against FAW or other Spodoptera examined the use of canola in a mixture with other other AI. Further bioassays to separate out the efficacy of canola oil on its own and in combination with other AI is recommended, and field trials should be conducted if merited.

Capsaicin

Capsaicin is the active ingredient in chilli peppers. It has repellent and insecticidal properties (Dougoud, Toepfer, Bateman, & Jenner, 2019).

1. *Efficacy:* While chilli pepper extracts have been used to control a wide range of insect pests with some level of success in field trials (Dougoud et al., 2019), no studies were found to document the effects of capsaicin on FAW larvae in the field in Africa or elsewhere in the previous study or through the current review. The previous study identified evidence of efficacy against FAW from the laboratory but there were no recent laboratory studies demonstrating the efficacy of capsaicin against FAW. While some of the products reviewed are registered against FAW, these products are generally a mixture of AI, e.g. capsaicin and other botanical extracts such as mustard oil or garlic oil.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria, so it is not considered to be an HHP. Human health hazards associated with the AI include the following: that it istoxic if swallowed (H301); harmful if swallowed (H302); causes skin irritation (H315); and causes serious eye damage (H318) (ECHA, 2020e). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Because it rapidly degrades and has a low toxicity, capsaicin is unlikely to cause unreasonable effects to the non-target organisms or the environment (US EPA, 2010b).
4. *Practicality:* No extraordinary equipment, PPE, storage or disposal requirements were listed on the labels reviewed. Overall, products containing capsaicin seem practical to use.
5. *Availability:* This AI is registered in 6 countries in the Americas but it is not registered in any of the 19 countries assessed in Africa. A product containing chilli extract is specifically registered for FAW in Colombia. Extracts of *Capsicum spp.* are prepared by farmers and used as an insect control in many countries (FAO, 2018a).
6. *Affordability:* No data available for FAW but a profitable benefit/cost ratio was observed when ground chili pepper was used to control stem borers in sorghum (Dougoud et al., 2019).

**Recommendation:** Capsaicin is the active ingredient in chili peppers, so it is potentially a candidate for local production. Further bioassays to separate out the efficacy of capsaicin on its own and in combination with other AI is recommended, and field trials should be conducted if merited.

*Chromobacterium subtsugae*

*Chromobacterium subtsugae* is a soil-dwelling bacteria which is toxic to many pests (Gelman, Martin, Blackburn, Rojas, & Hu, 2014).

1. *Efficacy:* The previous assessment found that *Chromobacterium subtsugae* is effective against armyworms and several other Lepidoptera species (Bateman et al., 2018). Efficacy assessment of commercial products based on *C. subtsugae* along with other insecticides against fifth instar FAW in Puerto Rico revealed very low mortalities of 5.1 to 7.1% in the field (Viteri et al., 2019).
2. *Human health and environmental hazards: C. subtsugae* has been found to be non-toxic and non-infective (US EPA, 2011b). Because of the lack of acute toxicity/pathogenicity, data has not been collected to assess reproductive fertility effects, carcinogenicity and immunotoxicity. No human health effects are anticipated to be associated with the use of products containing *C. subtsugae* (US EPA, 2012).
3. *Agronomic sustainability:* The US EPA indicates that *C. subtsugae* is toxic to terrestrial arthropods, aquatic invertebrates, and honey bees, and it states that mitigation measures such as restricting use sites and the use of buffer zones for aerial applications should be taken in order to reduce risks (US EPA, 2012). Likewise, products containing *C. subtsugae* should not be applied directly to water or areas where surface water is present.
4. *Practicality:* Use at application rate of 1-3 lbs/acre. Grandevo is best used early when adult populations of pests move into the field.
5. *Availability:* This AI is not registered in any of the 19 countries assessed in Africa. Of the 30 countries assessed, this AI is only registered in Mexico and the USA.
6. *Affordability:* $170 for 5 lbs. Kivett, Cloyd, & Bello (2015) found that cost savings of up to 34% (in US dollars) were possible when including *C. subtsugae* and other entomopathogenic organisms in an insecticide rotation program for *Frankliniella occidentalis* in a greenhouse production system*.* We found no reference to information on cost effectiveness against FAW in Africa.

**Recommendation:** *Chromobacterium subtsugae*is not registered for use in any of the reviewed countries in Africa. Therefore, no further action is recommended with respect to this AI.

Cinnamaldehyde

Cinnamaldehyde is the primary constituent of the essential oils of cinnamon and cassia (Mahdavi et al., 2017; US EPA, 2010c), and it has repellent and insecticidal properties (Oliveira et al., 2019).

1. *Efficacy:* Recent studies have examined the potential of nanofibers and microencapsulated films containing cinnamon oil for the management of several field and storage pests (Mahdavi et al., 2017; Oliveira et al., 2019; Song, Choi, Lee, Han, & Min, 2018). While their findings are promising, the current literature review failed to identify any references demonstrating the efficacy of cinnamaldehyde against FAW in agricultural settings.
2. *Human health and environmental hazards:* Because of its uses in food, considerable safety data exist for cinnamaldehyde. At levels ranging from 9 ppm to 4900 ppm, it is Generally Recognized As Safe (GRAS) by the Flavoring Extract Manufacturers' Association and is approved for food use (21 CFR 182.60) by the Food and Drug Administration (FDA) (US EPA, 2010c). The AI does not meet any of the HHP criteria (ECHA, 2020g), so it is not considered to be an HHP. Human health hazards associated with the AI include that it is harmful if swallowed (H302); harmful in contact with the skin (H312); causes skin irritation (H315); may cause an allergic skin reaction (H317); causes serious eye irritation (H319); and may cause respiratory irritation (H335). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Cinnamaldehyde is not soluble in water and degrades rapidly in the soil. It is not expected to pose any hazard to non-target organisms or to the environment (US EPA, 2010c), and it has low toxicity to bees (University of Hertfordshire, 2020a).
4. *Practicality:* No extraordinary equipment, PPE, storage or disposal requirements were listed on the labels reviewed.
5. *Availability:* Cinnamaldehyde is registered in Mexico, Panama, Peru and the USA, and the US it is registered for use against armyworm. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Cinnamaldehyde is the primary constituent of the essential oils of cinnamon and cassia so it is potentially a candidate for local production. While two products on the market in the USA are labelled for use against armyworm, there is little evidence in the literature for efficacy against FAW. Not recommended for further action.

Citric acid

Citric acid is found in citrus fruits. As noted in the previous assessment, different sources list different targets for citric acid, e.g. acidity regulator in some pesticide formulations, insecticide, disinfectant, sanitiser and fungicide.

1. *Efficacy:* In both the current and previous assessments, review of the literature failed to identify any references which demonstrated efficacy of citric acid against FAW or any other Lepidoptera in agricultural settings. Two recent studies have found that, when used as an additive to sprays of Bt-based products, citric acid either had no effect (for caterpillars of *Spoladea recurvalis* (Opisa, Akutse, Plessis, Fiaboe, & Ekesi, 2020)) or it reduced efficacy (for *S. littoralis* (Amer, Nouh, Yacoub, & Elhosary, 2014)).
2. *Human health and environmental hazards:* This AI does not meet any of the HHP criteria. According to the notifications provided by companies to ECHA, citric acid is harmful if swallowed (H302); causes skin irritation (H315); serious eye damage (H318); serious eye irritation (H319), and may cause respiratory irritation (H335) (ECHA, 2020h). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* The EPA risk assessment found that there are not likely to be any unreasonable adverse effects to non-target organisms or the environment (US EPA, 2008b).
4. *Practicality:* No data available.
5. *Availability:* Citric acid is registered in Mexico, Panama and Tunisia, but it is not registered for use against FAW or any other Lepidoptera in any of these countries.
6. *Affordability:* No data available.

**Recommendation:** Further follow-up action for this AI is not recommended.

Cryolite

Cryolite is the naturally occurring form of sodium aluminum fluoride which was covered by the previous assessment because at least one of the governments categorized it as a biopesticide. At present none of the governements classifiy cryolite as a biopesticide so the information on cryolite was not updated as part of the current review.

D-glucitol, octanoate

D-glucitol, octanoate can be produced from corn syrup, cane or beet sugar (NCBI, 2020). It is a biochemical insecticide and miticide which registration information indicates can be used against soft-bodied insects such as adelgids, aphids, caterpillars, mealy bugs, thrips and whiteflies. It is primarily a contact insecticide with limited residual activity.

1. *Efficacy:* Review of the literature in the previous and current assessment failed to identify references which demonstrated efficacy of D-glucitol propionate against FAW or any other Lepidoptera in agricultural settings.
2. *Human health and environmental hazards:* This AI does not meet any of the HHP criteria. According to the majority of notifications provided by companies to ECHA notifications no hazards have been classified (ECHA, 2019), and it is considered to be of low concern based on experimental and modeled data (NCBI, 2020). The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. Agronomic sustainability: No data available.
4. *Practicality:* No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Previously, this AI was only registered for use against FAW in the USA. There are no longer any products containing this AI which are registered for FAW in any of the countries assessed.
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Given that this AI is no longer registered for FAW in any of the countries and there is only limited information available on the AI, further follow-up action for this AI is not recommended.

D-limonene (Orange oil)

Commercial products containing orange oil are made of extracts of orange peel and orange seeds, and one of the primary constituents is d-limonene. Products containing orange oil are marketed as repellents, insecticidal sprays and fungicides. Orange oil products are typically labelled for sucking insects and certain plant pathogens.

1. *Efficacy:* The previous review found evidence of efficacy against FAW in the lab. The present review found no new evidence in the literature regarding the efficacy of orange oil against FAW.
2. *Human health and environmental hazards:* Orange oil does not meet any of the HHP criteria (ECHA, 2020i), so it is not an HHP. Human health hazards include that orange oil may be fatal if swallowed and enters airways (H304); causes skin irritation (H315); may cause an allergic skin reaction (H317); and causes serious eye irritation (H319). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. Orange oil is approved for use in organic agriculture in the EU. Orange oil is very toxic to aquatic organisms with long lasting effects (H410).
3. *Agronomic sustainability:* Orange oil has low toxicity to bees. The US EPA’s ecological risk assessment found that effects to mammals, birds, plants and aquatic animals are not expected but effects to terrestrial invertebrates are of concern (US EPA, 2014c).
4. *Practicality:* No extraordinary requirements for PPE, application equipment, storage or disposal were listed on the reviewed label.
5. *Availability:* Products containing orange oil are registered in Argentina, Mexico, Kenya and Malawi. None of the products were registered for FAW or other Lepidoptera.
6. *Affordability:* No data available.

**Recommendation:** There is some laboratory evidence for efficacy against FAW and no obstacles to the use of orange oil extracts were identified. Given that orange oil extracts are commercially available in Kenya and Malawi and potentially candidates for local production, efficacy tests in the laboratory and field are recommended.

*Dysphania ambrosioides* (Mexican tea)

Extracts of *D. ambrosioides* have been commercialised as a biopesticide, as monoterpenoids contained in the essential oil of *D. ambrosioides* possess insecticidal properties (Dougoud et al., 2019). Extracts of *D. ambrosioides* work through a physical mode of action, softening the cuticles of treated insects which then disrupts insect respiration.

1. *Efficacy:* The previous study’s findings on the efficacy of *D. ambrosioides* were mixed: some studies found that *D. ambrosioides* had an impact on FAW whereas others found that it did not cause mortality nor did it deter feeding (Bateman et al., 2018). More recent studies have found that extracts of *D. ambrosioides* to cause mortality to FAW in bioassays in Ethiopia (Sisay et al., 2019) and to have a strong anti-feeding effect against *S. exigua* when mixed with matrine and *Melia azedarach* extract (Kim et al., 2015). Extracts of this plant are used by farmers in the field on maize and other crops in South Africa, and the farmers who use it report it to be highly effective (Skenjana & Poswal, 2017). Based on the findings of bioassays on oviposition preference, attraction and repulsion, feeding, *D. ambrosioides* has been proposed for intercropping as repellent plants in a push–pull system (Guera, Castrejon, Robledo, Jiménez-Perez, & Sánchez-Rivera, 2020).
2. *Human health and environmental hazards:* Extract of *Dysphania ambrosioides* does not meet any of the HHP criteria, so it is not considered to be an HHP.According to the classification provided by companies to ECHA (ECHA, 2020f), this substance is toxic if swallowed (H301), may be fatal if swallowed and enters airways (H304), is toxic in contact with skin (H311), causes skin irritation (H315) and may cause an allergic skin reaction (H317). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU. The AI is very toxic to aquatic organisms with long lasting effects.
3. *Agronomic sustainability:* Extracts of *Dysphania ambrosioides* are not very persistent in the environment, typically degrading within 10 minutes of application to plants. The EPA risk assessment found that it was practically non-toxic to non-target organisms (US EPA, 2009a). *D. ambrosioides* is listed as an invasive species in many countries in Africa (CABI, 2019).
4. *Practicality:* The required elements of PPE are as follows: long-sleeved shirt and long trousers; chemical-resistant gloves made of any waterproof material such as polyethylene or polyvinyl chloride; shoes plus socks; protective eyewear; coveralls for high-pressure handwand and groundboom applicators. Additionally, for overhead exposure applicators should wear chemical resistant headgear, and when applied in a closed setting such as a greenhouse, applicators and other handlers must wear a NIOSH-approved respirator with an organic vapor (OV) cartridge or canister with any R, P or HE filter. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Of the 30 countries assessed, this AI is only registered in Mexico and the USA. No products containing it are registered in any of the 19 countries assessed in Africa, though extracts of the plant are used by farmers in South Africa (Skenjana & Poswal, 2017).
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Products containing extracts of *Dysphania ambrosioides* are labelled for use against Lepidoptera in the USA and recent laboratory studies suggest that it has an impact on FAW. Farmers in South Africa report using it in the field. Field studies still need to be conducted prior to pursuing registration. Given the history of invasiveness of *Dysphania ambrosioides*, local production of extracts of this plant is not recommended.

Emamectin benzoate

Emamectin benzoate is an insecticidal compound (including salts of benzoic acid) produced by fermentation of the soil actinomycete *Streptomyces avermitilis xx*. Emamectin benzoate was covered by the previous assessment because at least one of the governments categorized it as a biopesticide. At present none of the governements classify emamectin benzoate as a biopesticide so the information on this AI was not updated as part of the current review.

Ethyl palmitate

Ethyl palmitate is the ethyl ester of palmitic acid, an oil found in fruits of many species. A product containing ethyl palmitate is registered for the control of mites, caterpillars, mealybugs and bacterial blight in vegetables, cashew, mango and citrus in Ghana.

1. *Efficacy:* A laboratory study in Ghana found that ethyl palmitate caused pupal deformities in FAW (Fiaboe, Fening, & Gbewonyo, 2020).
2. *Human health and environmental hazards:* Ethyl palmitate does not meet any of the HHP criteria, so it is not an HHP. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU. It may cause long lasting harmful effects to aquatic life (ECHA, 2020k).
3. *Agronomic sustainability:* There is no data available regarding toxicity to bees.
4. *Practicality*: PPE requirements include appropriate personal protection (compatible chemical-resistant gloves, safety glasses, overalls, rubber boots) plus NIOSH approved respirator. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. Availability: It is only registered for use against caterpillars in Ghana, and 15% of surveyed farmers reported using it (Tambo et al., 2020).
6. Affordability: No studies were found on the cost effectiveness of ethyl palmitate, but findings from Ghana indicate that it tends to be more expensive than the synthetic pesticides which are used by farmers to manage FAW (Rwomushana et al., 2018). That said, the majority of farmers who reported using ethyl palmitate in Ghana received it for free.

**Recommendation:** In Ghana, ethyl palmitate is registered for use against Lepidoptera, it is provided for free to farmers for use against FAW and bioassays suggest that it may have an effect on FAW. Additional bioassays and field trials are needed to better understand its efficacy and cost effectiveness in order to refine how to include it in IPM schemes for FAW management.

Eugenol

Eugenol is an essential oil of several species of plants including *Piper* species (Jaramillo-Colorado, Pino-Benitez, & González-Coloma, 2019) and *Ocimum gratissimum* (Rioba & Stevenson, 2020).

1. *Efficacy:* The previous review found that mixtures containing eugenol deterred oviposition and changed feeding behaviour of *Spodoptera littoralis* and *S. litura*. More recent studies in the laboratory (Jaramillo-Colorado et al., 2019) and in the field in FAW’s native range (Figueroa Gualteros, Castro Triviño, & Castro Salazar, 2019) have also found antifeedant and phytotoxic effects of *Piper* extracts against several species of arthropods, including FAW and *S. littoralis.* Homemade aqueous extracts of *O. gratissimum* have been shown to control Lepidotopera in the field (Dougoud et al., 2019), and eugenol may also contribute to observed sublethal effects of extracts of *O. gratissimum* on FAW (Rioba & Stevenson, 2020). In field trials in Colombia, application of *P. nigrum* resulted in decreased FAW attack (Figueroa Gualteros et al., 2019), and in field trials in Cameroon, the severity of FAW attack was lowest in plants treated with extracts of *P. guineense* and the yields of plants treated with *P. guineense* did not differ from that of the synthetic pesticide (Tanyi, Nkongho, Okolle, Tening, & Ngosong, 2020), but it could be that the observed effect of *P. guineense* is due to other constituents of the extract, not eugenol. For some other insect species, zein nanoparticles containing eugenol have been shown to have the potential to be more effective in managing pests than essential oils (Oliveira et al., 2019)*.*
2. *Human health and environmental hazards:* Eugenol does not meet any of the HHP criteria (ECHA, 2020l), so it is not considered to be an HHP. Human health hazards associated with the AI include that it is harmful if swallowed (H302); may be fatal if swallowed and enters airways (H304); causes skin irritation (H315); may cause an allergic skin reaction (H317) and causes serious eye irritation (H319). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU. It is toxic to aquatic organisms.
3. *Agronomic sustainability:* Hymenoptera such as bees and wasps are listed as a target organisms for some of the products containing eugenol, suggesting potential toxicity to pollinators. Eugenol is registered as a fungicide in Kenya.
4. *Practicality:* No special requirements for PPE, application equipment, storage or disposal were listed.
5. *Availability:* Products containing eugenol are registered in Kenya, Peru and the USA, but only one product in the US is specifically registered for use against armyworm.
6. Affordability: No data.

**Recommendation:** Eugenol is registered in at least one country in Africa (but not for FAW). Bioassays and field trials suggest that eugenol and plant extracts containing eugenol (such as those of *O. gratissimum* and *Piper* species) may have an effect on FAW. Extracts of *O. gratissimum* and *Piper* species are candidates for local production. Additional bioassays and field trials to isolate the effect of eugenol versus that of the other constiuents of the plant extracts and to confirm efficacy against FAW are needed before expanding the label of products containing eugenol to cover FAW and recommending its inclusion in IPM schemes.

Garlic extract

Garlic oil is extracted from garlic, and it has insecticidal and acaricidal properties (Dougoud et al., 2019). For several of the products reviewed, the garlic extract was used in formulation with other AI such as azadirachtin, capsaicin, pyrethrins and other vegetable oils.

1. *Efficacy:* Findings on the efficacy of garlic extracts against insect pests (including *Spodoptera* species) in bioassays (Hamada, Awad, El-Hefny, & Moustafa, 2018) and in field trials (Dougoud et al., 2019) are mixed. In recent field trials in Colombia, application of garlic extract resulted in decreased FAW attack (Figueroa Gualteros et al., 2019), and in field trials in Costa Rica plants treated with homemade extracts of garlic, neem and detergent had relatively high yields even in comparison to the pesticide spinetoram (Mora & Blanco-Metzler, 2018).
2. *Human health and environmental hazards:* Garlic oil does not meet any of the HHP criteria, so it is not an HHP.According to the classification provided by companies to ECHA (ECHA, 2020n), garlic extract is harmful if swallowed (H302), causes serious eye irritation (H319), causes skin irritation (H315) and may cause an allergic skin reaction (H317). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Garlic oil has low toxicity to bees, and it is repellent to bees.
4. *Practicality:* Garlic extracts should be applied when infestation is anticipated or first detected, and applications should continue every 7 to 14 days in order to maintain control. Garlic extract should be applied no more than 21 times per season and should not be applied for 12 hours prior to harvest. The required elements of PPE are as follows: long-sleeved shirt and long trousers, waterproof gloves, and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Garlic extracts are registered in ten of the assessed countries (Argentina, Colombia, Costa Rica, Kenya, Mexico, Panama, Peru, Tanzania, Uganda and the USA), and it is specifically registered for FAW in Colombia and for armyworm in the USA. Garlic extracts are also registered for use in the EU. Garlic extract are often used as a traditional means of pest control and its use is recommended to farmers in many countries (Dougoud et al., 2019).
6. *Affordability:* The study in Costa Rica found homemade extracts of garlic, neem and detergent to be more cost effective than treatment with spinetoram (Mora & Blanco-Metzler, 2018).

**Recommendation:** Products containing garlic oil or garlic are labelled for use against FAW in the USA, and field studies in its native rangesuggest that it could potentially be effective against FAW. Given that garlic extract is commercially available in several countries in Africa and it is a potential candidate for local production, efficacy tests in the field in Africa are recommended.

GS-omega/kappa-Hxtx-Hv1a

GS-omega/kappa-Hxtx-Hv1a is a derived fraction of a naturally-occurring peptide found in the venom of the Funnelweb spider, *Hadronyche versuta*. It is labelled for use against Thysanoptera, Coleoptera and Lepidoptera pests, including armyworm. GS-omega/kappa-Hxtx-Hv1a was first registered in 2014 in the USA.

1. *Efficacy:* Spiders inject venom into their prey through their fangs. The previous assessment found very little information on the efficacy of spider venom toxins, and some initial work suggested that spider toxins unlikely to be effective on their own when applied topically as the toxin in unable to penetrate insects’ exoskeletons and the potency of spider venom tends to be much lower when ingested orally (Ikonomopoulou & King, 2013). Meanwhile, laboratory trials of GS-omega/kappa-Hxtx-Hv1a mixed with adjuvants resulted in 100% mortality of adults of *Drosophila suzuki* and reduced the survival of oviposited eggs (Fanning, Vanwoerkom, Wise, & Isaacs, 2018). Likewise, in a field trial, GS-omega/kappa-Hxtx-Hv1a gave comparable control to phosmet and reduced blueberry infestation. No laboratory studies or field trials were found in the literature regarding the efficacy of this AI against FAW. In surveys in Zambia some farmers reported using a product containing GS-omega/kappa-Hxtx-Hv1a and overall the surveyed farmers found that biologicals (farm-based plant extracts and biopesticides) were effective (Kansiime et al., 2019).
2. *Human health and environmental hazards:* In the risk assessment conducted by the US EPA prior to registration of this AI, the regulator concluded that GS-omega/kappa-Hxtx-Hv1a will not cause any unreasonable adverse human health or ecological effects (US EPA, 2014a). The acute toxicity of this AI is low. There is no data to indicate this AI is an HHP.
3. Agronomic sustainability: Studies indicate that this AI is not harmful to natural enemies (Cloyd & Herrick, 2018).
4. *Practicality:* According to a reviewed product label GS-omega/kappa-Hxtx-Hv1a is compatible with standard spray and irrigation equipment
5. *Availability:* One product containing GS-omega/kappa-Hxtx-Hv1a is registered in the USA for use against armyworm. While we found no information indicating that it is registered for use in any of the assessed countries in Africa, farmer surveys in Zambia indicate that it is used by 3% of farmers there (Kansiime et al., 2019).
6. *Affordability:* A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Given that GS-omega/kappa-Hxtx-Hv1a is now being used by farmers in some countries and there are indications that the farmers who use it consider that it works well (Kansiime et al., 2019), efficacy tests in the field in Africa are recommended.

*Helicoverpa armigera* nucleopolyhedrovirus (HaNPV) / *Helicoverpa zea* single capsid nucleopolyhedrovirus (HzSNPV)

HaNPV / HzSNPV is a naturally occurring baculovirus which was first detected in South Africa in 1891 that infects and kills larvae of *Heliothis* and *Helicoverpa* species (Farrar & Ridgway, 1999). Molecular studies indicate that HzSNPV and HaNPV are “variants of the same virus species”. While the two strains were initially isolated from different species, subsequent tests have demonstrated that the two strains have similar host ranges, virulence, physical properties and genome sequences (US EPA, 2015a).

1. *Efficacy:* One laboratory study found that HzSNPV is not effective against FAW (M. Shapiro & Hamm, 1999). Both the current and previous reviews of the literature failed to identify any references demonstrating the efficacy of HzSNPV against FAW.
2. *Human health and environmental hazards:* HzSNPV has been safely used as a microbial pesticide for many years in the US with no documented effects on human health or the environment (US EPA, 2014b). It is not an HHP or a cholinesterase inhibitor (University of Hertfordshire, 2018b), and the risks to human health and the environment are low (University of Hertfordshire, 2018a). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). HearNPV, which is considered to be a variant of the same species of virus, is approved for use in organic agriculture in the EU (EC, 2020).
3. *Agronomic sustainability:*  There is no evidence indicate that HzSNPV will compromise agronomic sustainability nor is there any indication that there is a risk of the development of pest resistance. Exposure of non-target organisms such as pollinators, natural enemies and other beneficial organisms is expected to be minimal and adverse effects are not anticipated (US EPA, 2014b; 2015a). It is not recommended to apply products containing HzSNPV directly to water or to areas where surface water is present. Water must not be contaminated when cleaning equipment or by disposal of water used to wash equipment.
4. *Practicality:* Gemstar LC can be stored between -20 to 10 oC and is stable if kept refrigerated. Applications rates are 4-10 fl. oz/acre. Non-ionic or oil-based spreaders/stickers and ultraviolet screening screening agents may enhance the performance fof this product. However, silicon-based spreaders must not be used as they may interfere with the adhesion of virus particles to the plant surface. If water pH is >8 or <6, it may be adjusted to pH 7 with a buffering agent. PPE includes safety glasses/googles, long sleeved shirt and trousers, shoes plus socks and protective gloves. No special ventilaton is required.
5. *Availability:* This AI is not registered in any of the 19 countries assessed in Africa. Of the 30 countries assessed, this AI is registered in Brazil, Mexico and the USA.
6. *Affordability:* No current data available.

**Recommendation:** Given that *Helicoverpa**zea* single nucleoolyhedrovirus virus has only been shown to be effective against *Helicoverpa zea* and is not registered for use in any of the reviewed countries in Africa, it is not recommended that any further action be taken with respect to this AI.

*Isaria fumosorosea* apopka 97 (*Paecilomyces fumosoroseus* fe9901)

*Isaria fumosorosea* Apopka strain 97 is a naturally occurring entomopathogen found in the bodies of infected or dead arthropods and in the soil (US EPA, 2011c). It infects a range of agricultural pests including aphids, spider mites, whiteflies and thrips. It differs from entomopathogenic fungi such as *Metarhizium* spp. in terms of its range of infectivity, safety perspective and requirements for mass production.

1. *Efficacy:* Zemek, Prenerová and Hussein (2012) showed that *I. fumosorosea* is effective in controlling *Spodoptera littoralis*. Likewise, there are studies that demonstrate that *I. fumosorosea Apopka* has an impact on FAW. First instar FAW larvae treated with inactive conidia, germinated conidia and hyphal bodies of *I. fumosoroseus* at 3 x104 propagules per cm2 resulted in 29, 43-49 and 61% mortality, respectively with LT50 values of 4.0 to 3.1 days (Fargues, Maniania, & Delmas, 1994). Isolates of *I. fumosorosea* were also reported to be highly pathogenic to the eggs and neonates of FAW (Lezama-Gutierrez et al., 1996).
2. *Human health and environmental hazards:* The product PFR-97 20% WDG is not classified by OSHA and has an EPA signal word of ‘caution’. Wear PPE (long sleeved shirt and long trousers, waterproof gloves and shoes plus socks) when applying the product, specifically a dust/mist mask to MSHA/NIOSH approval number prefix TC-21C or a NIOSH N-95, R-95 or P-95. Causes moderate eye irritation.
3. *Agronomic sustainability:* It is not recommended to apply PFR-97 20% WDG directly to water or to areas where surface water is present. Water must not be contaminated by equipment cleaning processes or by the disposal of water used to wash equipment.
4. *Practicality:* PFR-97 20% should be stored at 5-10oC (40-50oF). Once opened moisture from unused material must be sealed out by closing the bag tightly after squeezing out excess air. Should be used within 30 days or opening. Application rate of 14–28 oz of product/100 gallons of water. The product may be premixed with 5 gallons of water per pound of PFR-97 20% WDG, and should be aggitated for 20-30 minutes prior to use to ensure a well-dispersed suspension. Applications may be repeated at 3-10 day intervals over 2-3 weeks or as needed. Works best between 22-30˚C with high humidity.
5. *Availability:* This AI is not registered in any of the 19 countries assessed in Africa. Of the 30 countries assessed, this AI is only registered in USA.
6. *Affordability:* No data available. Kivett, Cloyd, & Bello (2015) found that cost savings of up to 34% (in US dollars) were possible when including *I. fumosorosea* and other entomopathogenic organisms in an insecticide rotation program for *Frankliniella occidentalis* in a greenhouse production system*.* We found no reference to information on cost effectiveness against FAW in Africa.

**Recommendation:** *Isaria fumosorosea* is not registered for use in any of the reviewed countries in Africa. Therefore it is not recommended that any further action be taken with respect to this AI.

Kaolin clay

Kaolin is a white mineral clay used to control insects, powdery mildew and as a plant growth regulator (US EPA, 2014d).

1. *Efficacy:* The previous review found evidence from both laboratory and field studies in the Americas and in Africa documenting the efficacy of kaolin against many Lepidoptera species, including FAW. This review did not find any new data on its efficacy for FAW management, but one study found kaolin caused mortality to *S. exigua* (Ebadollahi & Sadeghi, 2018).
2. *Human health and environmental hazards:* Kaolin has low acute toxicity and is categorized as “Generally Recognized as Safe” by US regulators (US EPA, 2014d). Some notifications indicate that kaolin may cause cancer through inhalation (H350), indicating that it is an HHP (ECHA, 2020p). Other human health hazards associated with the AI include the following; causes skin irritation (H315), causes serious eye irritation (H319), causes lung damage through inhalation (H370) and causes damage to organs through prolonged or repeated exposure (H372 and H373). The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. Kaolin is approved for use in the EU but is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Non-target effects from the use of kaolin pesticide products are expected to be negligible (US EPA, US EPA (United States Environmental Protection Agency), 2014d).
4. *Practicality:* When applied to plant surfaces, kaolin clay forms a protective film. For optimal performance, all plant surfaces should be coated. Treated plants will be whitish in colour after the spray film has dried. The protective film must be in place before insect attack in order to be effective. Kaolin clay should only be applied to dry plants to ensure formation of the film. The required elements of PPE are as follows: long-sleeved shirt and trousers, shoes plus socks, and dust/mist-filtering respirator with (MSHA/NIOSH approval number prefix TC-21C), or a NIOSH approved respirator with any N, R, P, or HE filter. Kaolin clay should be sprayed until tanks are empty and then the system and nozzles should be flushed with fresh water. No extraordinary equipment, storage or disposal requirements were listed on the label.
5. *Availability:* Kaolin is registered in Panama and the USA, and in the USA some products are specifically registered for use against FAW.
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Given that kaolin may be carcinogenous, it is not recommended for futher follow-up.

Lufenuron

Lufenuron is an insect growth regulator which inhibits chitin biosynthesis and is used to control chewing and sucking insects (University of Hertfordshire, 2020b). Lufenuron was covered by the previous assessment because at least one of the governments categorized it as a biopesticide. At present none of the governements categorize lufenuron as a biopesticide so the information on this AI was not updated as part of the current review.

Maltodextrin

Maltodextrin is a polysaccharide produced from starch by partial hydrolysis, often from maize in the USA and wheat in Europe. It is used as a horticultural insecticide in both open field and glasshouses. There is no physiological or biochemical activity, instead once sprayed on insects maltodextrin dries and blocks the insects' spiracles, causing death by suffocation. It can also have entrapment properties.

1. *Efficacy*: Field trials in Ghana found that maltodextrin may be effective in controlling FAW with the highest dose nearly reaching the yields of the positive control in one of the test sites (D. Babendreier et al., 2020).
2. *Human health and environmental hazards*: Maltodextrin does not meet any of the HHP criteria (EFSA (European Food Safety Authority), 2013; University of Hertfordshire, 2019c), so it is not an HHP. No other human health hazards were identified. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is approved for use in organic agriculture in the EU.
3. *Agronomic sustainability*: In its risk assessment, the European Food Safety Authority found that risks to most non-target organisms would be low but risks to honeybees cannot be excluded (EFSA, 2013). Drift should be minimized and plants should not be sprayed within 5 m of field boundaries in order to diminish risks to non-targets organisms (Certis Europe BV).
4. *Practicality*: No evidence was found to suggest maltodextrin cannot be tank mixed with other chemical and non-chemical active ingredients. No extraordinary equipment, storage or disposal requirements were listed on labels.
5. *Availability*: Maltodextrin is registered for use against FAW in Ghana and a survey of Ghanian farmers found that 4.5% of surveyed farmers are using it against FAW (D. Babendreier et al., 2020; Tambo et al., 2020).
6. *Affordability*: The abovementioned field study (D. Babendreier et al., 2020) found an unfavourable cost benefit ratio in Ghana.

**Recommendation**: There is field evidence of efficacy against FAW in Africa and, furthermore, maltodextrin has been recommended by the Government of Ghana for FAW control. Its impact on non-targets, including bees, has yet to be determined. Due to the high treatment costs and observed unfavourable cost benefit ratio, other controls such as neem-based products may be preferable.

Matrine

Matrine is an alkaloid found in plants from the *Sophora* genus.

1. *Efficacy:* The previous review found some laboratory evidence of matrine against FAW but the data from the field did not support this conclusion. The findings of other more recent laboratory studies are mixed. While two studies found that matrine had good insecticidal activity against *S. exigua* in the laboratory (Kim et al., 2015) and the field (Orak, Zandi-Sohani, & Yarahmadi, 2019), another study found that matrine was not effective against FAW in laboratory tests (Chen et al., 2019).
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria (ECHA, 2020b), so it is not considered to be an HHP. There are human health hazards associated with the AI including that it is harmful if swallowed (H302) and causes serious eye irritation (H319). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. Agronomic sustainability: No data available.
4. *Practicality:* No data available.
5. *Availability:* Matrine is registeted in 6 of the assessed countries, including Benin, Burkina Faso, Kenya and Mali. It is not registered for use against Lepidoptera in any of these countries.
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Given that findings from bioassays are mixed and the available data from field trials do not demonstrate that this AI is effective for managing FAW, it is not recommended for futher follow-up.

*Metarhizium anisopliae*

*Metarhizium* is an entomopathogenic fungus that is found in soil or as endophytes (beneficial plant symbionts) (Holmes et al., 2018). The spores or mycelium attach to the surface of the insects and then penetrate the host insect’s cuticle and use enzymes to penetrate the insect. Once inside the host insect body cavity, *Metarhizium* can multiply and then sporulates. These spores are then disseminated and the process begins again. The application of these entomopathogens to control insect pests in the field is well established and many commercial products are available.

1. *Efficacy:* Laboratory studies carried out by Lezama Gutierrez et al. (1996) demonstrated that *M. anisopliae* was effective in controlling *S. frugiperda* eggs and larvae and had the potential of becoming a microbial control agent for this pest. Ramos et al (2020) have recently shown that *M. anisopliae* (commercial strain Ma-80) can establish as an endophyte of maize in the roots (but not shoots and leaves) when used as a soil drench in Cuba, and in laboratory bioassays caused 100% and 75% mortality to 2nd and 4th instar fall armyworm, respectively. Ramanujam et al (Ramanujam et al., 2020) found that field trials using an indigenous strain of *M. anisopliae* (ICAR-NBAIR Ma-35) was effective against fall armyworm in India. A number of local isolates of *M. anisopliae* showed promising levels of mortality against eggs and neonate larvae of fall armyworm in laboratory bioassays in Kenya (Akutse et al., 2019). Among these ICIPE 78, marketed as “Mazao Achieve®” for use against red spidermites by RealIPM (K) Ltd and ICIPE 7, currently undergoing registration as “Mazao Tickoff ®” for use against livestock ticks highlighted promise for label extension/registration for use against Fall armyworm (Akutse, Subramanian, et al., 2020). Currently label extension trials for “Mazao Achieve®” and registration trials for a new formulation of ICIPE 7 as “Mazao Detain ®” are on-going in East Africa.
2. *Human health and environmental hazards:* Uganda haslisted *Metarhizium anisopliae* as an insecticide for general agricultural use in its ‘green’ list, meaning it is recommended for *Spodoptera* spp. control, amongst other insects. It is classified as having no chronic toxicity and has an EPA acute toxicity class of III and IV; moderately toxic and slightly toxic, respectively (US EPA, 2011a). In a review on the safety of *M. anisopliae* Zimmermann (2007b) concluded that *M. anisopliae* is considered to be safe with minimal risk to humans, vertebrates and the environment.
3. *Agronomic sustainability: Metarhizium anisopliae* has a low toxicity to non-target organisms.
4. *Practicality:* Real Metarhizium anisopliae 69 has a shelf life of 12 months if stored in a cool, dry conditions at 15-20°C.
5. *Availability: Metarhizium* products are available in 9 African countries; South Africa, Tanzania, Kenya, Ghana, Zimbabwe, Ethiopia, Mozambique, Uganda and Zambia (Akutse et al., 2020a), and two recent studies suggest that it is effective against *S. frugiperda*. There are also three products registered in Panama.
6. *Affordability:* Kivett, Cloyd, & Bello (2015) found that cost savings of up to 34% (in US dollars) were possible when including *M. anisopliae* and other entomopathogenic organisms in an insecticide rotation program for *Frankliniella occidentalis* in a greenhouse production system*.* We found no reference to information on cost effectiveness against FAW in Africa.

**Recommendation:** There are *M. anisopliae* products registered in nine African countries and field trials with these registered products should occur to test their effectiveness in those countries.

*Metarhizium rileyi*

*Metarhizium rileyi* (formerly known as *Nomuraea rileyi*) is a cosmopolitan fungal entomopathogen that is frequently encountered with lepidopterans and infects many noctuids (Fronza, Specht, Heinzen, & Barros, 2017). *Metarhizium rileyi* occurs naturally on several noctuids belonging to genus, *Anticarsia*, *Chrysodeixis, Heliothis, Rachiplusia* and *Spodoptera*. Recently, natural epizootics of *M. rileyi* on *Spodoptera frugiperda* has been recorded in its invasive range in Africa (Gichuhi et al., 2020) and in Asia (Firake & Behere, 2020; Varshney et al., 2020; Zhou et al., 2020).

1. *Efficacy:* Among the entomopathogenic fungi observed on the noctuids such as *Spodoptera,* most frequent epizootics are caused by *Metarhizium rileyi* (Fronza et al., 2017). Both *M. rileyi* and baculoviruses together resulted in >50% natural mortality of FAW in the field (Firake and Behere *et al.,* 2020). Under glasshouse conditions, application of Emulsifiable concentrate (EC) formulations of *M. rileyi* resulted in 57% reduction in plant damage to maize due to fall armyworm (Grijalba, Espinel, Cuartas, Chaparro, & Villamizar, 2018). Granular formulations of *M. rileyi* in 1 mm defatted corn germ resulted in 80% mortality of FAW in the lab (Pavone, Díaz, Trujillo, & Dorta, 2009).
2. *Human health and environmental hazards:* No data available.
3. *Agronomic sustainability: Metarhizium rileyi* has a low toxicity to non-target organisms.
4. *Practicality:* Compared to *M. anisopliae,* few commercial products based on *M. rileyi* are available for pest control*.* The high degree of variability of *M. rileyi,* rapid decline in viability and sporulation with successive passage in media,low shelf life are some of the challenges commercial production of *M. rileyi* encounters.
5. *Availability:* Few commercial products such as Nomu-Protec ® are available but not registered for FAW control.
6. *Affordability:* No data available

**Recommendation:** More focus on R4D in terms of characterisation, optimization of mass production and formulation is needed.

Methoxyfenozide

Methoxyfenozide is a synthetic insect growth regulator which mimics the moulting hormone of Lepidopteran insects (Bouzeraa & Soltani-Mazouni, 2014). Methoxyfenozide was covered by the previous assessment because at least one of the governments categorized it as a biopesticide. At present none of the governements categorize methoxyfenozide as a biopesticide so the information on this AI was not updated as part of the current review.

Oxymatrine

Oxymatrine is an alkaloid found in plants from the *Sophora* genus (Krishna, Rao, Sandhya, & Banji, 2012).

1. *Efficacy:* The current and previous reviews did not find any data on the efficacy of oxymatrine against FAW, and there was little new information on its efficacy against other Lepidoptera.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria (ECHA, 2020a), so it is not an HHP. The only human health hazards associated with the AI is that it is harmful if swallowed (H302). Based on this, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. Agronomic sustainability: No data available.
4. *Practicality:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.
5. *Availability:* Oxymatrine is registered in 6 of the assessed countries. In Ghana, oxymatrine is broadly registered for use against insect pests in fruit and vegetable crops. It is also registered for other pests (not Lepidoptera) in Ethiopia and Kenya.
6. *Affordability:* No data available.

**Recommendation:** Oxymatrine has been demonstrated to be effective against other Lepidoptera but no information was found regarding its efficacy against FAW. Data was not available on agronomic sustainability, practicality and affordability. Given that oxymatrine is registered in three countries in Africa, bioassays and field trials (if merited) to determine its efficacy against FAW are recommended.

Potassium salts of fatty acids (Potassium laurate)

Potassium salts of fatty acids (potassium laurate) are commonly referred to as “soap salts”, and they are produced by adding potassium hydroxide to fatty acids found in animal fats and oils of plants such as palm, coconut, olive, castor, and cotton. Soap salt products are registered as algaecides, herbicides, insecticides, acaricides, and animal repellents. As an insecticide they work by disrupting the exoskeleton, causing insects to die (US EPA, 2015c). Several products containing potassium salts of fatty acids are registered for use against FAW in the USA, but many of these products also contain other AI such as neem or pyrethrins.

1. *Efficacy:* Both the current and previous reviews of the literature failed to identify any references demonstrating the efficacy of potassium salts of fatty acids against FAW or any other *Spodoptera spp.* in agricultural settings.
2. *Human health and environmental hazards:* Potassium salts of fatty acids do not meet any of the HHP criteria, so they are not considered to be an HHP. The US FDA classifies potassium soap salt as “generally recognized as safe” to humans (US EPA, 2015c). Human health hazards associated with potassium salts of fatty acids include the following; they cause skin irritation (H315), cause serious eye irritation (H319), and may cause respiratory irritation (H335) (ECHA, 2020m). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is approved for use in organic agriculture in the EU. Potassium salts of fatty acids are toxic to aquatic organisms with long-lasting effects (H411).
3. *Agronomic sustainability:* Potassium salts of fatty acids are moderately toxic to bees. If care is used to avoid contaminating water and to reduce exposure to bees, then products containing potassium salts of fatty acids should not have any negative impact on agronomic sustainability.
4. *Practicality:* Potassium salts of fatty acids should be applied when the first signs of damage are detected. Products containing this AI should not be applied in full sun. The required elements of PPE are as follows: long-sleeve shirt, long trousers, shoes and socks, and chemical resistant gloves. This AI can be applied using standard equipment. There are no special requirements for application equipment, storage or disposal.
5. *Availability:* Globally, insecticidal soaps are registered in many countries, and several products are registered for use against armyworm in the USA. In Africa, potassium soap salts are only registered against aphids and thrips in Kenya
6. *Affordability:* No data available.

**Recommendation:** Given that there is little evidence of efficacy against FAW and it is not readily available, further follow-up action for this AI is not recommended.

Pyrethrins

Pyrethrins, derived from the dried, powdered flowers of *Chrysanthemum cinerariaefolium* Vis. (formerly *Pyrethrum*), are non-persistent contact insecticides used to control a variety of insects and some mites in agriculture as well as domestic and public health settings. Pyrethrins are often formulated with the synergist piperonyl butoxide.

1. *Efficacy:* The previous assessment found evidence of pyrethrin efficacy against many Lepidoptera but only limited evidence of its efficacy against FAW*.* More recently, one laboratory study reported that pyrethins are not very effective against FAW (Chen et al., 2019).
2. *Human health and environmental hazards:* Pyrethrins do not meet any of the HHP criteria, so they are not HHPs. According to the classification provided by companies to ECHA(ECHA, 2020q), pyrethrins are harmful if swallowed (H302), harmful in contact with skin (H312) and harmful if inhaled (H332). Based on this, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is allowed for use in organic agriculture in the EU.
3. *Agronomic sustainability:* There is the potential for non-target effects. Pyrethrins are highly toxic to bees, and they are also very toxic to aquatic organisms with long lasting effects (H410). A recent study found that pyrethrin is more toxic to the natural enemy *Podisus maculiventr*is than it was to the pest *S. exigua* (Castro et al., 2018).
4. *Practicality:* The required elements of PPE are as follows: long-sleeved shirt, long trousers, shoes and socks, and chemical-resistant gloves such as Barrier Laminate, Nitrile Rubber, Neoprene Rubber, or Viton. In addition to the above PPE, applicators using hand-held foggers in an enclosed area must wear a half-face, full-face or hood-style NIOSH-approved respirator with: a dust/mist filtering cartridge (MSHA/NIOSH approval number prefix TC-21C), or a canister approved for pesticides (MSHA/NIOSH approval number prefix TC-14G), or a cartridge or canister with any R, P or HE filter. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Pyrethins are registered in 14 of the assessed countries, 10 of which are in Africa: Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda, South Africa, Tanzania, Tunisia and Uganda. In South Africa, products containing pyrethrin are specifically registered for use against FAW.
6. *Affordability:* No data available. A literature search for information on cost effectiveness found no relevant publications during the past ten years.

**Recommendation:** Thus far, the evidence for efficacy against FAW is not strong so further follow-up action for this AI is not recommended.

Sex pheromones

Female FAW moths attract males by emitting a pheromone. Pheromones can be used for monitoring FAW populations, but here we consider their use in control. Two approaches to controlling FAW with pheromones may be possible. The first, mass trapping, involves deploying many traps that catch a high proportion of the male population, resulting in not all females being able to mate. The second approach involves applying a relatively large amount of the pheromone in the field, which confuses the males so they are unable to locate females. In the Americas there appear to be some geographic differences in the most effective blend of these components, but no major differences between the two FAW strains (Unbehend, Hänniger, Meagher, Heckel, & Groot, 2013). Not all the compounds listed above are necessary for a lure to be effective; commercial lures use 2-4 of the components. IPS, for example, has a 2-component lure containing Z9-14:OAc (99%) and Z7-12:OAc (1%), but also one containing Z9-14:OAc (84%), Z7-12:OAc (2%), Z11-16:OAc (13%) and Z9-12:OAc (1%). Some work on pheromones, including mating disruption, is in progress in Africa by public and private sector organisations, though in the context of monitoring rather than control. Some findings suggest that pheromone blends will need to be tailored to the FAW populations in Africa (Haenniger et al., 2020). The number of traps required per field/unit of area is still being determined. Most companies and researchers interviewed recommended deploying pheromones in conjunction with other control measures, for example, to determine the appropriate timing of application. One company (Provivi) has developed and tested a FAW pheromone for mating disruption in Kenya.

Compounds identified in fall armyworm pheromone blends.

|  |  |  |
| --- | --- | --- |
| **Abbreviation** | **Full name** | **References** |
| Z7-12:OAc | (Z)-7-Dodecanyl acetate | 1,2,3 |
| Z9-12:OAc | (Z)-9-Dodecanyl acetate | 1,6 |
| E7-12:OAc | (E)-7-Dodecanyl acetate | 1,7 |
| 12:OAc | Dodecanyl acetate | 1 |
| Z9-14:Ald | (Z)-9-Tetradecanal | 3 |
| Z9-14:OAc | (Z)-9-Tetradecenyl acetate | 1,2,3,4,5 |
| Z10-14:OAc | (Z)-10-Tetradecenyl acetate | 1 |
| Z11-14:OAc | (Z)-11-Tetradecenyl acetate | 1 |
| 14:OAc | Tetradecenyl acetate | 1 |
| Z11-16:OAc | (Z)-11-Hexadecenyl acetate | 1,3,5 |

1. Bestmann, Attygalle, Schwarz, Vostrowsky, &Knauf (1988)

2. Andrade, Rodriguez, & Oehlschlager (2000)

3. Tumlinson et al. (1986)

4. Haenniger et al., 2020

5. Lima & McNeil (Lima & McNeil, 2009)

6. Unbehend et al (Unbehend et al., 2013)

7. (Batista-Pereira et al., 2006)

1. *Efficacy:* The previous assessment found that while pheromones can be a valuable monitoring tool, mass trapping is at best only partially effective (Bateman et al., 2018). Findings on the efficacy of mating disruption trials are not yet available.
2. *Human health and environmental hazards:* Straight chain lepidopterous pheromonones (SCLPs) such as these are of low risk, and present no known hazards to humans or the environment. The US Environmental Protection Agency determined that “no risks to human health are expected from the use of lepidopteran pheromones based on the low toxicity found in animal testing and the expected low exposure to humans” (US EPA, 2008).
3. *Agronomic sustainability:* Pheromone use does not compromise agronomic sustainability. If the insects did evolve a different pheromone, it would be straightforward to determine the new composition. Adverse impacts on non-target organisms are not expected because the pheromones are released in very small quantities in the environment and are species-specific in their effects (US EPA-OPP, 2008).
4. *Practicality:* Mass trapping or mating disruption is generally more likely to be effective if used over a large area. In areas with many small farms, this would be difficult to organise. The lures in pheromone traps need replacing every 4-8 weeks, and they should be stored below 5˚C, which would pose additional practical difficulties in some areas. The mating disruption Pherogen Sporf dispenser is pegged on a 2 feet stick planted at a spacing of 15 x 15 m and would be easy to install.
5. *Availability:* Fall armyworm pheromone is commercially available in several countries in Africa. For example, Russell IPM (a UK company) has distributors for its 4-component lure in DRC, Malawi and Zambia; Kenya Biologics is marketing a fall armyworm lure on its website that is said to last for 8 weeks; Pheromones for FAW trapping are currently being sold in South Africa and Togo. A pheromone-based mating disruption product is registered in Brazil and Mexico, and registration field trials are on-going in East Africa. In Kenya, efficacy trials have been conducted for a pheromone-based mating disruption product from Provivi, whose results show some promise in large scale plantings.
6. *Affordability:* In Brazil a trap plus pheromones costs the equivalent of about US$6, but only the lure needs regular renewal. Kenya Biologics recommends 10 traps/ha (or double that if infestation persists) and replacement of lures every 2 months, so the costs can build up. Provivi recommends 50 dispensers on one hectare. The dispensers are installed before germination of the new crop, and once installed will last for the entire maize season. The cost of each dispenser is not yet known. In an experiment in Togo, Meagher et al. (Meagher et al., 2019) found that a trap of local design was most cost effective, catching more than 21 moths per dollar.

**Recommendation:** Using pheromones for monitoring purposes should be developed further for monitoring. Depending on the outcomes of the registration field trials in East Africa, mating disruption products could also be tested in other countries and applied for control purposes.

Silicon dioxide (diatomaceous earth)

Silicon dioxide (diatomaceous earth) is composed of naturally occurring fossilised diatoms (Chintzoglou, Athanassiou, & H., 2008). Chemically it is mainly silicon dioxide, which occurs in amorphous and crystalline forms, but diatomaceous earth is largely amorphous. Silicon dioxide was covered by the previous assessment because at least one of the governments categorized it as a biopesticide. At present none of the governements categorize silicon dioxide as a biopesticide so the information on this AI was not updated as part of the current review.

S-methoprene

S-methoprene is an analog of the juvenile hormone in insects that controls their development from one stage to the next and as a consequence must be applied to larval stages to be effective (US EPA, 2019c).

1. *Efficacy:* The previous assessment found only limited evidence on the effect of s-methoprene on FAW, and no new information was found through the current assessment.
2. *Human health and environmental hazards:* S-methoprene does not meet any of the HHP criteria (ECHA, 2020o), so it is not an HHP. Human health hazards include that s-methoprene causes skin irritation (H315) may cause respiratory irritation (H335). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. S-methoprene is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* There are a few cases of resistance to methoprene reported for some Diptera (Mota-Sanchez & Wise, 2020). Immature stages of other insects that come into contact with the pesticide could be affected. Exposure to juvenile hormone and juvenile hormone analogues like s-methoprene can induce changes in bee behaviour resulting in precocious transition from nursing to foraging in adult worker bees (Huang, Lin, & Ahn, 2018). S-methoprene is not harmful to birds or mammals, but it is very toxic to aquatic life with long lasting effects (ECHA, 2020o).
4. *Practicality:* Use of s-methoprene would not present any major practical difficulties different to the use of other pesticides. Having relatively low mammalian toxicity it would present less of a hazard to farmers who do not wear personal safety equipment when spraying pesticides.
5. *Availability:* Methoprene is not widely available even in developed countries, except for flea control in pets. Nigeria was the only country where it was found to be registered in Africa.
6. *Affordability:* No information available.

**Recommendation:** There is little evidence to support further work on s-methoprene.

Soybean oil

Soybean oil acts as a contact pesticide and soybean oil residue on plant surfaces can serve as a feeding and ovipositioning deterrent. Soybean oil is thought to act as an irritant and to prevent gas exchange and water loss by covering the insects’ bodies (Copping, 2009).

1. *Efficacy:* Both the present and previous review of the literature failed to identify any references demonstrating the efficacy soybean oil against FAW or any other Lepidoptera in agricultural settings. Even so, some products containing soybean oil as an AI are specifically labelled for used against armyworm in maize in the USA.
2. *Human health and environmental hazards:* Soybean oil does not meet any of the HHP criteria, so it is not considered to be an HHP. Some notifications indicate that soybean oil may cause seriuous eye irritation (H319) (ECHA, 2020r). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs.
3. *Agronomic sustainability:* The US EPA has concluded that end-use products containing soybean oil are of minimal risk and there are no concerns of adverse effects to non-target organisms (US EPA, 2010d).
4. *Practicality:* Soybean oil should be applied when insects first appear, and the target pests should be completely covered by the spray. The required elements of PPE are as follows: long-sleeved shirt and long trousers, waterproof gloves and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Soybean oil is registered in six countries (Argentina, Mexico, Panama, Peru, Togo and the USA), and it is specifically registered for use against FAW in the USA.
6. *Affordability:* No data available.

**Recommendation:** No compelling evidence was found in the literature that soybean oil is effective against FAW, and the need to spray soybean oil directly on the insect suggests that it may be an impractical control measure to apply. No follow-up action recommended.

Spinetoram

Spinetoram is an insecticide compound derived from the fermentation of a naturally occurring soil actinomycete bacterium, *Saccharopolyspora spinosa* (FAO, 2009). Spinetoram is a semi-synthetic spinosyn and acts by both contact and ingestion. Spinetoram was covered by the previous assessment because at least one of the governments categorized it as a biopesticide at that time. At present none of the governements categorize spinetoram as a biopesticide so the information on this AI was not updated as part of the current review.

Spinosad

Spinosad is an insecticide compound derived from the fermentation of a naturally occurring soil actinomycete bacterium, *Saccharopolyspora spinosa* (US EPA (United States Environmental Protection Agency), 2018). Spinosad is a mixture of two synthetic forms, spinosyn A and spinosyn D; it is active by both contact and ingestion and has been used around the world for the control of a variety of insect pests, including Lepidoptera, Diptera, Thysanoptera, Coleoptera, Orthoptera, and Hymenoptera. Spinosad is an important component of FAW management strategies in many countries (Gutiérrez-Moreno et al., 2019; Lira et al., 2020; Okuma et al., 2018).

*1. Efficacy*: In the previous review, the authors found numerous references demonstrating efficacy of Spinosad against FAW in both lab and field settings. A more recent laboratory study in Africa demonstrated that spinosad increased FAW larval mortality, reduced leaf damage, and increased biomass in maize compared to the untreated control (Sisay et al., 2019).

*2. Human health and environmental hazards*: Spinosad does not meet any of the HHP criteria, so it is not considered to be an HHP. Some notifications indicate that spinosad may cause seriuous eye irritation (H319) (ECHA, 2020r). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; and it is not a candidate POP. It is on PAN’s list of HHPs because of its toxicity to honeybees (PAN, 2019).

*3. Agronomic sustainability*: Spinosad poses potential chronic risks to non-target organisms such as freshwater invertebrates, birds, reptiles, terrestrial-phase amphibians, and mammals and acute risks to terrestrial invertebrates such as honey bees (US EPA, 2018). Measures to reduce risks to non-target organisms include reducing drift by leaving a buffer zone at the downwind edge of the field, avoiding spraying when it is windy, spraying close to the plant canopy, applying coarser droplets; reducing run-off by avoiding spraying when the forecast is for rain to fall within the next 24 hours; and reducing feeding on treated seeds by covering seeds with soil or collecting spilled seeds (US EPA, 2018).There are references of FAW resistance to Spinosad (Mota-Sanchez & Wise, 2020). For example, a recent study on FAW in Puerto Rico documented the development of low levels of field-evolved resistance to Spinosad in a relatively short amount of time (Gutiérrez-Moreno et al., 2019), and cross resistance with another spinosyn, Spinetoram, has been confirmed (Lira et al., 2020). There are also indications that there is a high fitness cost associated with resistance to Spinosad (Okuma et al., 2018). IPM and an insecticide resistance management should be applied in order to prevent the development of resistance to this AI.

*4. Practicality*: Spinosad is available in a range of formulations (granular, powder, liquid, solid bait etc) and is compatible with standard spray equipment.

*5. Availability*: Spinosad is registered in many countries (80+) including a number of countries in Africa. There are products in Africa which are specifically registered for use against FAW, armyworm and / or Lepidoptera.

6. Affordability: Prices vary. Studies of spinosad use against other pests have found favourable benefit-cost ratios (Sahu, Ashwani, & Khan, 2017; Simon et al., 2019).

**Recommendation**: Strong evidence of efficacy, practicality and availability with multiple registrations in Africa. There are serious concerns regarding impact on non-target organisms. Proceed with caution, and if used mitigation measures to diminish impacts on non-target organisms should be applied.

*Spodoptera exigua* nucleopolyhedrovirus (SeNPV)

Beet armyworm nucleopolyhedrovirus or *Spodoptera exigua nuclear polyhedrosis virus* (SeNPV) – also known as *Spodoptera exigua multinucleopolyhedrovirus* (SeMNPV) -- is a baculovirus that infects beet armyworm (*S. exigua*) (Bateman et al., 2018). The genome of this virus is strikingly similar to that of the Spodoptera frugiperda multiple nucleopolyhedrovirus (SfMNPV) and was also found to replicate in FAW (Serrano et al., 2013).

1. *Efficacy*: While SeNPV can replicate in FAW when in the presence of SfMNPV, it cannot replicate on its own in FAW (Serrano et al., 2013). Both the current and previous reviews of the literature failed to identify any references demonstrating the efficacy of SeNPV against FAW.
2. *Human health and environmental hazards*: SeNPV has been safely used as a microbial pesticide for more than 20 years with no documented effects on human health or the environment (US EPA, 2015b). SeNPV is not an HHP or a cholinesterase inhibitor (University of Hertfordshire, 2019d). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019). It may cause moderate eye irritation. Contact with skin, eyes and clothing should be avoided and it can be harmful if inhaled. It is recommended that applicators wear long-sleeved shirts and trousers, shoes and socks. The US EPA also requires that requires that labels for products containing SeNPV to call for the use of particulate respirators since repeated exposure to high concentrations of microbial proteins can cause allergic sensitization (US EPA, 2015b).
3. *Agronomic sustainability*: There is no evidence to indicate that SeNPV will compromise agronomic sustainability nor is there any indication that there is a risk of the development of pest resistance. Exposure of non-target organisms such as pollinators, natural enemies and other beneficial organisms is expected to be minimal and adverse effects are not anticipated (US EPA, 2015b).
4. *Practicality*: Commercial preparations can be applied using conventional ground or aerial application equipment. Store at temperatures below 32°C as above this temperature can impair activity. Shelf-life can be prolonged by storing in fridge or freezer.
5. *Availability*: This AI is not registered in any of the 19 countries assessed in Africa. Of the 30 countries assessed, this AI is only registered in Mexico and the USA.
6. *Affordability*: No data available.

**Recommendation:** This active ingredient is not registered for use in any of the reviewed countries in Africa therefore it is not recommended that further action be taken at this time.

*Spodoptera frugiperda* multiple nucleopolyhedrovirus (SfMNPV)

*Spodoptera frugiperda nucleopolyhedrovirus* (SfMNPV) is a baculovirus that infects FAW (D. I. Shapiro, Fuxa, Braymer, & Pashley, 1991).

1. *Efficacy:* The previous assessment reported the findings of Cruz, Figueiredo, Valicente and Oliveira (Cruz, Figueiredo, Valicente, & Oliveira, 1997) which showed that SfMNPV isolates were effective in killing *S. frugiperda* (Barrera, Simón, Villamizar, Williams, & Caballero, 2011; Behle & Popham, 2012; Cruz et al., 1997). Efficacy tests of SfMNPV in Africa are currently underway (Rwomushana et al., 2018).
2. *Human health and environmental hazards:* In the registration review of SfMNPV, the US EPA concluded that this AI is unlikely to cause harm to human health and that harm from this active ingredient’s residues on food commodities is also unlikely (US EPA, 2016). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN, 2019).
3. *Agronomic sustainability*: Adverse effects to birds, mammals, honey bees, non-lepidopteran insects, plants, and aquatic animals are not expected.This AI should not be applied directly to water, surface water or intertidal areas below the mean high water mark. When cleaning equipment or disposing of equipment wash waters or rinsate, water contamination should be avoided.
4. *Practicality:*  Apply when larvae are in the first and second instar. Larvae must ingest the occlusion bodies to be infected. It should be stored at temperatures below 90˚F (32˚C) in a cool dry place. Freezing or refrigerating the product will increase the shelf-life.
5. *Availability:* In the Americas, products containing SfMNPV are registered for use in Brazil (5), Colombia (1) and USA (3). SfMNPV is not yet registered in any of the 19 countries assessed in Africa but applications are pending at least 7 African countries.
6. *Affordability:* No data available.

**Recommendation:** Assuming that costs are not prohibitively high, recommended for inclusion in IPM schemes.

*Spodoptera littoralis* nucleopolyhedrovirus (SpliNPV)

Spodoptera littoralis nucleopolyhedrovirus (SpliNPV) is a baculovirus which was first detected in cotton leaf worm caterpillars (*Spodoptera littoralis*) and work has been done on SpliNPV since the 1970s (Merdan, Crozier, & Veyrunes, 1977).

1. *Efficacy:* SpliNPV is effective against 1st to 3rd instar larvae of FAW and a product containing SpliNPV (RavageX) has been successfully tested in Cameroon (Guo et al., 2020). Likewise, trials in Ghana found that SpliNPV was effective and gave a similar level of control to emamectin benzoate (Andermatt Biocontrol AG, 2018).
2. *Human health and environmental hazards:* SpliNPV is not an HHP or a cholinesterase inhibitor (University of Hertfordshire, 2017). The AI is not listed in the Rotterdam database of notifications (Rotterdam Convention, 2020); it is not a candidate POP (Stockholm Convention, 2020); and it is not on PAN’s list of HHPs (PAN (Pesticide Action Network), 2019).
3. *Agronomic sustainability*: Adverse effects to birds, mammals, honey bees, non-lepidopteran insects, plants, and aquatic animals are not expected.This AI should not be applied directly to water, surface water or intertidal areas below the mean high water mark. When cleaning equipment or disposing of equipment wash waters or rinsate, water contamination should be avoided.
4. *Practicality:* Wear coveralls, waterproof gloves and shoes plus socks. Apply when larvae are in the first and second instar. Larvae must ingest the occlusion bodies to be infected. It should be stored at temperatures below 90˚F (32˚C) in a cool dry place. Freezing or refrigerating the product will increase the shelf-life.
5. *Availability:* A product containing SpliNPV is registered for use in Cameroon and registrations in a number of other African coutries are pending.
6. *Affordability:* No data available.

**Recommendation:** Assuming that costs are not prohibitively high, recommended for inclusion in IPM schemes.

*Steinernema carpocapsae*, *S. feltiae* and other entomopathogenic nematodes

Entomopathogenic (insect-killing) nematodes (EPNs) are soil-inhabiting roundworms that carry insect-killing bacteria in their guts; on encountering insect prey they enter the insect and release the bacteria, which causes the death of the host through septicaemia.

1. *Efficacy*: There are a number of references showing good efficacy of *Steinernema* spp. or *Heterorhabditis* spp. against FAW under laboratory conditions (Guo et al., 2020). Studies under greenhouse or field settings resulted in a significant reduction of FAW larvae but did not positively affect yield (Andaló, Santos, Moreira, Moreira, & Moino Jr., 2010; Richter & Fuxa, 1990). Past work suggests that EPNs could potentially be used as an option for reducing damage to the ears of corn in late-stage infections (Richter & Fuxa, 1990). Recently, field trials started in Rwanda to assess local *Heterorhabditis* spp. isolates on fall armyworm (Fallet et al., 2020).
2. *Human health and environmental hazards*: *Steinernema* spp. do not meet any of the HHP criteria.
3. *Agronomic sustainability*: Despite the polyphagous nature of most entomopathogenic nematodes, the authors have found no reports of long-term or population level effects on non-target organisms or other environmental impacts following the application of indigenous or exotic EPNs.
4. *Practicality*: In general EPNs are compatible with standard spraying equipment and irrigation systems, however the choice of application equipment and the manner in which they are applied can influence control efficacy. Exposure to UV and temperature extremes (with the exception of cold conditions for storage) must be avoided; EPNs also require adequate soil moisture to move and locate prey. Foliar applications have generally been less successful than soil applications due to EPN susceptibility to desiccation and sunlight but new formulation .
5. *Availability*: *Steinenema* spp. and *Heterorhabditis* spp. are registered for use in Kenya, however only *Heterorhabditis* spp.are labelled for Lepidoptera, is. It is presumed that many countries in Africa do not require registration for EPNs. In the case where registration is not required but commercial products containing EPN are not available local production could be an option.
6. *Affordability*: No data available; however applications at a field scale are generally known to be relatively expensive

**Recommendation**: Whilst EPNs have proven efficacy against FAW, their vulnerability to sunlight, high temperatures and lack of moisture are major obstacles to overcome before they may be considered for biological control of FAW. Field trials to address these obstacles by novel application technique are under way. Actively foraging EPN would be useful to field trial, especially for older caterpillars and spraying in the whorl.

Sucrose octanoate

Sucrose octanoate is a synthetic sugar ester that is produced by reacting sugars with fatty acids, and it is used to control various soft-bodied insects and mites (US EPA, 2006).

1. *Efficacy:* The current and previous reviews of the literature failed to identify any references demonstrating the efficacy of sucrose octanoate against FAW. The previous assessment found some laboratory studies demonstrating efficacy against other Lepidoptera.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria, so it is not considered to be an HHP. Information on other human health hazard statements was not available. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* The US EPA has classified sucrose octanoate as practically non-toxic to honey bees, and it concluded that risk is minimal due to the lack of exposure, low toxicity, use pattern, and application methods (US EPA, 2006).
4. *Practicality:* No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Previously, this AI was only registered for use in the USA. There are no longer any products containing sucrose octanoate which are registered for FAW, Spodoptera or Lepidoptera in general in any of the countries assessed.
6. *Affordability:* No data available.

**Recommendation:** Given that this is AI is no longer registered for FAW, Spodoptera or Lepidoptera in general in any of the countries and there is only limited information available on the efficacy of AI against Lepidoptera, further follow-up action for this AI is not recommended..

Sulphur

Sulphur is naturally occurring element which is used as a fungicide, acaricide and insecticide (Boone, Bond, Hallman, & Jenkins, 2017; US EPA, 2013b).

1. *Efficacy:* Both the present and previous review of the literature failed to identify any recent references demonstrating the efficacy sulphur against FAW.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria, so it is not considered to be an HHP. Human health hazards include that sulphur causes skin irritation (H315) (ECHA, 2020s). Based on these human health hazards, the signal word “Warning” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* Sulphur is a permitted pesticide in organic farming. However, it is toxic to important beneficial organisms such as parasitoids or predatory mites. Care should be taken, when e.g. *Trichogramma* is also released. The arthropod pesticide resistance database cites only one case of resistance to sulphur, interestingly in a predatory rather than pest species (Mota-Sanchez & Wise, 2020). Accumulation in organisms is not expected due to its insolubility in water, it will not be readily bioavailable.
4. *Practicality:* There are no specific practical constraints associated with sulphur. As it has low mammalian toxicity, it is appropriate for smallholders who lack the resources for full personal safety equipment.
5. *Availability:* Sulphur is registered in a number of countries, particularly for the control of powdery mildew in flowers, but there are also registrations for spider mite control in flowers and vegetables. Some products contain sulphur alone; others may contain other active ingredients such as natural pyrethrins. Currently, only the US has products containing sulphur which are registered for armyworms or caterpillars in general.
6. *Affordability:* No information available.

**Recommendation:** No evidence to merit further work

Thyme oil

Thyme oil is extracted from the herb thyme, and is used as an insecticide and repellent (US EPA, 2010e). Thymol is the most abundant component and the chief active constituent of thyme oil in laboratory tests (Tak, Jovel, & Isman, 2016).

1. *Efficacy:* Some laboratory studies have found that thyme oil has an impact on *S. littoralis* (Farag, Abd-El-Aziz, Abd-El-Moein, & Mohamed, 1994; Sajfrtova et al., 2013)and other Lepidoptera (Sangha, Astatkie, & Cutler, 2017; Tak et al., 2016; Yiğİt, Saruhan, & Akça, 2019; Yiğit et al., 2019). In another study, feeding FAW extracts of *Lippia graveolens,* of which thymol was the most abundant component, led to higher pupal mortality and all adults which emerged were deformed (Guevara et al., 2018). There is no evidence of efficacy against FAW or other *Spodoptera spp.* from the field.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria, so it is not considered to be an HHP. Human health hazards include that thyme oil is harmful if swallowed (H302), may be fatal if swallowed and enters airways (H304), causes severe skin burns and eye damage (H314), may cause an allergic skin reaction (H317), and causes serious eye damage (H318) (ECHA, 2020t). Based on these human health hazards, the signal word “Danger” applies to this AI. The AI is not listed in the Rotterdam database of notifications; it is not a candidate POP; and it is not on PAN’s list of HHPs. It is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* The US EPA has concluded that thyme oil poses negligible to non-existant ecological risk when applied as directed (US EPA, 2010e).
4. *Practicality:* No extraordinary equipment, storage or disposal requirements were listed on the reviewed label (Kittrich Corporation, 2015).
5. *Availability:* Products containing thyme oil are registered in several countries, including in Kenya where it is registered as a fungicide. One product containing thyme oil is registered for use against *Spodoptera* in the US, but the product is labelled for use against armyworm in turfgrass, not agriculture (Kittrich Corporation, 2015).
6. *Affordability:* No information.

**Recommendation:** Given that there is little evidence of efficacy against FAW and the product which is registered for use against armyworm is not intended for use in agriculture, this AI is not recommended for further action.

*Trichogramma* spp.

Wasps in the *Trichogramma* genus are egg parasitoids of mostly lepidopterans and are among of the most widely used biological control agents globally (Holmes et al., 2018). *Trichogramma* are generally released as parasitized eggs either attached to a piece of card (known as a Tricho-card) or placed in small capsules providing protection against biotic (predators) and abiotic factors. Adult *Trichogramma* females emerging from these devices search for pest eggs into which they lay their eggs. This will kill the larvae before they hatch, thus preventing them from doing any damage. In many countries *Trichogramma* is produced locally using low tech means.

1. *Efficacy:* As reported previously, *Trichogramma spp.* have been successfully tested for biological control of FAW in its native range, and commercial products of *T. pretiosum* are registered for use against FAW in Brazil.
2. *Human health and environmental hazards:* Applying Tricho-cards poses no hazard to human health or the environment. Care should be taken during the mass production process to avoid inhalation of scales from the moth rearing host by workers. Residues are not an issue.
3. *Agronomic sustainability: Trichogramma* parasitizes the eggs of Lepidopteran species, so their non-target effects are limited as has also been shown during comprehensive risk assessments with *T. brassicae* (D. Babendreier, Kuske, & Bigler, 2003). Only few non-pest lepidopterans may be found in maize fields and others are potentially at risk only at very close proximity to maize fields. Where this is of concern risk assessments may be conducted to assess whether the *Trichogramma* species under consideration for release pose any risk to non-target Lepidoptera. The development of resistance to *Trichogramma* is highly unlikely.
4. *Practicality:* For the management of FAW, *Trichogramma* should be released when moths are first detected in monitoring traps and may be re-released every 7-10 days thereafter, depending on crop stage. *Trichogramma* must be released prior to their emergence from the egg cards or capsule. Emergence can be delayed but altogether it has a limited shelf life (approximately 10 days at 8°-12°C). Evidence suggests that *Trichogramma* wasps cannot access and parasitize all eggs from egg masses having several layers, thus other measures may be required for good pest control. *Trichogramma* is not compatible with the use of broad-spectrum pesticides.
5. *Availability*: Many countries in Africa do not require registration for parasitoids. Some *Trichogramma* species are native to countries in Africa and those should clearly be given priority. Native species are generally allowed for use whereas non-native species would require an import permit, which is likely to be issued only following a thorough risk assessment by the National Plant Protection Organisation (NPPO). In the case where commercial products containing these parasitoids such as *Trichogramma spp.* are not available and the species is either native or permission to import has already been granted, local production could be an option.
6. *Affordability*: Some studies of the use of *Trichogramma spp.* for the management of other pests have found it to be cost effective (Manisha, Visalakshi, Kumar, & Varma, 2020; Nayak, Das, & Shial, 2019).

**Recommendation:** *Trichogramma* can be effective against FAW even though additional measures might need to be taken (see above). *Trichogramma* can be mass produced easily and native species could be candidates for local production and distribution through channels such as farmer cooperatives. Given the short shelf life and the temperature constraints, it is likely that it would not be feasible to source *Trichogramma* over long distances through an extended supply chain.

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1. Extracts of *Dysphania ambrosioides* are used by farmers in South Africa [↑](#footnote-ref-1)
2. Currently being used by farmers in Zambia [↑](#footnote-ref-2)